ENCULTURATED PREDICTIVE PROCESSING

A PHILOSOPHICAL FRAMEWORK FOR RESEARCH ON READING AND ITS DISORDERS

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Books are made between the words and spaces left by the writer on the page and the reader who reinvents them through her own embodied reality, for better and for worse. The more I read, the more I change. The more varied my reading, the more able I am to perceive the world from myriad perspectives.

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1. INTRODUCTION

Reading matters. In literate societies, reading is a ubiquitous cognitive tool for communication, thinking, reasoning, remembering, or planning. The successful, iterative engagement with written language has brought about specific modes of cultural transmission and intellectual progress. It is reasonable to argue that “[t]he evolution of a literate tradition, then, involves more than the accumulation of knowledge or the development of an accumulative research tradition. It involves a new way of classifying and organizing knowledge” (Olson 1991, 160). We need to take this into account if we wish to explore the cognitive foundations of the rich socio-cultural history (at least in Western societies) of ideas, innovations, or stories that literacy and expertise in reading have influenced. Reading has also influenced the development and formation of philosophy both as a mode of thinking and as an academic discipline. Much philosophical reasoning is facilitated by the philosopher’s capacity to read and re-read her own writings and treatises by other thinkers. From this perspective, it is astounding that reading – understood as a genuine, thought-promoting cognitive process that vitally influences many intellectual enterprises – has never become a proper target phenomenon in philosophy (for an exception, see Menary 2014, 2015). This dissertation is an attempt to help fill this gap.

Reading is a phenomenon that is both biological and cultural: like other cognitive achievements, it is “the result of a synergistic combination of internal neural mechanisms, bodily capacities and constraints, and environmental and social context” (Anderson 2015, 249). Reading is special, however, because it is a phylogenetically recent, culturally acquired skill that recruits and co-ordinates an impressive variety of neuronal, bodily, and socio-cultural sub-processes.
If we wish to understand these fine-grained co-ordinations that render reading possible, we need to depart from the traditional idea that reading is a matter of *translating* ‘external’ representations into an ‘internal’ representational code. This idea has been suggested by representationalist and computationalist views in cognitive psychology that date back to the cognitive turn. For example, Walter Kintsch’s (2004) *construction-integration model* – and its precursor developed by Kintsch and van Dijk (1978) – have influenced computational modelling and the design of behavioural experiments. According to this model, successful reading performance relies on different stages of mental representation, such as

propositional representations and abstract *situation models*. This idea shares many theoretical commitments with Philip N. Johnson-Laird's (1983) theory of *mental models*. It also stands in the tradition of Kenneth Craik's (1967) assumption that cognizers need to mentally represent "small-scale models" of external events in order to be able to anticipate and contextualize states of affairs and events in the external world. These lines of research are not interested in the concrete neuronal realization of the mental representations that are held responsible for successful instances of reading and reasoning. In contrast, Lawrence Barsalou (1999) suggests that mental representations that play a crucial functional role in text-based reasoning and language processing are not abstract and a-modal, but entwined with perceptual states. On this view, the representation of linguistic tokens is supposed to involve *linguistic symbols* that are associated with *perceptual symbols*, i.e., neuronally realized vehicles that have perceptual content.

Applied to reading, this "translation view of language" (Clark 2006a, 292) is seriously flawed for several reasons. First, it remains unclear what the specific relationship between representata and representanda is supposed to be. This applies to both the construction-integration model and to the perceptual symbols account. Second, this view neglects that human organisms are embodied and that their embodiment is likely to play a crucial functional role in specific classes of cognitive processing such as reading. Third, this view does not provide an account of the cognitive developmental trajectory of human organisms as they acquire expertise in their interaction with written language. Fourth, this traditional view of language processing neglects the clear-cut case that language is a socio-culturally shaped phenomenon. This dimension in turn influences how individuals deal with linguistic structures and any coherent theory of reading should be able to take this into account. Fifth, it remains to be established how the traditional view can account for reading disorders and aberrant reading performance more generally. Finally, on the "translation view of language" it remains unclear what the overall cognitive function of reading is supposed to be. If cognitive interactions with tokens of a writing system just amount to an 'internal' representation of their contents, it is not clear why reading might be beneficial to the overall cognitive capacities of human organisms. As Andy Clark (2006a, 304) puts it, "[…] it is hard to see how our linguistic encounters can do anything more than inculcate a kind of useful shorthand for ideas whose very thinkability requires only the more fundamental tokenings (in mentalese or neuralese) with which they have come to be associated."

As a tractable alternative, Clark (2006b, 371) suggests that linguistic tokens are *complementary* to more traditional cognitive states: “Central to this vision of language as a complementary resource is an appreciation of the power of added worldly structure (in this case, perceptible material symbols) to transform the tasks that confront an intelligent agent.” This alternative view is important, because is acknowledges the crucial contribution of reading to thought and reason in literate societies. It also implies that reading has culturally evolved partly because it can facilitate and augment certain types of cognition. Furthermore, it is likely that this view can outperform the “translation view of language” in its descriptive scope and its capacity to account for many crucial aspects of reading, which are hardly considered by the traditional view. However, Clark’s *complementarity view* tends to overlook that reading is itself a complex cognitive process. Competence in the performance of this cognitive process needs to be laboriously acquired over years of formal schooling and instruction. Some individuals are not able to become a skilled reader or lose this capacity at a certain stage of their life. Any serious theoretical proposal, I suppose, needs to take this into consideration if we ever wish to arrive at a well-balanced, carefully developed, and progressively complete account of reading.

The main purpose of this dissertation is to do justice to the multi-faceted character of reading by proposing a novel and original framework for its conceptual and empirical investigation. This framework, which I call *enculturated predictive processing*, seeks to integrate diverse philosophical and empirical strands of research and to co-ordinate different levels of description. It is opposed to the “pure translation view of language”. At its core, enculturated predictive processing is the idea that reading is the result of fluent, ever-new sub-personally realized adjustments of predictions and sensory information in the context of socio-culturally structured learning environments. Ultimately, enculturated predictive processing suggests that expertise in reading is associated with the ongoing, well-balanced interaction of the embodied human organism with its linguistically structured environment.

This dissertation is a theoretical attempt to explore the descriptive landscapes that philosophy of mind and philosophy of cognitive science have to offer to the investigation of reading. As the consideration of the “translation view of language” has already suggested, research on reading has a longstanding tradition. Investigations of phenomena associated with reading in psychology, cognitive neuroscience, and psycholinguistics date back to the end of the 19th century. The time has come, I suggest, to have a fresh, philosophically minded look at the results and desiderata of these lines of empirical investigation. It is in this sense that enculturated predictive processing aims to meet Thomas Metzinger's (2013, 1) requirements for research working at the crossroads of philosophy and the cognitive sciences:

> […] the philosophy of psychology and the philosophy of cognitive science are not about psychological states or cognitive processing *per se*, but about the *theories* we construct about such states and processes, about what counts as an explanation, about what the explananda really are – and about how to integrate different data-sets into a more general theoretical framework. (italics in original)

The ideas to be developed in this dissertation take this meta-theoretical statement seriously. Enculturated predictive processing will turn out to be a detailed proposal of a unifying, integrative, and synthesizing theoretical framework that is able to contextualize and interpret vast sets of empirical results from a descriptive, conceptually shaped perspective. Furthermore, enculturated predictive processing is thought to provide new conceptual tools that can help investigate reading and the associated sub-processes in a conceptually coherent und empirically plausible way.

This dissertation consists of three parts. In the first part, I will develop the basic ideas and commitments of enculturated predictive processing. At its core, enculturated predictive processing is a synthesis of two recently developed philosophical accounts of cognition. Therefore, chapter 2 and 3 will serve to review both accounts, namely cognitive integration (e.g., Menary 2007, 2015) and predictive processing (e.g., Clark 2013a, 2015), respectively. In chapter 4, I will argue that cognitive integration and predictive processing are strictly complementary and can thus be theoretically synthesized. This chapter will also serve to defend enculturated predictive processing against possible objections and to justify its theoretical commitments.

The second part will serve to apply the enculturated predictive processing framework to research on the sub-processes of reading. In chapter 5, I will be concerned with visual word recognition. Here, the main question will be how previous empirical research can be interpreted from a unifying, philosophically informed perspective. In this chapter, we will also start to explore how reading has become possible given its phylogenetic recency and the functional and structural constraints on brain development. In chapter 6, I will approach sentence processing, again by taking the existing empirical literatures on this topic into account. I will attempt to show that proficient readers are able to process written sentences because they sub-personally hold and apply a vast set of knowledge about probability distributions of coherent and cohesive sequences of words. For theoretical reasons to be explored, I will argue in chapter 7 that eye movements play an indispensable functional role in reading. I will develop the idea that they significantly contribute to the entire reading process. Chapter 8 will be dedicated to the question how reading is rendered possible on an ontogenetic timescale. In particular, I will apply key ideas of enculturated predictive processing to the investigation of the neuronal, bodily, and socio-cultural conditions of reading acquisition.

In the third and last part of this dissertation I will explore reading disorders from the enculturated predictive processing perspective. The pragmatic reason for this is that reading disorders affect a significant number of individuals. Therefore, it is important to do conceptual justice to the problems and challenges these individuals face in contemporary literate societies. The theoretical reason is that the investigation of specific classes of disorders can contribute to a better understanding of both aberrant and ‘normal’ realizations of a specific cognitive target phenomenon. More generally, this approach is inspired by Thomas Metzinger’s (2003, 213) following assertion:

> If we are interested in a better understanding of a complex domain of phenomena – especially in an initial, preparadigmatic phase of theory formation – an analysis of borderline cases and restricted situations has frequently proved to be of great heuristic value with regard to a general interpretation of the standard phenomenon.

We will see that this descriptive strategy will turn out to yield new and interesting theoretical results that might inspire future empirical research. I will be concerned with both developmental and acquired disorders affecting different aspects of reading performance. Chapter 9 will be dedicated to circumscribed cases of developmental dyslexia. In chapter 10 I will investigate the reading behaviour of a specific sub-group of individuals diagnosed with autistic spectrum disorders. We will see that this type of disorder is important, because high-functional autistic individuals exhibit average or superior visual word recognition skills, while their capacity to process syntactically structured sequences of words is significantly impaired. The last chapter will be concerned with an acquired reading disorder, namely pure alexia. I will conclude by summarizing the most important results of my conceptual and theoretical analyses and by making suggestions for future research.[1] If you agreed in the end that enculturated predictive processing is an compelling and plausible position, your new ways of thinking and philosophizing about reading would be a proof for the idea that "[…] the real properties of physical text transform the space of possible thoughts" (Clark 1998, 176).

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[1] Parts of chapter 2, 3, 4, and 8 were published in Fabry (2015).

PART I

THEORETICAL BACKGROUND

2. COGNITIVE INTEGRATION AND ENCULTURATION

2.1. INTRODUCTION

This chapter serves to introduce the theory of *cognitive integration* and the key notion of a *cognitive practice*. Any philosophical attempt to describe the cognitive processes associated with reading needs to clarify the conditions under which this target phenomenon can be said to occur. This equally concerns phylogenetic and ontogenetic, bodily and neuronal, biological and cultural conditions. The assumption underlying this chapter is that the cognitive integration (CI) framework provides the conceptual tools required for this analysis. CI will be shown to contribute in an important way to a unifying framework for reading that is both conceptually coherent and empirically plausible.

Generally, CI is opposed to theoretical approaches to cognition assuming that cognitive processes are exhaustively described by referring to computational and representational processes being localized in the brain. That is, in contrast to traditional internalistic and individualistic attempts to describe and explain certain cognitive phenomena,[2] CI claims that it is the close interaction of neuronal, bodily, and 'external' components that gives rise cognitive processes: "Cognitive integration views cognition as based on both the co-ordination of bodily processes, including neuronal ones, and manipulations of external material vehicles that enable agents to complete cognitive tasks" (Menary 2007b, 626; see also Menary 2007a, 5). Cognitive tasks are understood as any activity that serves to "achieve a particular kind of goal, such as solving a problem, planning or making inferences" (Menary 2007a, 5f);[3] it requires "the exercise of particular cognitive capacities" (ibid., 14). The integration of neuronal, bodily, and environmental components, it is argued, is superior to performing cognitive tasks by relying on brain-bound resources alone (cf. Menary 2007a, 3; Menary 2010a, 231). One important motivation for this

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[2] CI is related to approaches that describe cognition as embodied, embedded, situated, extended, or enactive. It shares certain basic commitments with these attempts in doing justice to the observation that it is not exclusively neuronal processes that give rise to cognitive processes, but also extracranial bodily processes and the organism's interactions with its socio-culturally shaped environment. For a discussion of the similarities and differences of CI and extended cognition and for convincing replies to criticisms against non-internalistic theories raised by Adams and Aizawa (2001, 2010) and Rupert (2004, 2010), see e.g., Menary 2006, 332-342; 2007a, 61-76; 2010c.

[3] The achievement of a particular kind of cognitive goal is called the "cognitive purpose" (cf. Menary 2007a, 5).

argumentative move is to sidestep difficulties associated with the *parity principle* (Clark & Chalmers 1998), which is the intuition that brain-bound and extended cognitive processes can and do fulfill a similar function in certain well-defined situations. By stressing the superiority of integrated cognitive processes over brain-bound ones, CI is robust against arguments questioning this strand of externalistic reasoning (see Menary 2006, 333; 2007a, 55-59, 62; 2010c).

2.2. FIVE CONSTITUENT THESES OF COGNITIVE INTEGRATION

The approach to cognition proposed by CI rests on five theses that will be introduced in turn. First, it is claimed that "[c]ognitive capacities are not intrinsically different from other kinds of capacities found in the natural world" (Menary 2009, 31).[4] This is the *continuity thesis*, which emphasizes the importance of investigating the evolutionary and socio-cultural trajectories that lead to genuinely human cognitive phenomena (cf. Menary 2007a, 173). In particular, the continuity thesis is supported by Kim Sterelny's (2003, 2012) work on *cognitive niche construction* (see e.g., Menary 2013a, 28). In general, niche construction can be understood as "the process whereby organisms, through their metabolism, activities, and choices, modify their own and/or each others' niches" (Odling-Smee & Laland 2011, 220).[5] It is a pervasive phenomenon that characterizes structuring activities undertaken by many animals (cf. Laland & O'Brien 2011, 193). *Cognitive* niche construction is the idea that human cognition is rendered possible by the cumulative, intergenerational, and socially structured modification of the environment. It may be "[…] defined as the process by which animals build physical structures that transform the problem spaces in ways that aid (or sometimes impede) thinking and reasoning about some target domain or domains" (Clark 2008, 62; see also Clark 2006b, 370). This type of niche construction is special, because it relies on *epistemic engineering* (see Menary 2014, 291; 2015, 6),[6] that is "on organizing our physical environment in

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[4] For a related idea, see Sterelny (2003, 146).

[5] A niche can be defined as "the organism-environment relationship that is a function of both the state of the organism and the constructed, inherited (persisting) environment" (Kendal 2011, 242).

[6] This is consistent with Clark's (1997, 179) idea "[…] that the basic form of individual reason (fast pattern completion in multiple neural systems) is common throughout nature, and that where we human beings really score is in our amazing capacities to create and maintain a variety of special external structures (symbolic and social-institutional)." In addition, there is a striking similarity in the cognitive integrationist's continuity thesis and Anderson's (2015, 291) "principle of continuity", which "[…] implies not just that organisms can be arrayed on a biological and psychological continuum, with many differences in degree but few sharp fundamental discontinuities to be found between the mental powers of 'higher' and 'lower'

ways that enhance our information-processing capacities" (Sterelny 2012, xii; see also Clark 2008, 66f; Stotz 2010).[7] Additionally, Menary (2013a, 27) emphasizes the crucial role of "developmental and neural plasticity" which enables sophisticated ontogenetic, socially constrained learning trajectories.[8] In turn, these trajectories are influenced by the phylogenetic history of human organisms in their niche (see also Sterelny 2012, 151).

The second thesis defended by CI is the *hybrid mind thesis*. Stressing the hybridity of a vast variety of cognitive processes[9] means to acknowledge that they "involve the integration of neural manipulations of vehicles and bodily manipulations of environmental vehicles" (Menary 2010a, 236; see also Menary 2007b, 627).[10] This is just another way of expressing the crucial functional role played by extraneuronal bodily sub-processes in addition to, and in close interaction with, neuronal sub-processes operating on vehicles in the environment. According to Menary (2006, 342), hybrid cognitive phenomena need to be described in terms of a "reciprocal causal interaction between internal and external vehicles and processes". However, this seemingly clear-cut distinction between the 'internal' (i.e., neuronal activities) and the 'external' (i.e., bodily actions targeted at environmental resources) is assumed to be only a heuristic one. This is because "the nature of reciprocal coupling makes it difficult to study the components as separate systems because

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organisms, but also that within each organism higher mental faculties develop from and rest on the foundations of the lower."

[7] Put differently, Odling-Smee and Laland (2011, 228) depict the scope of human niche construction as follows: "When we engage in niche construction, like other organisms, we modify both selective and developmental environments for ourselves, our offspring, and other organisms that inhabit our planet. However, we shape developmental environments in an astonishingly diverse range of ways, from constructing schools to promote our children's learning to using propaganda to manipulate others into buying products, voting for our candidate, or fighting our wars […]."

[8] Similarly, in summarizing Sterelny's (2003) view Clark (2008, 67) emphasizes that contemporary humans originate in their hominid forbearers who adapted "[…] to the variability of environments and to the spread of variation itself." He goes on to argue that "[t]o cope with such variability, we are said to have evolved powerful forms of developmental plasticity. These allow early learning to induce persisting and stable forms of neural reorganization, impacting our range of automatic skills, affective responses, and generally reorganizing human cognition in deep and profound ways" (ibid.). In later chapters we will consider this sketched relationship between epistemic engineering and the scope and limits of neural plasticity in some detail with regard to reading and its preconditions.

[9] Within this framework, cognitive processes are defined as being "aim[ed] at completing a cognitive task; and it is constituted by manipulating a vehicle" (Menary 2007a, 15).

[10] A similar idea is put forward by Mark Rowlands (1999, 25), who argues that "[…] cognitive processes are essentially hybrid in character, made up of both internal processes and bodily manipulation of external structures".

they are continuously influencing and responding to one another" (Menary 2007b, 628f).[11]

Methodologically, this idea shares basic commitments with dynamical systems approaches to cognition, which assume that cognitive systems are comprised of components that interactively and symmetrically influence each other over time in a nonlinear fashion (cf. Menary 2007a, 42f; see Beer 1995, 132).[12] As such, "[…] a dynamical analysis of a cognitive process seeks to understand the unfolding of that process over time and the multiple internal and external influences whose interplay shapes the unfolding" (Beer 2000, 91). Importantly, these components interacting over time comprise neural, bodily, and environmental dynamical sub-systems. According to dynamical systems approaches, complex and intelligent

> […] behaviour emerges when a neural system linked to the sensory and motor surfaces is immersed in an environment to which it is adapted. The complete system, including neural network and coupling through the body and environment, can be understood as a dynamical system." (Schöner 2008, 104)

This gives CI the mathematical tools to apply the hybrid mind thesis to the investigation of certain cognitive processes. As a result, it is argued that "[…] the dynamical approach to cognition is important in giving cognitive integrationists the explanatory resources necessary to explain how we manipulate external cognitive vehicles" (Menary 2007a, 48; see also Menary 2015a, 2).[13]

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[11] Technically, in dynamical systems approaches the notion of *coupling* is defined as follows: "Often, change in a system depends on factors outside the system itself […], referred to here as parameters. Sometimes, changes in a parameter depend in turn on the system itself. […] This kind of reciprocal, direct dependence is known as coupling. System variables and coupled parameters can be regarded as forming a larger system" (van Gelder 1998, 617). The formulation of the hybrid mind thesis appears to be inspired by causal coupling defined along these lines. This becomes even more obvious once we take Barandiaran's and Moreno's (2006, 177) summary of coupled dynamical structures into account: "The structure of behaviour depends on the way in which internal dynamic structures are coupled (through the body) with the environment; but behaviour sustains dynamic structures too: i.e. the stability of dynamic structures depends on the particular sensorimotor correlations that the coupling it sustains generated."

[12] More technically, "[t]he core ideas behind a Dynamical Systems perspective are the idea of a state space, the idea of a trajectory or a set of possible trajectories through that space, and the use of mathematics (either continuous or discrete) to describe the laws that determine the shapes of these trajectories. The Dynamical Systems perspective thus builds in the idea of the evolution of system states over time as a fundamental feature of the analysis" (Clark 1997, 99). For an elaboration on these ideas, see Clark (1997, 114-128).

[13] The initial appeal of dynamical systems approaches to cognition is nicely captured by Clark's (1997, 102) remark that "[b]y treating the brain as a dynamical system, we treat it in essentially the same terms as we treat bodily mechanics and environmental processes. As a result, it becomes especially easy and natural to characterize adaptive behavior in terms of complex couplings of brain, bodies, and environment." We will revisit this idea in chapter 4.

Third, CI is constituted by the *transformation thesis*. Here, the idea is that it is not only the "complementarity of the internal and external cognitive resources necessary for their integration" that is crucial for certain cognitive processes, but also "the transformatory impact this integration has on our cognitive capacities, both in the here and now and during cognitive development" (Menary 2006, 341). That is to say that the neuronal and bodily functions are altered in the course of integrated cognitive processing (cf. Menary 2013b, 364). This in turn leads to an augmentation of the cognitive abilities that are ascribed to a human organism as a whole (cf. Menary 2007a, 133).[14] The transformation of neuronal functions is closely related to the idea of neural "learning driven plasticity" (LDP; Menary 2015a, 8; Menary 2013b, 356). This type of plasticity is understood as any change of cortical organization that is correlated with an organism's acquisition of new cognitive skills:[15]

> Structurally, LDP can result in new connections between existing cortical circuits. Functionally, LDP can result in new representational capacities (the ability to represent public symbolic representations such as alphabets and numerals) and new cognitive abilities, such as mathematics, reading, and writing (Dehaene 2009; Ansari 2012). (Menary 2015a, 8)[16]

In addition to the transformation of neuronal functions, integrated cognitive processing also results in changes of bodily functions. For instance, the body schemas underlying the successful bodily engagement with environmental resources are modified in the course of an organism's learning history (cf. Menary 2013b, 364).[17] Importantly, these co-occurring and highly interactive kinds of transformation are dependent upon the organism's immersion into a socio-cultural environment. Put differently, "[…] the point of the transformation thesis is to drill down into the process of acquiring knowledge, skills, and cognitive abilities via learning-driven plasticity and scaffolded learning" (Menary 2015a, 8).[18]

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[14] A related idea emphasizing the properties of cognitive resources is "[…] that external structures (including external symbols like words and letters) are special insofar as they allow types of operations not readily (if at all) performed in the inner realm" (Clark 1997, 65).

[15] For a recent neuroscientific account of neural plasticity, see e.g., Ansari (2012).

[16] In earlier integrationist descriptions of neural plasticity, learning driven plasticity (LDP) is also referred to as *learning-dependent plasticity* (L-plas; Menary 2013b, 356f; 2014, 293-295).

[17] In accounting for the crucial contribution of body schemas to the successful performance of cognitive tasks, Menary (2007a, 2007b, 2009, 2010a, 2010b, 2013b) relies on Shaun Gallagher's (2005) approach to embodied cognition. In particular, Gallagher (2005, 24) defines a *body schema* as "[…] a system of sensory-motor capacities that function without awareness or the necessity of perceptual monitoring." This needs to be contrasted with a *body image*, where this notion is understood as referring to "[…] a system of perceptions, attitudes, and beliefs pertaining to one's own body" (ibid.).

[18] Originally, the notion of *scaffolding* has been developed in Clark (1997). Here, "[…] scaffolding (as I use the term) denotes a broad class of physical, cognitive, and social

Fourth, CI rests on the *manipulation thesis*, which is closely related to the hybrid mind thesis presented above. According to this thesis, “integrationists take the manipulation of external vehicles to be a pre-requisite for higher cognition and that embodied engagement is a pre-condition for these manipulative abilities” (Menary 2007a, 4f; see also Menary 2010a, 232).[19] The notion of manipulation goes back to Mark Rowlands’ (1999, 23f) account of *environmentalism*, which claims that “cognitive processes are, in part, made up of manipulation of relevant structures in the cognizer’s environment”. In this context, manipulation is defined as “any form of bodily interaction with the environment – manual or not, intrusive or otherwise – which makes use of the environment in order to accomplish a given task” (ibid., 23). In adopting this approach to embodied manipulative activities targeted at cognitive resources, Menary (2010b, 564) emphasizes that the notion of manipulation should be understood in a broad sense. That is, it does not refer exclusively to “[…] a manual operation using the hands. It might involve a saccade or re-orientation of the body to better be able to see.” Thus, the notion of manipulation is equally applied to any employment of body schemas as well as eye movements that contribute to the completion of a certain cognitive task. Importantly, it is assumed that bodily manipulations causally interact with neuronal sub-processes. This emphasizes the hybridity of cognitive processes (cf. Menary 2007a, 138). In addition, it is argued that the manipulation of cognitive resources is constrained by cognitive norms. In this vein, Menary (2007a, 5; 2010a, 233) argues that “[o]ur abilities to manipulate the extrabodily environment are normative and are largely dependent on our learning and training histories.”

This brings us to the fifth and last constituent thesis, the *cognitive norms thesis*. This thesis states that the human organism that is neuronally and bodily engaged with cognitive resources, finds itself “embedded in a physical and social environment, and that environment contains norms which determine the content of environmental

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augmentations – augmentations that allow us to achieve some goal that would otherwise be beyond us” (Clark 1997, 194f; see also Clark 1998, 163).

[19] Menary (2007a, 105) emphasizes both the phylogenetic and the ontogenetic development of bodily manipulation: “The phylogenetic history of an organism establishes its manipulations of the environment as adaptations, but the ontogenetic history of the organism may include all sorts of fine-tuning of this adaptation, relative to niche, perhaps through learning history.” This is important, because it emphasizes the need for 1. a thorough investigation of the evolutionary conditions under which manipulations could have emerged; and 2. the crucial relationship between learning and bodily engagements with environmental resources on an ontogenetic timescale.

vehicles and how we manipulate them" (Menary 2010a, 229). According to Menary (cf. 2010a, 239; 2010b, 570f), there are at least five different types of cognitive norms that govern the successful manipulation of environmental resources, namely purposive, corrective, manipulative, interpretative, and creative norms. This means that integrated cognitive activities ought to serve a purpose, to alter certain behaviours as a result of manipulating cognitive resources, to follow certain rules for the correct manipulation of these resources, to interpret these resources in line with socio-culturally established habits, and to create new instances of cognitive resources in accordance with certain requirements that a socio-cultural community has adopted. These norms, whose importance and prioritization vary depending on the cognitive task for which they are relevant, are acquired through scaffolded learning and social instruction (cf. Menary 2010b, 572). Throughout cognitive development, the human organism learns to manipulate environmental resources automatically and fluently in accordance with these cognitive norms (see Menary 2013a, 29).[20]

In sum, the position defended by CI is constituted by the following claims:

1. Human cognition is continuous with animal cognition on both diachronic and synchronic scales. However, it has a special status because it is situated in a particular cognitive niche and heavily rests upon neural plasticity, which is itself an adaptation.
2. Certain cognitive processes are hybrid because they are constituted by neuronal and extracranial bodily components.
3. In the course of ontogenetic hybrid cognitive processing, the constitutive neuronal and bodily functions are transformed.
4. The bodily manipulation of specific environmental resources plays a crucial functional role in integrated cognitive processes.
5. These manipulations are constrained by cognitive norms which are acquired through learning and mirror socio-culturally developed habits for the interaction with cognitive resources. These five theses culminate in the notion of a *cognitive practice*, which will be introduced in the next section.

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[20] For an elaboration on this idea with regard to reading acquisition, see chapter 8.

2.3. COGNITIVE PRACTICES AND ENCULTURATION

Cognitive practices are defined as “culturally endowed bodily manipulations of informational structures” (Menary 2012, 150; 2013b, 353).[21] That is, a cognitive practice is any activity that involves the processing of representational vehicles. It is constituted by neuronal and bodily components in order “to complete a cognitive task” (Menary 2007a, 143; see also Menary 2007a, 137; 2010a, 238).[22] This follows from the assumption that “[c]ognitive practices are dependent upon the manipulation thesis and the hybrid mind thesis” (ibid., 136). At the same time, cognitive practices are normatively constrained, “[t]here are right and wrong ways to do them” (Menary 2013a, 29). This is “because we learn how to manipulate the representations correctly and because of the cognitive purpose of the practice” (ibid., 5; see also Menary 2010a, 239). Accordingly, successful learning processes in the course of the ontogenetic development of human organisms are of crucial importance for the performance of cognitive tasks. These learning processes are tightly connected to the acquisition of the relevant cognitive norms. This is because “we learn cognitive practices by learning the cognitive norms that govern the manipulation of vehicles” (Menary 2007b, 628). It is important to bear in mind that these vehicles are tokens of representational systems, such as writing systems. They are located in the cognitive niche of human organisms.[23] The acquisition of cognitive practices is socially structured. That is to say that children and adolescents are “scaffolded by parents and caregivers” and other members of a certain socio-cultural group (Menary 2010b, 572). It is this socially structured learning of cognitive practices which ensures that a

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[21] The notion of a cognitive *practice* may emphasize the assumptions that the cognitive processes under consideration are “dynamic“ and “active“ (Menary 2013a, 27) and that they are socially shared and culturally developed procedures.

[22] At earlier stages of the formation of CI, Menary (2007a, 84; see also 2010a, 564-570) differentiates cognitive practices and other types of manipulating the environment. These types include *biological coupling* (e.g., “extended phenotypes”), *epistemic actions* (i.e., “using the environment as its own representation”; see Kirsh & Maglio 1994), and *self-correcting actions* (i.e., employing “language and exogenous props to direct and structure practical actions in completing tasks”). On this taxonomy, the crucial difference between epistemic actions and cognitive practices is that the former are not necessarily co-constituted by ‘internal’ representations (cf. Menary 2007a, 87). Lately, the scope of the notion of a cognitive practice has been broadened, such that it now also comprises epistemic and self-correcting actions (Menary, personal communication).

[23] In this context, it is important to emphasize that the tokens of writing systems (and of other representational systems) have physical properties. This is because they are realized by specific representational media (cf. Peterson 1996, 11). Accordingly, the tokens of a writing system are *material* symbols in the sense of Clark (2006). At the same time, however, tokens of writing systems have abstract properties that deeply influence and constrain the ways in which competent human organisms can meaningfully interact with these tokens. As we shall see in greater detail in chapter 8, these abstract properties mainly concern the structural organization and the graphemic compositionality of a certain writing system.

human organism is able to cognitively process certain information-bearing structures in its environment in accordance with specific cognitive norms. Importantly, “cognitive practices extend our cognitive capacities” (Menary 2013a, 28). In order to achieve this kind of augmented cognitive competence, individuals have to learn how to enact a cognitive practice. This process is comprised of different time-consuming stages and it involves different degrees of competence and automaticity concerning the compliance with the norms. These norms “[…] are often, but not always, encoded as rules or simple procedures to be followed (especially for the neonate or novice)” (ibid., 29). More specifically, the “properties of cognitive norms are altered from being entirely explicit and context free to being entirely implicit and embodied” (Menary & Kirchhoff 2013, 9). This is in line with Dreyfus and Dreyfus’s (1986) five-stage model of expertise.[24] Combining the transformative effects of learning on the one hand and the socio-cultural situatedness of cognitive practices on the other, Menary and Kirchhoff (2013, 2) propose the *extended expertise model*:

> Expertise is extended in two senses:
> - First, expertise in a domain requires the transformation of abilities through development and learning. This transformation leads to extended abilities, which are the basis of extended expertise.
> - Secondly, expertise is extended across a group working collaboratively to some end.

Thus construed, the acquisition of expertise is associated with the transformation of both neuronal *and* bodily functions contributing to hybrid cognitive processes (cf. Menary 2013a, 28).[25] Furthermore, cognitive practices are always *patterned practices* in the sense proposed by Roepstorff et al. (2010), because they are situated in a socio-cultural context and are shared by many human organisms in the cognitive niche.[26] Here, the assumption is that patterned practices that are genuinely cognitive “coordinate neural networks in action and facilitate learning and adaptation

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[24] Dreyfus’ and Dreyfus’ (1986, 21-36) model of skill acquisition comprises of the following five stages: 1. novice; 2. advanced beginner; 3. competence; 4. proficiency; 5. expertise. Menary (2007a, 81) and Menary and Kirchhoff (2013) explicitly mention this model in order to specify the conditions under which the learning of cognitive practices and the fluid enaction of these practices proceeds.

[25] This is in line with Vygotsky’s (1978, 1981) account of cognitive development, which has influenced the formation of CI (Menary 2006, 2007a, 2010a, 2010b). In particular, Vygotsky (1978, 46) emphasizes both the biological and social components giving rise to the cognitive development of contemporary human organisms that are immersed into a culturally structured environment: “Within a general process of development, two qualitatively different lines of development, differing in origin, can be distinguished: the elementary processes, which are of biological origin, on the one hand, and the higher psychological functions, of sociocultural origin, on the other. The history of child behaviour is born from the interweaving of these two lines.”

[26] This conceptual connection is made by Menary (2013a, 29; 2013b, 353) and Menary and Kirchhoff (2013,2).

as a process extending from the individual brain to sociality and material-discursive environments" (Roepstorff et al. 2010, 1054).

This association of cognitive transformation with the immersion into a socio-culturally structured environment is captured by the notion of *enculturation* (cf. Menary 2012, 148).[27] Enculturation is defined as "the plasticity of the brain in redeploying older neural circuits to new, culturally specific functions" (Menary 2015a, 2). Theoretically, cognitive integration can be understood "as a process of enculturation" (ibid., 9).[28] Enculturation, in turn, is justified by the adequacy and persuasiveness of the cognitive transformation thesis, which "[…] is warranted by phenotypic and neural plasticity, in particular by learning driven plasticity" (ibid.). Becoming enculturated normally leads a sufficient degree of expertise in cognitively processing representational systems. This in turn facilitates the performance of certain cognitive practices: "Many of these practices involve artefacts such as tools, writing systems, number systems and other kinds of representational systems. These are not simply static vehicles that have contents, but are active components embedded in dynamical patterns of cultural practices" (Menary 2012, 152; see also Menary 2013a, 29). Thus, it is a certain socio-cultural community that has diachronically developed representational systems whose manipulation is dependent upon socially distributed learning processes or "[s]ocial learning techniques" that give rise to the successful enactment of cognitive practices (ibid.).

Enculturation depends upon two crucial factors that concern the neuronal sub-processes that partly constitute integrated cognitive processes. First, it is assumed that many neuronal functions are results of *neuronal recycling* (Dehaene 2010). The assumption here is that the cognitive benefits of these functions, for example those associated with reading or arithmetic, are too recent for being the result of phylogenetic inheritance: "The cortical circuits with which we are endowed through evolution are transformed to perform these new culturally specified cognitive

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[27] A related point is put forward by Hutchins (2011, 445), who "[…] propose[s] the hypothesis of enculturated cognition: The ecological assemblies of human cognition make pervasive use of cultural products. They are always initially, and often subsequently, assembled on the spot in ongoing cultural practices." This resemblance of approaching cognitive processes that are profoundly influenced by the socio-culturally structured environment of the cognizing organism is acknowledged by Menary (2013a, 33).

[28] Menary (2012, 148) contrasts his view of enculturated cognition with *artefact extension*, "[…] which is the idea that an artefact gets integrated into the cognitive system through the right kind of causal coupling (Clark and Chalmers 1998; Clark 2008, 2010) and which puts it on a functional par with 'in-the-head' cognitive processes (Wheeler 2010)." It is argued that the position adopted by the enculturated cognition approach is superior to artefact extension, because it avoids the problems associated with the *parity principle*, and because it is aimed at demonstrating what the actual cognitive activities and their transformation in the course of ontogenetic development amount to.

functions, even though they evolved to perform different functions" (Menary 2013b, 354). Neuronal recycling is considered to be a neuro-functionally realized "form of reorientation or retraining: it transforms an ancient function, one that evolved for a specific domain in our evolutionary past, into a novel function that is more useful in the present cultural context" (Dehaene 2010, 146). The important point is that existing neural circuits are supposed to be *reused* for phylogenetically recent and culturally acquired functions which are in turn constrained by the overall neural architecture of the human brain (cf. ibid.; see also Anderson 2010). In general, the principle of *neural reuse* is defined as "the use of local regions of the brain for multiple tasks across multiple domains" (Anderson 2015, 4). This principle rests on the claim that "[…] resource constraints and efficiency considerations dictate that whenever possible neural, behavioral, and environmental resources should have been reused and redeployed in support of any newly emerging cognitive capacities" (ibid., 7). There are at least two constraints for the reuse of brain regions: 1. "cortical regions have specific biases that limit the uses to which they can be put without extensive rewiring" (ibid., 15); 2. reuse requires "the presence of a sufficient degree of functional relatedness between existing and newly developing purposes" (ibid., 26). In the case of cognitive practices, neuronal recycling – understood as a pervasive type of neural reuse – is not only determined by these constraints, but also by the culturally shaped purpose requiring its instantiation. Thus construed, "the functions of the new interconnected circuits are dependent upon the cultural practices which determine these functions" (Menary 2012, 150).

The second assumption in support of enculturation concerns neuronal LDP, which is considered to be an adaptation (cf. Menary 2013b, 357).[29] One of the conditions for the manifestation of LDP is the immersion into a socio-culturally structured environment and a community whose members share their expertise in the performance of cognitive practices with their offspring:[30] "Our developmentally plastic brains exhibit learning plasticity when we are coupled to a highly scaffolded learning environment; the brain is profoundly transformed, and consequently, we are cognitively transformed in a deeply profound way" (ibid.). The consideration here is that contemporary human organisms would cognize very differently if their brains

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[29] For a similar idea, see Sterelny 2003, 163. In particular, Sterelny (2003, 170) claims that "there is good reason to believe that cognitive and neural developmental plasticity is adaptive".

[30] Similarly, Daniel Ansari (2012) highlights the importance of neural plasticity for adequate descriptions and explanations of neuro-cognitive functions that are culturally acquired. His approach presupposes that cultural phenomena and educational interventions play a causal role in changes of neural mechanisms.

where not open to plasticity. This property allows them to engage with cognitive resources that ultimately crucially influence their cognitive development. Thus, there are both phylogenetic and ontogenetic neuronal factors that causally contribute to the enculturation of human organisms and their ability to engage in cognitive practices.

In sum, the notion of a cognitive practice refers to cognitive activities that are constituted both by neuronal and bodily components.[31] These activities are situated in a rich, socio-culturally structured environment and are aimed at the completion of certain cognitive tasks. The successful performance of cognitive practices is rendered possible by the mastery over the relevant cognitive norms for the manipulation of representational systems and other cognitive resources. These norms need to be learned in the course of cognitive development. Learning is made possible by enculturation. That is to say that the transformation of both neuronal and bodily functional components is a result of the close interaction of developing human organisms with their environment and their socio-cultural group.

2.4. READING AS A COGNITIVE PRACTICE

So far, I have presented the constitutive theses of CI and the approach to cognitive practices and enculturation. For the remainder of this chapter, I will point to various aspects of CI that render this theoretical framework most suitable for a philosophical investigation of reading. One the one hand, CI provides the conceptual tools for the analysis of the sub-components of reading. On the other hand, reading will be considered to be an important type of cognitive practices. In turn, the investigation of reading might help refine the theoretical assumptions made by CI.

In literate societies, writing systems are an important part of the cognitive niche. The manipulation of their tokens is a vital component of cognitive processing routines. We are situated in an environment that is enriched by books, papers, homepages, letters, e-mails and so on. It is our acquired capacity to manipulate these cognitive resources that allow us to solve many cognitive tasks fluently and successfully.[32] For instance, consider the influential thought experiment about the Alzheimer patient Otto and his notebook introduced by Clark and Chalmers (1998). As a

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[31] When I speak of neuronal and bodily components, I would like to emphasize that the interaction of neuronal processes in the brain and physical processes in the entire body of the (human) organism together give rise to genuinely cognitive processes.

[32] A similar point is made by Peterson (1996, 7) who argues that “the acquisition of an appropriate FOR [i.e., form of representation] can be epistemically advantageous, and can facilitate understanding, problem solving, calculation and the growth of knowledge.”

compensation for his memory deficits, he retrieves information from his notebook in order to fulfil the cognitive task of remembering a specific location, the address of the MoMa in New York, as the thought experiment has it. Similarly, many human organisms organize their daily activities by having a diary which serves as an ‘external’ resource for remembering dates and for planning activities in the future. This can be considered as a case of hybrid cognitive processing being constituted by the reciprocal causal interaction of neuronal and bodily components operating on environmental resources. This is because “the external process of retrieving information from the diary and the concurrent process in my brain jointly govern my future behaviour” (Menary 2007a, 52). These brief examples of remembering and planning illustrate that the presence of representational vehicles belonging to an (alphabetic) writing system is one important case of epistemic engineering in the sense introduced earlier. In turn, epistemic engineering is a crucial factor of the cognitive practice of reading. If we understand reading as a cognitive practice, we can acknowledge the fact that the associated processing routines enhance our cognitive capacities for remembering, imagining, planning, reasoning, and so forth. Furthermore, by considering reading as a “hybrid abilit[y]” that is constituted both by neuronal and bodily components (Menary 2012, 150), we will come to appreciate the interactions between eye movements in terms of bodily manipulations and neuronally realized sub-processes associated with visual word recognition and sentence processing. This point will be extensively dealt with in the course of the following chapters. Finally, the normative aspect of cognitive practices will allow for a careful investigation of the cognitive norms underlying the interactions of human organisms with tokens of a writing system. In sum, by treating reading as an important type of cognitive practices, the conceptual investigation and the careful interpretation of a vast array of empirical data will yield new and highly promising results. This also means to abandon the “pure translation view of language”, which considers reading to be an exclusively internalistic process by which ‘external’ symbols are *translated* into an ‘inner’ code that is correlated with neural activities. By embracing CI and the notion of a cognitive practice, I will emphasize that reading is constituted both by neuronal and bodily sub-processes that occur because the cognizing organism is situated in a socio-culturally developed, symbol-rich environment.

Another important consequence of describing reading as a cognitive practice is to consider reading acquisition as an important target phenomenon in its own right.

The assumption here is that learning to read can be described in terms of enculturation and cognitive transformation. This is perfectly in line with Menary's (2013b, 357) and Menary and Kirchhoff's (2013, 12) claim that "[t]he deeply transformative power of our learning histories in the cognitive niche is one that reformats the representational capacities of the brain in terms of public representational systems." On this construal, reading acquisition brings about new representational capacities of the brain due to LDP. As suggested by Menary (2012, 149; 2013b, 354), "[l]earning to read and write is a wonderful, cognitive example of the brain's plasticity." I will elaborate on this line of reasoning in the course of the next chapters. In addition, reading acquisition is subject to *cultural inheritance*. In contrast to genetic inheritance, cultural inheritance has the purpose to transmit knowledge and skills within a socio-cultural group in the cognitive niche (cf. Odling-Smee & Laland 2011, 227). Put differently, "[t]hrough cultural inheritance, knowledge, skills, and artefacts are passed on to the next generation, but learning environments and learning techniques are also passed on so that the next generation can acquire and be transformed by the inherited cultural capital" (Menary 2014, 291; 2015, 7). As we will see in later chapters, reading acquisition is just a special type of cultural inheritance, which relies heavily on LDP and scaffolded learning. For the time being, the important point is that CI provides the conceptual resources necessary for describing the neuronal changes that are associated with reading acquisition while also allowing for a careful analysis of the transformation of bodily components in the course of the learning process:

> Development in the cognitive niche results in an integrated cognitive system. The integrated cognitive system has been through the dual component process of transformation where one gains mastery over the symbol system in public space, which leads to a transformation of our limited cognitive capacities such that we can complete cognitive tasks by manipulating symbols in public space or by manipulating symbols in neural space, but most importantly by a combination of both sets of resources. This transformation results in new body schemas for action and new cortical functions for reading, writing, and mathematics. (Menary 2013b, 364; Menary & Kirchhoff 2013, 12)

This is to be understood as a specification of *enculturation*, i.e., of the idea that "our cognitive abilities are enculturated […] by a process of transforming existing cognitive abilities to perform new, cultural functions" (Menary 2012, 152; 2013b, 354). Reading clearly is one of these culturally acquired cognitive functions. At the same time, this "extension of a cognitive ability" profoundly enhancing our capacities to solve cognitive tasks is associated with a sufficient degree of expertise (Menary

2012, 152). In the context of reading, expertise concerns the set of norms that guide the successful interaction with tokens of an (alphabetic) writing system.

2.5. CONCLUDING REMARKS

To conclude, I assume that reading is a cognitive practice that profoundly transforms our cognitive capacities, both in neuronal and bodily terms. Furthermore, the ability to read can be described as the result of a process of enculturation, of a process of socially scaffolded and culturally situated cognitive development, that is. In what follows, I will enrich these assumptions by suggesting that the predictive processing framework can significantly contribute to a deeper understanding of enculturated cognitive processes.

3. PREDICTIVE PROCESSING

3.1. INTRODUCTION

In the last chapter, I have introduced CI and the notion of a *cognitive practice*. I have argued that CI and its approach to cognitive practices and enculturation provide the right kind of conceptual tools for a coherent und empirically plausible approach to reading. So far, I have said nothing about the possible neuronal and bodily mechanisms that might underlie cognitive practices. To this end, I will introduce the predictive processing (PP) framework in this chapter. After having presented the core ideas and basic principles proposed by this framework, I will argue in the next chapter that this mechanistic approach is a promising candidate for describing both the neuronal and bodily constituents of cognitive practices. Furthermore, I will argue that the combination of CI and PP leads to a parsimonious and epistemically useful perspective for the investigation of reading.

Recently, the idea that human perception, action, and cognition can be described and explained in terms of a hierarchically organized predictive processing mechanism realized in the human brain has enjoyed widespread attention within cognitive neuroscience, philosophy of mind, and philosophy of cognitive science (e.g., Clark 2012, 2013, 2015a, 2015b, in progress; Friston 2005, 2010; Friston et al. 2012; Hohwy 2011, 2012, 2013, 2014, 2015; Seth 2015). The overall epistemic goal of this emerging approach is to describe these target phenomena within a single framework by relying on unifying mechanistic principles that can be approached on several levels of description.

3.2. PROBABILISTIC GENERATIVE MODELS AND PREDICTION ERROR MINIMIZATION

Accounts of PP generally assume that human perception, action, and cognition are realized by Bayesian probabilistic generative models realized in the human brain. The purpose of these generative models is “[…] to capture the statistical structure of some set of observed inputs by inferring a causal matrix able to give rise to that very structure” (Clark 2016, 21; see also Clark 2013a, 182). Here, the idea is that generative models help solve the *inverse problem* of human perception (cf. Lawson et al. 2014, 1). The human brain only has access to “on the one hand the predicted sensory input, and on the other the actual sensory input” (Hohwy 2015a, 3; see also Seth 2015, 5). What the brain does not have access to are the environmental (or bodily) causes giving rise to sensory effects, where causes are just “the states of processes generating sensory data” (Friston 2005, 819). This is problematic since “any number of causes could cause any particular sensory input, and similarly, the same cause could give rise to many different sensory inputs” (Hohwy 2011, 267). In order to infer the causes of sensory effects, the brain “[…] makes an assumption about the cause by favouring the model with the highest prior probability and then it predicts the effect on that basis” (ibid., 267f; see also Seth 2015, 4f).[33] We can elaborate on the idea that generative models encode probability distributions by referring to Bayes’ rule. Each generative model provides several hypotheses about the causes of a certain sensory input. The system has somehow to ‘decide’ which hypothesis needs to be chosen in order to account for the cause of the sensory effect. The descriptive power of Bayes’ rule lies in its capacity to capture the probabilistic estimations underlying these choices:[34]

> This rule tells us to update the probability of a given hypothesis […] given some evidence […] by considering the product of the likelihood (which was the probability of the evidence given the hypothesis) and the prior probability of the hypothesis (normalized so probabilities sum to 1). The resulting assignment of probability to the hypothesis is known as the *posterior probability*. The best inference is then to the hypothesis with the highest posterior probability. (Hohwy 2013, 17; italics in original)

Applied to cases of human perception and cognition, Bayesian generative models are assumed to be realized in hierarchically organized structures comprising multiple, highly interactive low- and high-level cortical areas. This is referred to as the *Bayesian brain hypothesis* (cf. Friston 2010, 129; Hohwy 2015a, 17). The particular hierarchical organization of probabilistic generative models is then combined with a specific version of *predictive coding*, where predictive coding “depicts the top-down flow as attempting to predict and fully ‘explain away’ the driving sensory signal, leaving only any residual ‘prediction errors’ to propagate forward within the system” (Clark 2013a, 182).[35] That is to say, selected hypotheses form prior predictions (*priors*) about the sensory input to be expected at each level of

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[33] More formally, this idea can be stated as follows: “A generative model is specified in terms of a prior distribution over the causes p (v; θ) and the generative distribution or likelihood of the inputs given the causes p(u|v; θ)” (Friston 2005, 820).

[34] For a more formal, yet philosophically inspired treatment of Bayes’ rule, see Hohwy (2013, 34-37). As Clark (2014, 230) puts it in simple terms, “Bayes’ rule […] describes an optimal way of altering existing beliefs in response to new information or evidence.”

[35] This is the reason why I prefer to follow Andy Clark in talking about *predictive processing* rather than *predictive coding*. While predictive coding is a “data compression strategy” being applied in a variety of contexts, the notion of predictive processing refers more specifically to the “use of that strategy in the special context of hierarchical systems deploying probabilistic generative models” (Clark 2013a, 202, footnote 5; see also Clark 2016, 25f; Clark 2014, 232).

the hierarchy. These predictions fulfil the function of encoding knowledge about statistical regularities of patterns in the observable (or any imaginable) world. This hypothesis selection happens in accordance with Bayes' rule.[36] The processing of sensory input gives rise to prediction errors, that is, to discrepancies between the input to be expected and the result of processing routines at lower levels. Importantly, the only neuronal information that is passed on to the next superordinate level of the hierarchy is prediction error (cf. Clark 2013a, 182f; Hohwy 2012, 3; 2013, 47; Hohwy 2014, 4). The overall aim of this multi-level processing mechanism is to *minimize prediction error*, that is, to reduce or to 'explain away' the discrepancy between predictions and the sensory information that is an effect of environmental (or bodily) causes (cf. Clark 2013a, 187; Clark 2014, 232f; Hohwy 2011, 269; Hohwy 2013, 88). This is known as *prediction error minimization*.

3.3. PREDICTION ERROR MINIMIZATION AND THE FREE ENERGY PRINCIPLE

Prediction error minimization is a special way of minimizing *free energy* in accordance with the principle "that any self-organizing system that is at equilibrium with its environment must minimize its free energy" (Friston 2010, 127). Applying this thermodynamic principle to human perception, cognition, and action, free energy can be understood "[…] as the difference between the way the world is represented (modelled) as being, and the way it actually is. […] The better the engagements, the lower the information-theoretic free energy […]" (Clark 2016, 305). Minimizing free energy therefore means to minimize the amount of unbound energy available to the perceiving, cognizing, and acting organism. Put differently, the less the amount of free energy, the more efficient the processing routines of the organism are supposed to be. Prediction error minimization avails itself as a computationally and neuronally tractable strategy to minimize free energy. It is the prediction error signals that provide information about the amount of free energy relative to an organism. That is to say that "free energy can be understood as the sum of prediction error" (Hohwy 2015a, 4; Hohwy 2015b, 297). An elaboration on this idea adds a third information-theoretic quantity, that helps formulate the close relationship between free energy minimization and prediction error minimization: "Prediction error reports this information-theoretic free energy, which is

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[36] For this reason, the combination of probabilistic generative models and the predictive coding strategy is also referred to as *empirical Bayes* (cf. Clark 2016, 25f; Friston 2005, 822; Hohwy 2012, 3; Hohwy 2013, 61).

mathematically constructed so as always to be greater than ‘surprisal’ (where this names the sub-personally computed implausibility of some sensory state given a model of the world […])” (Clark 2016, 306).

Surprisal is an information-theoretic notion that refers to “the discrepancy between the internal model that codifies what you expect and the actual input” (Hohwy 2011, 268):[37] “It is defined as the negative log probability of a given state, such that the surprise of a state increases the more improbable it is to find the creature in that certain state […]” (Hohwy 2015a, 3). According to the free energy principle, organisms need to minimize surprisal, “since surprising sensory states are likely to reflect conditions incompatible with continued existence” (Seth 2015, 6). The relationship between free energy and surprisal then is that “[…] free energy is an upper bound on surprise, which means that if agents minimize free energy, they implicitly minimize surprise” (Friston 2010, 128). Suprisal, however, cannot be estimated directly by the system (cf. Hohwy 2015a, 3; Hohwy 2015b, 296). According to Hohwy (2012, 3), the reason is that “there is an infinite number of ways in which the organism could seek to minimize surprise and it would be impossibly expensive to try them out.” The solution to this problem lies in implicitly minimizing surprisal (and in minimizing its upper bound, i.e., free energy) by minimizing prediction error (cf. Hohwy 2013, 85; Seth 2015, 6). It is exactly here where prediction error minimization avails itself as a tractable expression of more general dynamic life-sustaining mechanisms. Understood like this, “PP can be considered as a special case of the *free energy principle* […]” (Seth 2015, 5; italics in original).

3.4. PERCEPTUAL INFERENCE AND ACTIVE INFERENCE

Prediction error minimization can be achieved in two distinct, yet complementary ways. First, consider *perceptual inference*, which can be described as “[…] an iterative step-wise procedure where a hypothesis is chosen, and predictions are made, and then the hypothesis is revised in light of the prediction error, before new and hopefully better predictions are made on the basis of the revised hypothesis” (Hohwy 2013, 45). That is, prediction errors are propagated up the hierarchy leading

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[37] *Surprisal*, understood as an information-theoretic quantity applied on a sub-personal level of description, needs to be distinguished from *suprise* in a rather folk-psychological sense (cf. Hohwy 2015b, 296). However, Clark (2013a, 190) suggests that suprisal and surprise might be related in an interesting way. Surprise might be the phenomenally accessible result of indirectly computed surprisal: “Successful perception requires the brain to minimize surprisal. But the agent is able to see very (agent-) surprising things, at least in conditions where the brain assigns high reliability to the driving signal.”

to an adjustment of the initial hypothesis, thereby achieving an approximation of the hypothesis generating the predictions and the actually given sensory input. This occurs at every level of the hierarchy until any prediction error is (at least theoretically) accommodated. This gives rise to perception: "Perception thus involves accommodating the driving (incoming) sensory signal by matching it with a cascade of predictions pitched at a variety of spatial and temporal scales" (Clark 2016, 37; see also Clark 2013a, 187). These scales concern the environmental (or bodily) regularities that are predicted and the division of labour between the levels constituting the processing hierarchy (see Hohwy 2012, 2; Hohwy 2013, 31f):

> Fast changing regularities are good for detail; slower regularities are more general and abstract. […] Regularities can be ordered hierarchically, from faster to slower. Levels in the hierarchy can be connected such that certain slow regularities, at higher levels, pertain to relevant lower level, faster regularities […]. A complete such hierarchy would reveal the causal structure and depth of the world – the way causes interact and nest with each other across spatiotemporal scales. (Hohwy 2013, 27f; see also Hohwy 2014, 3f; Hohwy 2015a, 7; Clark 2014, 234f)

On Andy Clark's account of PP, one important consequence of this is that the traditional distinction between perception and cognition gets blurred. It is replaced by a reconceptualization of perceptual and cognitive processes as a continuous employment of the same prediction error minimizing mechanism on multiple scales:

> All this makes the lines between perception and cognition fuzzy, perhaps even vanishing. In place of any real distinction between perception and belief we now get variable differences in the mixture of top-down and bottom-up influence, and differences of temporal and spatial scale in the internal models that are making predictions. Top-level (more 'cognitive') models intuitively correspond to increasingly abstract conceptions of the world, and these tend to capture or depend upon regularities at larger temporal and spatial scales. Lower-level (more 'perceptual') ones capture or depend upon the kinds of scale and detail most strongly associated with specific kinds of perceptual contact. (Clark 2013a, 190)

Consequently, processes associated with perception and cognition can only be distinguished by considering the temporal and spatial resolution of the realization of PP mechanisms and the levels at which model revision ensues, respectively. For this reason, Hohwy (2013, 72) suggests that the classical conceptual distinction between percepts and concepts is softened on the PP construal, since "[…] the difference between percepts and concepts comes out in terms of a gradual movement from variance to invariance, via spatiotemporal scales of causal regularities. There is thus no categorical difference between them […]." Perhaps even more importantly, "[…] percepts and concepts interact in a complicated top-down–bottom-up manner and modulate each other, subject to how prediction error is best suppressed throughout the hierarchy" (ibid., 73). This continuity assumption about perception and cognition, and percepts and concepts, is one of the important reasons why the prediction error minimization framework has great descriptive and explanatory power. For it offers a unified perspective on perceptual and cognitive processes by positing that they can be depicted as following the same underlying functional and neuronal principles.

Perceptual inference is only one way to minimize prediction error. The second one is *active inference*, where "[…] the agent will selectively sample the sensory input it expects" (Friston 2010, 129). Contrasting both types of prediction error minimizing inference emphasizes their distinct, yet complementary functional roles (cf. Hohwy 2013, 81):

> […] prediction error can be minimized in perceptual inference, where hypotheses about the world are updated in the light of their ability to predict sensory input; and prediction error can be minimized in active inference, where the confidence in hypotheses is updated in the light of the way sensory input can be brought to fit their predictions. (Hohwy 2013, 88; see also Seth 2015, 5)

The idea is that the system can minimize prediction error by bringing about the states of affairs (environmental causes) that are predicted by a certain hypothesis. This is achieved by performing any type of bodily movement, including eye movements, that let the selected prediction come true. The predictions at play in active inference are *counterfactual*, because "[…] they say how sensory input *would* change if the system *were* to act in a certain way. Given that things are not actually that way, prediction error is induced, which can be minimized by acting in the prescribed way" (Hohwy 2013, 82; italics in original; see also Clark 2015a, 6f; Friston et al. 2012, 2; Seth 2015, 9). Accordingly, in active inference the selected prediction is held constant and leads to bodily activities that minimize prediction error by altering the sensory input such that it fits the prediction.[38] Active inference is of crucial importance for prediction error minimization, "[…] since it provides the only way (once a good world model is in place and aptly activated) to actually alter the sensory signal so as to reduce sensory prediction error" (Clark 2013a, 202; see also Clark 2016, 133).

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[38] Intriguingly, according to Seth (2015, 19) active inferences that serve the consolidation of predictions and sensory inputs are only one type of active inference: "Actions can be selected that (i) are expected to confirm current perceptual hypotheses (Friston et al. 2012); (ii) are expected to disconfirm such hypotheses; or (iii) are expected to disambiguate between competing hypotheses […]" (italics in original). If this were true, it would render active inferences more functionally complex than initially assumed. In addition, it would emphasize the vital importance of active inference for the organism's viability and, as we shall see in later chapters, for its cognitive capacities.

This suggests that perceptual and active inference, or perception and bodily action for that matter, mutually influence each other, thereby minimizing prediction errors and optimizing hypotheses. However, perceptual and active inference have a "different direction of fit" (Hohwy 2013, 178; see also Clark 2014, 237; Hohwy 2015a, 4).[39] This is because in perceptual inference, the predictions are aligned to the sensory input, while active inference is a matter of aligning the sensory input to the predictions (cf. Clark 2016, 121; Lawson et al. 2014, 1).[40] It follows "[…] that to optimally engage in prediction error minimization, we need to engage in perceptual inference and active inference in a complementary manner" (Hohwy 2013, 91). Since both perceptual and active inference are aimed at minimizing prediction error and optimizing generative models,[41] "[p]erception and action here follow the same basic logic and are implemented using the same computational strategy. In each case, the systemic imperative remains the same: the reduction of ongoing prediction error" (Clark 2015a, 8; see also Clark 2012, 760). Furthermore, it is both perceptual and active inferences that (indirectly) minimize free energy (see Seth 2015, 6).

As emphasized earlier, perception and cognition are deeply related to the extent that both phenomena are the result of the same underlying functional and neuronal mechanisms. By extension, action is also deeply intertwined with cognition.[42] This is obvious given that 1. perception and cognition are continuous; and 2. perception and action follow the same principles of prediction error minimization, although they

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[39] The notion of two functions having "a different direction of fit" originates in J. L. Austin's (1953, 234) speech act theory and in G. E. M. Anscombe's (1963, 56) example illustrating how words and states of affairs can relate to each other (cf. Clark 2016, 123; Madary 2015, 4). I would like to thank Thomas Metzinger for pointing out the philosophical history of this notion.

[40] It should be stressed that while both perceptual inference (perception) and active inference (action) minimize free energy by minimizing prediction error, "only action minimises surprise (because surprise is an attribute of sensations actively sampled" (Friston 2013, 212; see also Hohwy 2012, 7f). The notion of *surprise* as used by Friston refers to *surprisal* as introduced earlier.

[41] As Clark (2013a, 203) notes, "[…] there is always a single hierarchical generative model in play." However, in describing the processing routines of several generative models realized in the human brain, it is emphasized "[…] that the hierarchical structure supports many levels of processing which distribute the cognitive labor by building distinct 'knowledge structures' that specialize in dealing with different features and properties (so as to predict events and regularities obtaining at differing temporal and spatial scales)" (ibid.; see also Clark 2016, 318).

[42] Interestingly, this picture of perception, action, and cognition is consistent with Clark's (1997, 221) view of the human "[…] mind as a grab bag of inner agencies whose computational roles are often best described by including aspects of the local environment (both in complex control loops and in a wide variety of informational transformations and manipulations)." On this construal "[…] the traditional divisions among perception, cognition, and action look increasingly unhelpful" (ibid.). This is exactly what the PP framework suggests (at least according to Clark's interpretation).

fulfill distinct functional roles.[43] Therefore, on Clark's account, which he dubs *action-oriented predictive processing*, prediction error minimization "[…] depicts perception, cognition and action as profoundly unified and, in important respects, continuous" (Clark 2013a, 187).[44] The reason is that "[p]erception and action are […] similarly and simultaneously constructed, and intimately entwined" (Clark 2016, 296).

An important consequence of this approach to cognition, perception, and action is that we can re-conceptualize traditional philosophical accounts of believes and believing. In PP-style approaches, the notion of belief is usually used in a way that significantly departs from its employment in traditional philosophical discourses on propositional attitudes. On Clarks (2015a, 11) construal of PP, beliefs are defined as "the multi-level, multi-modal webs of probabilistic expectation that together drive perception and action." In terms of empirical Bayes, beliefs are nothing but neuronally realized probabilistic density distributions. Put differently, the notion of belief is supposed

> […] to cover any of the contents of the generative models that guide perception and action. There is no requirement that such beliefs be consciously accessible to the reflective agent. Indeed, for the most part, they will comprise a variety of sub-personal states whose best expressions are probabilistic rather than sentential. (Clark 2016, 55)

That is to say that this Bayes-inspired talk of beliefs happens to be an attempt to replace the traditional folk-psychological discourse about propositional attitudes. If this were true, classical propositions such as "she believes that p" could be recast in terms of high-level probabilistically determined predictions targeted at p. In this case, p could be, for example, a specific sensory input or some proprioceptive feedback predicted to be the result of active inference. The application of this line of reasoning to both simple and nested propositional attitudes (e.g., she believes that he believes that p) would lead to a re-description of imagination in terms of the general prediction error minimizing mechanism:

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[43] There is an intriguing similarity between this line of reasoning and Dewey's (1896, 357f) still timely approach to perception, action, and cognition: "The older dualism between sensation and idea is repeated in the current dualism of peripheral and central structures and functions; the older dualism of body and soul finds its distinct echo in the current dualism of stimulus and response. Instead of interpreting the character of sensation, idea and action from their place and function in the sensori-motor circuit, we still incline to interpret the latter from our preconceived and preformulated ideas of rigid distinctions between sensations, thoughts and acts."

[44] Similarly, Seth (2015, 5) argues that "[i]n most cases, these processes are assumed to unfold continuously and simultaneously, underlining a deep continuity between perception and action […]."

> Imagination is there too, since the capacity to self-generate (at least in approximation to) the sensory signal implies that systems that can perceive the world this way can also generate, off-line, perception-like states for themselves. Such self-generation is simply another use of the same generative-model-style knowledge that enables them to meet incoming sensory stimulations with apt sensory predictions. (Clark 2016, 8)

Understood like this, the proposition “she believes that he believes that p” could be recast in terms of a complex interaction of offline high-level predictions realized in the human cortex (possibly enriched by simulated active inferences). If this is on the right track, the PP approach would be an embodied version of *eliminative materialism*:

> Because the existing characterization of the human brain's high level capacities, embodied in what, for want of a better term, is referred to as ‘folk psychology’, may well be reconfigured as time and cognitive neuroscience proceed. This too is an empirical hypothesis, and one for which empirical support already exists. […] The possibility of nontrivial revision and even replacement of existing high level descriptions by 'neurobiologically harmonious' high level categories is the crux of what makes eliminative materialism *eliminative*. (Churchland 1994, 26; italics in original)

This illustrates that the PP framework has the conceptual resources and the descriptive power to easily and elegantly reconcile traditional philosophical debates about the conditions of propositional attitudes and related cognitive phenomena.

3.5. THE NEURONAL REALIZATION OF PREDICTION ERROR MINIMIZATION

It is now time to say more about the realization of prediction error minimization in the human brain. Generally, hierarchical generative models are assumed to be neuronally realized by multiple connections across low- and high-level cortical areas. As Clark (2014, 239) puts it, “[a]t the level of gross neuroanatomy, the predictive processing architecture makes good sense – and very efficient use – of a complex neuroanatomy in which recurrent connectivity is massive and apparently functionally asymmetric […].” According to this kind of neuronal architecture, each level within the cortical hierarchy is connected to the next subordinate and supraordinate level (cf. Hohwy 2013, 67f), thereby ensuring effective inter-level message passing: the cortical “[…] hierarchy is simply *defined* by these patterns of interaction” (Clark 2016, 143; italics in original).

Since prediction and prediction error play different functional roles, there should also be differences in their neuronal realization. According to Clark (2013a, 187), predictive generative models are realized in “a kind of duplex architecture”. This means that there are distinct neuronal units dedicated to the representation of predictions of environmental (or bodily) causes, so-called *representation units*, on the one hand, and those dedicated to the encoding of prediction error, so-called *error units*, on the other (cf. ibid.; see also Clark 2014, 238; Clark 2016, 37f; Friston 2005, 829). Representation units and error units are supposed to influence each other in an ongoing inter-level exchange of neuronal information: “[…] the error units process signals from the representation units both at their own level and at the level above, and the representation units send signals to the error units both at their own level and at the level below” (Clark 2013a, 192). Message-passing on the same level of the hierarchy is of crucial importance for the selection of prediction error that is fed forward to the next supraordinate level: “[…] lateral connections within the same hierarchical level serve to decorrelate prediction units such that when a particular hypothesis begins to emerge as having the highest posterior probability other units are progressively prevented from influencing inference […]” (Hohwy 2013, 61). To date, a detailed account of the concrete neuronal realization of these functionally distinct units of message-passing is still missing (cf. ibid.). However, it is hypothesized that representation units might correspond to superficial pyramidal cells, while error units might correspond to deep pyramidal cells (cf. Friston et al. 2012, 8; Friston et al. 2014, 434; see also Clark 2013a, 187f; Clark 2016, 39). More empirical evidence is needed in order to confirm this hypothesis or to arrive at another possible neuro-functional distinction between units conveying predictions and units reporting prediction error. Yet, the assumption underlying the cortical realization of hierarchical generative models remains the same: “However it may (or may not) be realized […] predictive processing demands *some* form of functional separation between encodings of prediction and of prediction error” (Clark 2016, 39; italics in original).

3.6. PRECISION ESTIMATION

There is yet another component of the PP framework that needs to be considered. The coordination of perceptual and active inference just described can be called first-order statistics. It is complemented by second-order statistics, where this concerns the estimation of the *precision* of prediction error (cf. Hohwy 2012, 4). Sensory signals informing perceptual inference can be more or less noisy (or uncertain) and any predictive system needs to take this into account in order to be able to process information reliably and efficiently. The certainty in the signal is estimated by the precision (i.e., the inverse variance) of the prediction error it gives rise to (cf. Clark 2015a, 12; Seth 2015, 5). This means that “[…] the brain is required to extract regularities having to do with precisions and use these to optimize the passing of messages back and forth in the perceptual hierarchy" (Hohwy 2013, 65). The functional role fulfilled by the estimation of precision is to determine "[…] the impact of specific prediction error signals to be altered according to task, context, and background information" (Clark 2016, 204; see also Clark 2014, 12). On a neuronal level of description, the estimation of precision is captured in terms of increasing or decreasing the *synaptic gain* of specific error units (cf. Clark 2014, 236; Feldman & Friston 2010, 2; Friston et al. 2014, 434). That is, "[t]he more precision that is expected the more the gain on the prediction error in question, and the more it gets to influence hypothesis revision" (Hohwy 2013, 66; see also Friston 2010, 132). Conversely, if the precision is expected to be poor on the basis of second-order statistics, the synaptic gain on the error unit is inhibited such that the prediction on the supraordinate level is strengthened (cf. ibid., 123). As with first-order statistics, second-order statistics is assumed to occur throughout all levels of the hierarchy, thereby determining the overall influence of low- and high-level prediction error by estimating (or 'weighting') the precision of prediction error on each level. Neuronally, the estimation of precision is supposed to be encoded by the modulatory effects of neurotransmitters such as dopamine (Fletcher & Frith 2009, 55; see also Clark 2013a, 190).

However, precision estimation does not only have a crucial influence on perceptual inference, but also on active inference. In active inference, precision estimation is achieved by "context- and task-reflecting assignments of precision" (Clark 2016, 187). In other words, "[…] expected precision drives action such that sensory sampling is guided by hypotheses that the system expects will generate precise prediction error" (Hohwy 2015a, 6). The performance of a particular action that is induced by a selected prediction is thus equivalent to increasing the synaptic gain on certain error units by proving reliable (certain) information as a result of that very action (see Seth 2015, 19).

The particularly interesting point about precision estimation is that it is assumed to be functionally and neuronally equivalent to *attention*. This means that "attention is nothing but optimization of precision expectations in hierarchical predictive coding" (Hohwy 2013, 70; see also Feldman & Friston 2010, 2; Hohwy 2015a, 5). More specifically, "[…] attention requires learning state-dependent patterns of noise and precision and then using such prior beliefs to set the gain on prediction error" (ibid, 195; see also Clark 2016, 57; Hohwy 2014, 4). Considered this way, the weighting of prediction error in terms of precision estimation can account for both exogenous and endogenous attention. *Exogenous attention* is directed at unexpected salient features of the environment (or the body). The sensory signals caused by these features “are implicitly ‘expected’ to display a high signal-to-noise ratio” (Clark 2016, 77). As a result, the prediction error produced by these signals should have a great impact on the optimization of predictions, since “error units exposed to such signals should thus expect high precision and be given larger gain” (Hohwy 2012, 6). In contrast, *endogenous attention* is associated with precision expectations generated by the predictive system itself in specific contexts. This means “[…] that it works as an increase in baseline activity of neuronal units encoding beliefs about precision” (ibid., 7). Depending on the current task the predictive system needs to solve, endogenous attention is thus a function of attending to sensory signals that are most likely to be reliable, thereby increasing the synaptic gain on those error units that report features of that signal. Attention, both exogenous and endogenous, influences active inference, because “one is selectively sampling the world under expectations of high precision” (Hohwy 2013, 200). On this construal, “[…] action essentially turns into an attentional phenomenon” (Hohwy 2015a, 6). Thus, attention crucially contributes to the coordination of perceptual and active inference by modulating the precision expectations assigned to specific prediction errors (cf. ibid., 200f).

Finally, precision estimation promises to speak to the overall cortical organization of the human brain. According to Andy Clark (2013c, 1), precision estimation “[…] provides a means of altering the flow of influence between different neural areas, hence flexibly reconfiguring patterns of effective connectivity.” In contrast to structural connectivity (reporting synaptic connections within and across brain areas) and functional connectivity (reporting the correlation of events in distinct, but interacting brain areas), effective connectivity “aims to reflect short-term patterns of *causal influence* between neural events” (ibid., 3; italics in original). The proposal then is that “[…] the control of effective connectivity is achieved by the manipulation of the precision-weighting assigned to specific prediction errors” (ibid., 4). This means that the connections between error units having strong synaptic gain are strengthened. This, in turn, alters the overall causal influence of the hierarchical levels on each other. Since precision estimation is considered to be equivalent to attention, “[t]he neural mechanisms of attention […] are thus identical with the neural mechanisms that alter patterns of effective connectivity” (ibid.; see also Clark 2016, 148).

In sum, the estimation of precision offers a good strategy for predictive systems to constantly alter the fine-tuning of the causal influence predictions and prediction errors have over each other. This major functional role of precision estimation is nicely summarized by Clark (2016, 78): “Uniting perception and action in a single self-fuelling loop, estimates of precision thus enable the flexible task-varying combination of bottom-up sensory information (conveyed by prediction error) and top-down generative-model-based expectation.”

3.7. CONCLUDING REMARKS

To conclude, the PP framework offers a unified perspective on perception, cognition, action, and attention (cf. Clark 2013a, 186). It achieves this by depicting human organisms as being engaged in an ongoing dynamical, context-sensitive, and flexible process of prediction error minimization. This amounts to constantly predicting and altering its sensory input and concurrently estimating precision and uncertainty associated with prediction error. More generally, the PP framework allows for a conceptually coherent and empirically plausible investigation of perception, cognition, action, and attention by describing these phenomena in terms of the same general underlying functional and neuronal principles. This framework highlights important differences between these phenomena while stressing their interdependence. Methodologically, the PP framework is maximally parsimonious, since it subsumes the functional and neuronal mechanisms underlying a target phenomenon under the same general principles of prediction error minimization and precision estimation, all of which can be mathematically modelled. Yet, there are many questions open for further empirical research, which concern the more fine-grained realization of hierarchical generative models and the exact interaction of cortical areas in their attempt to minimize prediction error (cf. Clark 2013a, 194).

However, as we will see in the course of this dissertation, there is already much empirical evidence available that supports the adequacy of the PP framework. In the next chapter, I will develop several lines of reasoning in favour of the complementary of CI und it associated approach to enculturation on the hand and the PP framework on the other. I will call this new theoretical perspective *enculturated predictive processing*. As we shall see, the enculturated predictive processing approach endorses Clark’s (in progress, chapter 2, 27) claim “[…] that the probabilistic prediction machine perspective offers our best hope yet of an account of neural processing able to illuminate the profound cognitive entanglement of brain, body, and world.”

4. ENCULTURATED PREDICTIVE PROCESSING

4.1. INTRODUCTION

In the last two chapters, I have reviewed the key components of CI and the PP framework. The overall argument of this chapter will be that CI and PP are complementary with regards to the analysis of certain cognitive processes such as reading. I will argue that this new theory integration, which I call *enculturated predictive processing* (EPP), is conceptually coherent and epistemically rewarding. Furthermore, I will establish that EPP provides both the conceptual tools and the mechanistic principles to develop a framework that is able to account for a manifold of empirical results stemming from neuroscientific, psychological, and psycholinguistic attempts to explain reading.

4.2. THE HYBRID MIND THESIS AND PREDICTION ERROR MINIMIZATION

A major conceptual consequence of PP is that perception, action, and cognition are both continuous and unified, if this approach proves correct. This is because they follow the same principles of prediction error minimization, while at the same time being characterized by important functional differences. This kind of complementarity fits neatly with the *hybrid mind thesis* defended by CI. Recall that the hybrid mind thesis claims that cognitive processes are constituted both by neuronal and bodily components operating on environmental cognitive resources. By taking into account prediction error minimization, this claim can be cashed out by assuming that the neuronal components are equal to perceptual inferences at multiple levels of the cortical hierarchy, while the bodily components are mechanistically realized by active inferences.

The hybrid mind thesis emphasizes the indispensable, dynamic and flexible coordination of neuronal and bodily components which is held responsible for the completion of a cognitive task. The PP framework, or so I shall argue, provides the resources for a careful description and explanation of the underlying mechanism. It does so by depicting human organisms as being constantly engaged in prediction error minimization by optimizing predictions in the course of perceptual inference and by changing the stimulus array in the course of active inference. Furthermore, the transition from more ‘perceptual’ to more ‘cognitive’ sub-processes as depicted by PP, depending on the levels of realization of the processing routines within the cortical hierarchy, allows for a careful analysis of the constitutive neuronal components.

However, there is a potential tension here that needs to be resolved. Originally, CI is supposed to be dependent on some version of the dynamical systems approach. The task lying in front of us now is to show how CI is to be complemented by the prediction error minimization framework without losing its descriptive scope or its conceptual commitments. Call this the *dynamicity challenge*. Cognitive integrationists argue that “the organism-environment system is a hybrid system composed of both internal and external aspects” (Menary 2007, 105). This is in line with the major assumption inspiring mathematical descriptions of the behaviour of dynamical systems that “complex but highly structured behavior can arise as a global property of the interaction between the system’s individual components” (Beer 1995, 143). On this construal, “[…] an agent and its environment are modeled as two coupled dynamical systems whose mutual interaction is jointly responsible for the agent’s observed behavior” (ibid).[45] This means that the organism is integrated into a larger dynamical system, the agent-environment system (cf. Clark 1997, 98; Menary 2007a, 42). Dynamical systems approaches provide the mathematical resources to describe the trajectories of both the component systems and the global agent-environment system.[46] In particular, the basic strategy employed by dynamicists is summarized as follows:

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[45] There is an important distinction between dynamical modelling and dynamical systems theory (DST): “Dynamical modeling is a branch of applied mathematics; its concern is to understand natural phenomena by providing abstract dynamical models. […] DST, on the other hand, is a branch of pure mathematics. Its domain extends to any kind of describable change, but it focuses attention particularly on systems for which there is no known way to specify behaviors as functions of time […]” (van Gelder 1998, 620f).

[46] This applies at least to the majority of dynamical systems approaches that have become relevant for philosophical discussions over the last two decades. It should be kept in mind that there are exceptions to the idea that (human) cognitive systems should be dynamically approached by investigating them as hybrid, reciprocally coupled systems. For instance, Eliasmith (2009) argues that the received (theoretical) separation of brain, body, and the local environment can be maintained without losing the explanatory force of dynamicist reasoning. He presents his neural engineering framework (NEF) as a tenable alternative to language-of-thought-style, connectionist, and dynamical approaches to the functional realization of (human) cognition. According to him, the NEF preserves the assets of dynamical systems theory, namely its emphasis on temporal trajectories of a certain target system. In the NEF, however, dynamical systems theory is complemented by control theory, which allows it to account for the neuronal realization of a certain behaviour of a cognitive system. In particular, he argues that “[…] there are good reasons, even dynamical reasons, for performing a decomposition consistent with traditional boundaries. It is evidently a mistake, then, to rule out decomposition merely because of dynamic coupling” (Eliasmith 2009, 150). As I will try to show in the course of this chapter, this line of criticism does not

> Because an agent [A] and its environment [E] are in constant interaction, A and E are coupled nonautonomous dynamical systems. This coupling can be represented with a sensory function S from environmental state variables to agent parameters and a motor function M from agent state variables to environmental parameters. (Beer 1995, 130)

Based on these assumptions, I argue that the PP approach is nothing but a specific proposal about the realization of dynamical processes in (human) organisms.[47] This is because any biological dynamical system needs to minimize free energy: “The FEP [i.e., free energy principle] says that minimizing free energy is a necessary and sufficient condition for self-organizing adaptive systems to maintain a robust brain-body-environment system and hence, remain within physiological bounds” (Bruineberg & Rietveld 2014, 6; see also Friston 2013b, 1). The PP framework, in turn, formalizes “the shape of the specifically neuronal contribution” to this dynamical process of free energy minimization (Clark 2015a, 16). Put differently, the “mathematical formulation” of the free energy principle “forces Bayesian inference into the picture” (Hohwy 2015a, 17). However, the free energy principle can be interpreted in such a way that it is not reasonable to describe the neuronal processes in isolation, because they always interact with bodily and environmental components *over time*:

> The FEP implies a deep connection between the dynamics of the brain-body-environment system and the neurodynamics. What is crucial, for the organism, is that it anticipates the kind of interactions with the environment that lead to an adequate outcome […]. […] The internal dynamics, Friston’s generative model, can not be understood apart from its functioning within the integrated brain-body-econiche system. (Bruineberg & Rietveld 2014, 7; italics in original)

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affect the EPP perspective defended here. Thanks to Richard Menary (personal communication) for the suggestion to take Eliasmith’s (2009) position into account.

[47] If this line of reasoning is on the right track, two challenges for a complete and exhaustive dynamical-systems-style description can be met by endorsing the PP framework: “The first challenge concerns scaling and tractability. […] The practical applicability of Dynamical Systems theory to highly complex, high-dimensional, coupled systems (like the human brain) must […] be in serious doubt. The second and more fundamental challenge concerns the type of understanding such analyses provide. This type of understanding threatens to constitute abstract description rather than full explanation” (Clark 1997, 101). If it is fair to argue that the prediction error minimization is a theoretical application of the dynamical systems approach, it will become evident that certain types of genuinely human cognitive processing can be fruitfully explored and modelled by relying on the analytic resources provided by the PP framework. Furthermore, the PP framework makes concrete assumptions about the realization of the relevant neuronal sub-components and their modulation by neurotransmitter concentrations. Thus, the PP framework is far less abstract than the dynamicist approaches that we have been considering. This is a promising avenue that warrants future scrutiny by computational modelling and on-line neuroscientific investigation, which would be in line with Clark’s (1997, 121) epistemic requirement to “[…] continually [probe] beyond the level of collective variables and the like so as to understand the deeper roots of the collective variables themselves.”

On this construal, prediction error minimization avails itself as a strategy to minimize free energy in the context of *coupled dynamical systems* (cf. ibid., 7f). In terms of PP, it is due to the close interaction of the neuronal and bodily dynamical sub-processes in terms of perceptual and active inference that they mutually influence and constrain each other over time. As Clark (2015b, 6) puts it, "[d]ynamically speaking, the whole embodied, active system here self-organizes around the organismically-computable quantity 'prediction error'." The mutual interaction of neuronal and bodily sub-processes is rendered possible simply *because* predictive systems constantly interact with their environment. It is thus possible to depict predictive systems as "creating shifting problem-solving wholes that effortlessly span brain, body, and world" (Clark 2016, 250). This is just what the hybrid mind thesis requires. Thus, the idea of reciprocal coupling underlying the hybrid mind thesis can be recast in terms of prediction error minimization, where prediction error minimization is understood as a specific, mechanistically approachable strategy for coupled dynamical systems to indirectly minimize free energy. Recall, reciprocal coupling suggests that "[…] the organism manipulates its environment in one direction, but the result of this environmental alteration feeds back to the organism prompting further bodily actions" (Menary 2007a, 78). My claim is that this is perfectly compatible with the PP framework. This is because the ongoing interaction of perceptual and active inference and the constant changes in the environment caused by active inferences are just a specific expression of reciprocal coupling.

In addition, the claim that the hybrid mind thesis – with its emphasis on the dynamicity of cognitive processes – is reasonably complemented by the free energy principle and prediction error minimization, can be supported by taking the *ergodicity* of dynamical systems and the notion of *Markov blankets* into account. Ergodicity is the idea that "[…] the time average of any measurable function of the system converges (almost surely) over a sufficient amount of time" (Friston 2013b, 2). That is to say that ergodicity reports the probability of a certain system to occupy a certain state in its state space (cf. ibid.). A Markov blanket is defined as "[…] a set of states that separates two other sets in a *statistical* sense" (ibid.; my emphasis; see also Friston et al. 2014, 430). The relationship between a dynamical system, the property of ergodicity and a Markov blanket then is that "[…] any ergodic dynamical system that possesses a Markov blanket will appear to actively maintain its structural and dynamical integrity" (ibid.; Friston et al. 2014, 430). Such a system necessarily minimizes its free energy. The statistical function of a Markov blanket is to “[…] induce[] a partition of states into internal states and external states that are hidden (insulated) from the internal (insular) states by the Markov blanket” (ibid.; Friston et al. 2014, 430). The Markov blanket is comprised of two types of states, namely sensory and active states. These states induce “circular causality” to the system: “[…] external states cause changes in internal states, via sensory states, while the internal states couple back to the external states through active states such that internal and external states cause each other in a reciprocal fashion” (ibid., 2f; Friston et al. 2014, 430). In the present context, Markov blankets are responsible for an organism’s integrity and its ability to physically interact with its environment.[48] Understood like this, the idea is that “[…] biological behaviour rests on the existence of a Markov blanket – and that a Markov blanket is (almost) inevitable in *coupled dynamical systems* with short range connections” (ibid., 5; my emphasis). The consequence is that the statistical postulation of Markov blankets induces the kind of dynamicity required by the hybrid mind thesis. This is because it allows for the dynamical neuronal and bodily interaction of an organism with its environment in terms of reciprocal coupling. Organisms that interact dynamically with their environment almost necessarily minimize free energy (cf. Friston et al. 2014, 428). Furthermore, action fulfils a life-sustaining functional role on this construal, because “[…] active states will appear to maintain the structural and functional integrity of the Markov blanket” (ibid., 432). A tractable strategy to describe the concrete application of the free energy principle is to assume that free energy is indirectly minimized by a system’s ongoing attempt to minimize prediction error and to fine-tune precision estimation.

These considerations about the consistency of dynamical systems approaches, the free energy principle, the statistical significance of Markov blankets, and prediction error minimization are able to resolve the dynamicity challenge. This challenge can be met by assuming that

1. The hybrid mind thesis requires a dynamical systems style description of the interaction between neuronal and bodily component parts of human organisms;

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[48] More generally, Markov blankets can be ascribed to any biological entity on multiple scales: “[...] the Markov blanket of an animal encloses the Markov blankets of its organs, which enclose Markov blankets of cells, which enclose Markov blankets of nuclei and so on” (Friston 2013b, 10; see also Madary 2015, 4).

2. The free energy principle and the prediction error minimization framework are specific formulations of the dynamical organization of (human) organisms and their interaction with the environment;
3. Markov blankets enable (human) organisms to dynamically engage in ongoing interactions with their environments in terms of minimizing prediction error (and thereby indirectly minimizing free energy).

It follows that the PP framework is complementary to the hybrid mind thesis. This is because prediction error minimization avails itself as a specific expression of the dynamicity and interactivity of neuronal and bodily functions that are at the core of the hybrid mind thesis.

4.3. THE MANIPULATION THESIS, COGNITIVE PRACTICES, AND PREDICTION ERROR MINIMIZATION

Another advantage of the prediction error minimization framework is that it helps cash out the *manipulation thesis*. Please recall that the claim here is that "the manipulation of external vehicles [is] a prerequisite for higher cognition and embodied engagement [is] a precondition for these manipulative abilities" (Menary 2010a, 232). The notion of a cognitive practice directly flows from the hybrid mind thesis and the manipulation thesis. Futhermore, the assumption is that cognitive practices are performed in a highly structured, socio-culturally shaped environment (cf. Menary 2007a, 136f). In terms of the PP framework, bodily manipulation can be understood as an instance of active inference occurring in specific contexts. That is, in order to complete a certain cognitive task, the system changes its sensory input by altering the relevant states in its cognitive niche. This becomes even more obvious once we take into account that embodied activity is also a means of increasing the confidence in sensory input. This is achieved by the optimization of precision estimation. Understood like this, bodily manipulation avails itself as an important way of attending to relevant cognitive resources.

Generally, the cognitive niche of contemporary human organisms is highly structured and provides many resources for efficient and complex cognitive practices. Just consider the many opportunities brought about by the availability of writing systems. Once a human organism has gained mastery over such a system, it can complete many cognitive tasks by performing a cognitive practice fluently and efficiently which would be almost impossible without reliance on such 'external' resources. In terms of precision estimation, this means that socio-cultural resources promise to provide highly reliable sensory signals. Understood like this, the bodily manipulation of these resources leads to an increase of precision within the processing hierarchy, which in turn results in an overall improvement of the generative model. This is in line with Hohwy's (2013, 238) observation "[…] that many of the ways we interact with the world in technical and cultural aspects can be characterized by attempts to make the link between the sensory input and the causes more precise (or less uncertain)."[49] However, this does not mean that the bodily manipulation of socio-cultural resources does only serve to minimize prediction error and to optimize precision. In order to acknowledge this, we need to consider the broader context and the purpose of cognitive practices. In performing a cognitive practice, the minimization of prediction error and the optimization of precision estimation is not an end in itself. Rather, it serves to facilitate the completion of a certain cognitive task. Furthermore, the concrete bodily manipulations in terms of active inference are subject to cognitive norms that constrain the ways in which human organisms interact with cognitive resources. Similarly, the cognitive resources have unique, socio-culturally developed properties (cf. Menary 2015a,10).[50] It is these properties that are subject to cognitive norms. These norms must be acquired by the novice in order to be able to perform a certain cognitive practice fluently and successfully. The normative dimension of cognitive practices and cognitive resources highlights that the performance of a cognitive practice is not an individualistic enterprise; rather, it is deeply immersed into a socio-cultural context and shared by many human organisms in a particular cognitive niche. As Menary (2015a, 4) puts it, "[…] practices are not simply reducible to the bodily actions of individuals. […] The practice is a population, or group level phenomenon, not an individual one."[51] In this sense, cognitive practices are special

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[49] Similarly, Paton et al. (2013, 222) argue that "[…] through active inference prediction error is minimized, not only by selective sampling, but also by optimizing its precision: removing sources of noise in the environment and amplifying sensory input. Many of the technical, social and cultural ways we interact with the world can be characterized as attempts to make the link between sensory input and environmental causes less volatile."

[50] I would like to thank Richard Menary for raising this important point in personal communication. We will see in chapter 8 that knowledge about these properties needs to be acquired by the individual in order to be able to interact with a certain cognitive resource successfully and efficiently.

[51] In this vein, Clark (2014, 245) argues that the objectification of ideas by means of symbol systems, artifacts, etc. makes it obvious that the associated cognitive processes cannot be reduced to an individual human organism. Instead, cognitive processes involving the manipulation of cognitive resources is rendered possible by the larger socio-cultural niche an organism inhabits: "Our best models of the world are thus the basis for cumulative,

cases of “patterned practices” in the sense introduced by Roepstorff et al. (2010, 1051f),[52] where these are understood as “patterned activities [that] shape the human mind and body through embodiment and internalization. Vice versa, enacting practices shape and reshape norms, processes, institutions, and forms of sociality.” It turns out that this approach to patterned practices, and consequently also to cognitive practices, is highly compatible with the prediction error minimization framework:

> The affinities between ‘predictive brain’ models and a patterned practice approach may not be merely metaphorical. At different levels, they frame the link between action and perception as a continuous process of resonance, where networks-in-action order the coordination of input and output and networks-in-action form and unfold in practice. […] When these processes occur in human interaction, that is, coordinated in more than one brain, people may through sharing practices, be they linguistic or non-linguistic, come to construct common worlds […]. (ibid., 1057)

Importantly, these “human interactions” take place at various scales of time and space. They are constrained by norms shared by inhabitants of a cognitive niche, who actualize and reshape these norms as they perform cognitive practices in their ongoing engagement with cognitive resources. However, these norms do not only constrain cognitive practices, they also facilitate their performance.[53] This is because the compliance with these norms induces what Andy Clark (2013a, 195) calls “path-based idiosyncrasies”. That is, one of the reasons why the coordination of neuronal and bodily components in the manipulation of cultural resources is rendered so successful is that it takes place in a normatively constrained “multi-generational development of stacked, complex ‘designer environments’ for thinking such as mathematics, reading, writing, structured, discussion, and schooling” (ibid.; see also Clark 2015a, 14f; Clark 2016, 279). In terms of prediction error minimization, this also means that the establishment of these ‘designer environments’ has the effect “[…] that we can more easily minimize costly prediction error in an endlessly empowering cascade of contexts from shopping and

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communally distributed reasoning, rather than just the means by which individual thoughts occur.”

[52] This is also pointed out by Menary (2013a, 29; 2013b, 353).

[53] A related idea is put forward by Clark (1997, 180), who argues that “[…] advanced cognition depends crucially on our abilities to *dissipate* reasoning: to diffuse achieved knowledge and practical wisdom through complex social structures, and to reduce the loads on individual brains by locating those brains in complex webs of linguistic, social, political, and institutional constraints.” (italics in original)

socializing, to astronomy, philosophy, and logic" (ibid.).[54] Once acquired, the performance of cognitive practices in compliance with certain norms has the overall advantage of reducing cognitive effort, which can be captured as the minimization of overall prediction error and the optimization of precision on a sub-personal level of description.[55] In addition, the PP-style description of cognitive practices implies that it is the convenient manipulation of cognitive resources that renders those complex cognitive processes possible that would normally exceed the cognitive limitations of unenculturated contemporary human organisms. This is emphasized by Clark's (2014, 245) suggestion that "[c]ourtesy of all that concrete public vehicling (in spoken words, written text, diagrams, and pictures) our best models of reality […] are available in low-dimensional forms as stable, reinspectable […] objects apt for public critique and refinement." At the same time, however, cognitive practices themselves can be described, or so I shall argue, as having prediction error minimization as their underlying mechanism. This double role of cognitive practices, described in terms of prediction error minimization, can be fully appreciated once we consider the cognitive transformations brought about by the ongoing interaction with cultural resources.

4.4. THE TRANSFORMATION THESIS, COGNITIVE PRACTICES, AND PREDICTIVE PROCESSING

The neuronal and bodily engagements with the socio-culturally structured environment deeply transform our cognitive abilities (cf. Menary 2006, 341). This is the gist of the *transformation thesis*. Transformation occurs when human organisms interact with their cognitive niche, which includes representational writing systems, other notational systems, artifacts, and so forth. It is this immersion and, importantly, the scaffolding by other inhabitants of the cognitive niche, that ideally leads to the transformation of neuronal and bodily components into genuine constituents of

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[54] A similar point is made by Hutchins (2014, 38) who comments on Andy Clark's (2013a) approach to PP by hypothesizing "that cultural practices tend to reduce entropy (increase predictability) at all scales in a cultural cognitive ecosystem".

[55] When I refer to the difference between personal and sub-personal levels of description, I adopt Metzinger's (2013, 7) conceptual distinction: "Personal-level explanations are *horizontal*: they proceed from the past to the future in explaining single events by representing a diachronic causal relation as a horizontal line […]. Subpersonal explanations are typically *vertical*: they concern the relationship between micro- and macro-levels, for example by explaining the abilities or dispositions an organism has in terms of its parts and their causal relations, or by giving a functional analysis that becomes more and more fine-grained." (italics in original)

cognitive processes. In this sense, human organisms become enculturated. Enculturation occurs when a human organism learns how to perform a certain cognitive practice.

The PP framework, or so I will now argue, offers a highly promising account of learning that is most suitable for a sub-personal level description of the acquisition of cognitive practices. On the construal of PP, learning flows naturally from the mechanism of prediction error minimization.

Broadly understood, ‘learning’ thus figures as an umbrella term that describes the ongoing activity of prediction error minimization and model optimization throughout the lifetime of a human organism. This is because potentially ever new and ‘surprisaling’ sensory signals need to be ‘explained away’ through perceptual and active inference. For current purposes, however, ‘learning’ can also be understood in a more specific sense as the acquisition of a certain skill. Skill acquisition, on this construal, is also subject to prediction error minimization through perception, action, cognition, and attention. Either way, it is the world itself, be it natural or socio-culturally structured, that delivers new sensory signals that help optimize parameters of the generative model:

> Prediction-driven learning thus exploits a rich, free, constantly available, bootstrap-friendly, teaching signal in the form of the ever-changing sensory signal itself. Whether the task is ecologically basic […] or more ecologically advanced (e.g. […] predicting the next word in a sentence), the world can be relied upon to provide a training signal allowing us to compare current predictions with actual sensed patterns of energetic input. (Clark 2016, 19).

However, complex skills that are targeted at the completion of cognitive tasks cannot be learned simply by being exposed to the right kind of ‘training signal’. What is additionally needed is the engagement in activities that are scaffolded by inhabitants of the cognitive niche who have already achieved a sufficient degree of expertise. That is, the human organism needs to be devoted to what Andy Clark (2016, 287) calls “path-dependent learning”, where “[p]ath dependency, in its most familiar form, is the rationale for structured education and training.” The notion of ‘path-dependent learning’ has already played a crucial conceptual role in Clark (1997). Here, the suggestion is that

> [h]uman learning, like learning in artificial neural networks, appears to be hostage to at least some degree of path dependence. Certain ideas can be understood only once others are in place. […] The processes of formal education, indeed, are geared to take young (and not-so-young) minds along a genuine intellectual journey, which may even begin with ideas which are now known to be incorrect but which alone seem able to prime the system to later appreciate finer-grained truth. Such mundane facts reflect

> cognitive path dependence – you can't get everywhere from anywhere, and where you are now strongly constrains your potential future intellectual trajectories. (Clark 1997, 205; see also Clark 1998, 171f)

Path-dependent learning, from the perspective of prediction error minimization, amounts to the strategy of exposing predictive systems to highly structured, systematically ordered patterns of sensory input in the cognitive niche.[56] I take it that path-dependent learning is an important guiding principle of systematic scaffolded learning. The application of this principle proceeds by increasing complexity in a step-wise manner, which in turn leads to an ever more fine-grained repertoire of accurate predictions. This mechanistic process is described by Clark (2016, 277) as follows:

> Highly-weighted errors, if the system is unable to explain them away by recruiting some model that it already commands, result in increased plasticity and (if all goes well) the acquisition of new knowledge about the shape and nature of the distal causes responsible for the surprising inputs.

This means that prediction errors estimated as being precise under the conditions of path-dependent learning help establish and strengthen neuronal connections within and across levels of the cortical hierarchy. This in turn leads to the "exogenously driven" development of highly reliable predictions that are constantly optimized (Menary, personal communication). One plausible conjecture at this point is that this PP-style description of LDP could be captured in terms of *effective connectivity*. Recall that effective connectivity reports the causal interaction of neuronal activation across multiple levels of the cortical hierarchy (and across different brain areas) as a result of attention in terms of the optimization of precision expectations. This line of reasoning is implied by Clark (2013a, 190) who argues that "[a]ttention […] is simply one means by which certain error-unit responses are given increased weight, hence becoming more apt to drive learning and plasticity, and to engage compensatory action." The last point is important, because it stresses that it is not only perceptual inference that drives learning and contributes to the improvement of generative models, but also active inference. However, this approach to the acquisition of action patterns in concert with an optimization of precision might raise the worry that learning is depicted here as being a rather internalistic, brain-bound affair. But once we acknowledge that it is the performance and ongoing improvement of embodied

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[56] This point is supported by Andy Clark (2013a, 195), who emphasizes that "[s]uch learning routines make human minds permeable, at multiple spatial and temporal scales, to the statistical structure of the world as reflected in the training signals. But those training signals are now delivered as part of a complex developmental web that gradually comes to include all the complex regularities embodied in the web of statistical relations among the symbols and other forms of socio-cultural scaffolding in which we are immersed."

active inferences which plays an indispensable functional role in the completion of cognitive tasks, it becomes obvious that this worry is not warranted. This is because it is the close interaction of neuronal and bodily components in terms of prediction error minimization that is the result of path-dependent learning and efficient engagements of human organisms with their cognitive niche. Understood like this, path-dependent learning offers additional conceptual tools to describe the acquisition of cognitive practices and the associated cognitive norms. The exposure to the right kind of cognitive resources under the influence of scaffolded learning is nothing but an enculturation-oriented way to describe the path-dependent acquisition of the relevant cognitive norms. This is perfectly in line with Clark's (2014, 245) suggestion "[…] that the human-built environment becomes a potent source of a new intergenerationally transmissible structure that surrounds, scaffolds, and perhaps even fundamentally transforms the activity of our biological brains."

In sum, the PP approach to path-dependent learning and LDP avails itself as a parsimonious and coherent mechanistic perspective on cognitive transformation and enculturation. The predictive error minimization perspective on path-dependent learning provides a functionally and neuronally plausible sub-personal description of the acquisition of cognitive norms that are crucial for the fluent performance of cognitive practices. For it does justice to the interaction of neuronal and bodily sub-processes and to the refinement of these processes in the course of learning routines. Furthermore, it highlights the fact that learning takes place in an environment that offers a variety of cognitive resources and is characterized by the structured interaction with these resources scaffolded by expert members of a particular socio-cultural group. Hence, the acquisition of cognitive norms flows naturally from the occurrence of path-dependent learning in a socio-cultural context, but is now supplemented by a mechanistic proposal that attempts to account for the neuronal and bodily transformations that are the result of enculturation. This becomes even more obvious once we take into account that LDP as postulated by Menary (2013b, 2014, 2015) can now be considered in terms of the precision-weighted optimization of hypotheses throughout the cortical hierarchy and the ever new patterns of effective connectivity, as new cognitive practices are acquired and successfully performed.[57]

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[57] This line of reasoning resonates in Clark's (2016, 279) statement that "[…] the human built (material and sociocultural) environment becomes a potent source of new transmissible structure that trains, triggers, and repeatedly transforms the activity of the prediction-hungry biological brain."

The sub-personal description of cognitive transformation in terms of prediction error minimization also does justice to *neural reuse* as a guiding principle of the allocation of neuronal resources for phylogenetically recent functions such as reading and writing (Anderson 2010, 2015; Dehaene 2010). This is because PP, at least on the account put forward by Andy Clark (2016, 150), allows for a context-sensitive, reconfigurable, multi-purpose neuronal architecture that "combines functional differentiation with multiple (pervasive and flexible) forms of informational integration." In particular, Clark (ibid.) argues that "[d]istinctive, objectively-identifiable, local processing organizations now emerge and operate within a larger, more integrative, framework in which those functionally differentiated populations and sub-populations are engaged and nuanced in different ways so as to serve different tasks […]." As a consequence, PP fits well with neural reuse understood as an important constraint on the transformation of cognitive abilities in the course of ontogenetic development.[58] As a result, prediction error minimization is most suitable to complement cognitive transformation and enculturation by offering additional mechanistic descriptions of their constitutive components on a sub-personal level of description.

4.5. THE GIST OF THE ENCULTURATED PREDICTIVE PROCESSING APPROACH

In the last section, we have seen that there are good reasons to combine CI and the enculturated approach with the emerging PP framework. This is because the principles guiding the PP framework complement the tenets of CI and enculturation by making concrete suggestions about the functional, neuronal, and bodily realization of enculturated cognitive processes. I call this view that emerges from the claim that CI and PP are complementary (and not merely compatible) *enculturated*

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[58] Another important consideration stemming from the complementarity of CI and PP with regard to neuronal recycling and the wider perspective on cognitive transformation is that PP is also in line with the *continuity thesis*. As Clark (2016, 275) points out, "[p]rediction-driven learning […] and the canny exploitation of multi-timescale dynamics are all plausibly displayed, albeit to varying degrees, by other mammals." However, "adaptations of the human neural apparatus" working in concert with "our abilities of temporally co-coordinated social interaction (see Roepstorff (2013)) and our abilities to construct artifacts, and designer environments" have rendered possible new and human-specific forms of perception, action, attention, and cognition (ibid., 276). Similarly, Clark (2015a, 14) argues that "[t]he basic elements of the predictive processing story […] may be found in many types of organism and model-system." This should not come as a surprise, since predictive processing is just a specific version of more general, life-sustaining and dynamic processes having to do with the minimization of free energy.

predictive processing (EPP).[59] EPP subscribes to the idea that the enculturation approach and CI provide important conceptual tools for the investigation of certain types of cognitive processing routines. What EPP adds, however, is the insight that the approach to enculturation needs to be supplemented by a PP-style description. This strategy allows to account for the fine-grained functional and neuronal details of cognitively integrated phenomena. Vice versa, the PP framework is decisively enriched by CI-inspired attempts to describe specific classes of cognitive processes. For it is only when we account for the enculturated, transformative, embodied, and normative dimensions that we arrive at a coherent and thorough description of specific prediction error minimizing cognitive processes.

In a nutshell, EPP boosts the descriptive power of both CI and PP. By integrating two sets of conceptual tools, this theory synthesis leads to a more complete and sophisticated theoretical approach to certain cognitive practices, as it would be possible by focusing on either CI or PP in isolation. Understood like this, EPP is line with Menary's (under review, 13) requirement that "[…] PP is a sub-personal account of neural processes that fits with a larger account of the brain-body-niche nexus. If one embraces CI/ENC [i.e., enculturation] then there's more to the mind than what? Now." Put differently, EPP intends to do justice to the guiding principles of CI and enculturation. What is more, it complements them with the additional conceptual resources provided by the prediction error minimization framework.

We can sharpen the understanding of EPP by emphasizing that it takes a pronounced epistemic stance. To see this, it is worth to redeploy van Gelder's (1998) distinction between metaphysical and epistemological hypotheses. He introduces this distinction in his discussion of the status of dynamical systems approaches in philosophy of cognitive science: "The *nature* hypothesis is a claim about the nature of cognitive agents themselves; it specifies what they are (i.e., dynamical systems). The *knowledge* hypothesis is a claim about cognitive science: namely, that we can and should *understand* cognition dynamically" (van Gelder 1998, 619; italics in original). Applied to EPP, the nature hypothesis would be that cognitive systems actually *are* enculturated predictive systems. The knowledge hypothesis suggests that cognitive systems are best *understood* by describing them

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[59] In Fabry (2015, 11) I argue that CI and PP are complementary and not merely compatible, because both approaches inform and enrich each other in important ways. If EPP is on the right track, the complementarity of CI and PP yields greater descriptive and predictive power than each approach would be able to achieve in isolation.

in terms of EPP. EPP remains neutral with regards to the metaphysical consequences that might or might not follow from its theoretical commitments. At its core, EPP defends the epistemic hypothesis that cognitive agents engaging in certain complex, socio-culturally shaped cognitive processes are best investigated from the integrative EPP perspective.[60] From this perspective, the relevant question is not whether or not certain cognitive processes are brain-bound in a metaphysically interesting sense. Rather, the crucial question is how we can theoretically *approach* and *understand* our target phenomenon, i.e., reading, in a way that is both coherent and consistent.[61] In this sense, EPP will offer a theoretical proposal, new hypotheses and conceptual tools that might help give preliminary answers to this question.

If we take the social and normative scope of cognitive practices and the associated idea of enculturation seriously, it will be worthwhile to operate on at least two large-scale levels of description. As I have argued in Fabry (2015), we can approach

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[60] The EPP framework can be seen as a first step towards a model of (certain types of) cognition that does justice to the idea that many cases of intelligent human behaviour emerge from the fine-tuned interaction of an embodied human organism with its environment. Understood like this, the PP framework can be seen as a timely attempt to realize Clark's (1997, 130) research agenda: "We should indeed view the brain as a complex system whose adaptive properties emerge only relative to a crucial backdrop of bodily and environmental structures and processes. However, to fully understand these extended processes we must understand in detail the contributions of specific neural systems and the complex interactions among them. The stress on organism-environment interactions should thus not be seen as yet another excuse for cognitive science to avoid confrontation with the biological brain. The real question, then, is not 'should we study the brain?' but 'how should we study the brain?' What *kind* of neuroscientific models best engage with our emphases on embodied action and real-time success? And if such models exist, how well are they supported by neuroanatomical and cognitive neuroscientific data and experiments?" (italics in original)

[61] The distinction between metaphysical and epistemic hypotheses can be illustrated by taking Ned Block's (2005) critique of Alva Noë's formulation of enactive perception into account (Metzinger, personal communication). For Block, the crucial success condition of Noë's enactive account of perceptual experience (and probably other embodied and/or externalism-friendly accounts) is its metaphysical persuasiveness: "[…] it is the issue of what is – and is not – part of the *minimal* metaphysically sufficient condition of perceptual experience (the minimal supervenience base)" (Block 2005, 264; italics in original). Applied to EPP, the question would then be what "the minimal metaphysically sufficient condition" of the cognitive practice of reading is supposed to be. However, even if a metaphysical account of reading in terms of supervenience turned out to be informative (and I believe that there are good reasons to deny this), we would still be unable to understand the target phenomenon *as such* from an empirically informed theoretical perspective. Therefore, I focus in this dissertation on the (in my view) more relevant epistemic question how and under which conditions we can *describe* and *understand* the cognitive practice of reading. Even if it were true that this particular type of cognitive processing *is* metaphysically brain-bound, this would still leave us with the possibility to argue that reading is best *understood* as a cognitively integrated, enculturated, normatively constrained, prediction error minimizing process in an epistemically warranted, informative, non-trivial way.

cognitive practices on a group level and on an individual level. On the group level, we would investigate the interactions of groups of individuals who share many cognitive norms and who have developed specific means of scaffolded learning. This is reasonable, given that cognitive practices are brought about by socio-culturally shaped and phenotypically determined ways of solving cognitive tasks in the cognitive niche (cf. Menary 2015a, 4). On the individual level of description, we would be concerned with the acquisition and performance of certain cognitive practices with regard to individual human organisms. In this dissertation, I will operate mainly on the individual level of description. The simple reason for this decision is that most empirical research chooses individuals as their unit of analysis. However, it is important two acknowledge that future research should consider to include group level descriptions into their investigation of certain classes of cognitive processes. This is because many cognitive processes are the result of socio-cultural developments and interactions (e.g., epistemic engineering and scaffolded learning). That is, these processes turn out to be cognitive practices that result from enculturation – they are phenomena that are deeply rooted in normatively constrained social interactions. We need to keep this in mind if we wish to understand how this socio-cultural context influences the cognitive capacities of individual human organisms.

To summarize, EPP makes the following assumptions:

1. The performance of cognitive practices is a special case of the dynamically organized realization of the free energy principle.
2. The neuronal and bodily sub-processes operating on cognitive resources should be described in terms of perceptual inference, active inference, and the optimization of precision estimations.
3. Specific cognitive practices, such as reading, are rendered possible by the enculturation of human organisms in their cognitive niche. These practices are of particular relevance, because they significantly augment the cognitive capacities of human organisms.
4. The cognitive transformations occurring in the course of scaffolded learning can be described in terms of LDP and path-dependent learning.
5. Cognitive practices are subject to cognitive norms. Any account of socio-culturally shaped cognitive processes needs to take this into account.

In the previous sections of this chapter, I have developed several argumentative strands that lead to these assumptions in favour of EPP. In particular, I have argued that

1. The PP framework provides the conceptual resources to complement the hybrid mind thesis with its appeal to dynamicist approaches to cognition;
2. The idea of bodily manipulation can be complemented by active inference on the PP construal;
3. Cognitive transformation and the associated emphasis on LDP and scaffolded learning can be complemented by the taking effective connectivity and path-dependent learning as derived from the prediction error minimization framework into account.

However, it is equally important to defend this new and original approach against several objections. This is the purpose of the next section.

4.6. DEFENDING ENCULTURATED PREDICTIVE PROCESSING

The EPP approach is an epistemic attempt to arrive at a conceptually coherent and empirically plausible description of enculturated cognitive processes. Reading will serve as a paradigm case for the plausibility of the idea that this synthesis of CI and PP is needed in order to arrive at a complete and elaborate philosophical account of this target phenomenon. Understood like this, I do not make any assumptions about the generalizability and the ultimate scope of EPP. The strategy of the following chapters will be to show how EPP can be applied to different sub-processes associated with reading and its disorders.[62] If this strategy proves successful, we will have good reasons to embrace EPP not only as a new and potentially fecund conceptual framework, but also as a research program in its own right. That is to say that EPP should be understood primarily as a philosophical framework for research on reading and its disorders. Whether or not a similar theoretical approach to enculturated cognitive target phenomena other than reading is feasible, is itself an interesting conceptual question, but also an empirical target that will require future research. EPP will turn out to be valid only if it is sufficiently supported by empirical research. Conceptually, EPP will qualify as a warranted approach to reading only if it can be shown to possess sufficient descriptive and predictive power. Obviously, this also means that EPP can be falsified if there is significant and unequivocal direct empirical evidence speaking against it. Additionally, EPP can be disqualified if it can

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[62] If this strategy turns out to be successful, we will have good reasons to assume that the EPP framework is able to contribute to a (at least partial) solution of what Andy Clark (1997, 82) calls "*the problem of tractability*": "How, given this radically promiscuous view of cognition as forever leaking out into its local surroundings – are we to isolate tractable phenomena to study? Doesn't this rampant cognitive liberalism make nonsense of the hope for a genuine science of the mind?" (italics in original)

be refuted by consistent counter-arguments on a conceptual level. I am confident that the next chapters will establish that there is indeed a vast array of empirical results that support the validity of EPP. In addition, I am optimistic that the contents of the remaining chapters will provide us with good theoretical and conceptual reasons to embrace EPP. However, meanwhile it is reasonable to anticipate possible objections against EPP and to show how they can be rejected.

EPP could be criticized by arguing that prediction error minimization could be construed as being a purely internalistic, brain-bound affair. On this construal, PP would not leave any room for the idea that cognitive processes are constituted both by neuronal and bodily components that are normatively constrained, socially scaffolded, and deeply anchored in a socio-culturally structured environment. Thus, consider a position that takes for granted that cognitive processes can be coherently described in terms of prediction error minimization, but denies that cognitive processes are co-constituted by neuronal and bodily sub-processes operating on socio-cultural resources. Such a position is defended by Jakob Hohwy (2013, 240) who argues that "[…] many cases of situated and extended cognition begin to make sense as merely cases of the brain attempting to optimize its sensory input so it, as positioned over against the world, can better minimize error." In particular, on his interpretation of the prediction error minimization framework, "[…] the mind remains secluded from the hidden causes of the world, even though we are ingenious in using culture and technology to allow us to bring these causes into sharper focus and thus facilitate how we infer to them" (ibid., 239). For Hohwy, this directly follows from the causal relations holding between a system and the environmental causes it constantly tries to infer. According to him (ibid., 228), this relation needs to be characterized as 'direct' and 'indirect' at the same time:

> […] the intuition that perception is indirect is captured by its reliance on priors and generative models to infer the hidden states of the world, and the intuition that perception is direct is captured by the way perceptual inference queries and is subsequently guided by the sensory input causally impinging on it.[63]

Since the causal relation that holds between a system comprised of inverted generative models and the world is partly indirect, so the argument goes, the system is in constant embodied interaction and direct contact with its environment only insofar as it tries to make the effects of hidden causes fit the predictions. This

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[63] A similar point is made by Paton et al. (2013, 222). Since perception and cognition are continuous, this argument holds by extension for cognitive processes as well.

precludes the theoretical possibility of depicting prediction error minimizing systems as being situated, scaffolded, integrated, or extended.

This line of reasoning fails to acknowledge the important contribution of embodied active inference to the minimization of prediction error, the optimization of predictions, and the estimation of precision. For even if the causal relations holding between a predictive, generatively organized system and environmental causes are mediated by hypotheses, predictions, prediction errors and precision estimation, it does not follow that this system needs to be understood as a passive receiver of sensory input that informs it about remote states of affairs in the rather detached environment. This resistance to acknowledge the deeper conceptual consequences of active inference is also identified by Clark (2016, 170f) who argues that the view that predictive systems are secluded from their environment originates in "[…] a failure to take sufficient account of the role of action, and of organism-specific action repertoires, in both selecting and constantly testing the ongoing stream of prediction itself."

Similarly, it does not necessarily follow from the prediction error minimization framework that it "[…] creates a sensory blanket – the evidentiary boundary – that is permeable only in the sense that inferences can be made about the causes of sensory input hidden beyond the boundary", as Hohwy (2014, 7) claims. Rather, the predictive system is part of its socio-culturally structured environment and has many possibilities to bodily act in that environment in order to facilitate its own cognitive processing routines. Considering active inference, it turns out that the causal relation holding between embodied action and the changes of the set of available stimuli in the environment is as direct as any causal relation could be. This is because these changes are an immediate (i.e., causally proximate) effect of these very prediction error-minimizing and precision-optimizing actions, which in turn contribute to the performance of cognitive tasks. Furthermore, we have to take into account that genuinely human cognitive processes occur in a culturally sculpted cognitive niche, which is characterized by writing systems, notational systems, artifacts, and the like, and other human organisms to interact with. If it were warranted to claim that there is an "evidentiary boundary" separating the predictive system from environmental causes, it is hard to see how we could account for this variety of system-environment interactions. This point is supported by Clark (2016, 170), who argues that it is a mistake

> […] to conceive of all inference-based routes to adaptive response as introducing a kind of representational veil between agent and world. Instead, it is only the structured probabilistic know-how distilled from prediction-driven learning that enables us to see *through the veil of surface statistics* to the world of interacting causes itself. (italics in original)

In support of his claim that there is an “evidentiary boundary” separating the system from its secluded environment, Hohwy (2014) refers to Friston’s (2013b) account of Markov blankets discussed earlier in this chapter. In particular, in his ‘neurocentric’ account of the prediction error minimization framework, Hohwy (2014, 25) argues that “[…] the sensory input and active output at this [sensory] boundary forms a so-called Markov blanket […]. […] Causes beyond this blanket, such as bodily states or external states, are rendered uninformative once the states of the blanket are known.” Recall that a Markov blanket *statistically* separates an ‘internal’ and an ‘external’ set of states. It is due to the Markov blanket that ‘external’ and ‘internal’ states are coupled in the sense that they “cause each other in a reciprocal fashion” (Friston 2013b, 2f). From here, it is hard to see how the consideration of Markov blankets lends conceptual support to the idea that cognition is (metaphysically) brain-bound and warrants an internalistic or ‘neurocentric’ approach. If my understanding of Friston’s (2013b) approach to Markov blankets is on the right track, the statistical purpose of Markov blankets is simply to demonstrate how cells, organs, or entire organisms can persist over time *and* dynamically interact with other cells, organs, or the environment.[64] From this perspective, Hohwy’s (2014) implication that the “evidentiary boundary” is to be identified with a Markov blanket appears to be rather uninformative and arbitrary. This argumentative move is uninformative to the extent that there simply *must* be a statistical separation of the ‘inside’ and the ‘outside’ of an organism. Otherwise it would not be able to resist the second law of thermodynamics and fail to minimize free energy. Hohwy’s idea of an “evidentiary boundary” is arbitrary in the sense that it is safe to assume that there is a large amount of Markov blankets that can be ascribed to an organism (cf. Friston 2013b, 10). Thus, it is not easy to see how and why Hohwy chooses a specific Markov blanket as his unit of analysis and declares it as the “evidentiary boundary” separating ‘internal’ and ‘external’ (i.e., not-sensory or environmental) states. Furthermore, the very idea of Markov blankets rests on the assumption that any system that possesses a Markov blanket can be described as being a member of a

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[64] Just consider how the semi-permeability of membranes allows (organic) cells to interact with their environment: “[…] while segregating many of their constituents from the external milieu, membranes do not cut them off completey” (Bechtel 2009, 163). This is in perfect agreement with the definition of Markov blankets.

coupled dynamical system (cf. Friston 2013b, 5). This last point is neglected by Howhy (2014, 25), who argues that

> […] if we treat the mind as a dynamical system, described by a set of differential equations (which in our case describes free-energy minimization), then we can observe that none of the variables in these equations refer to objects beyond this narrow, neurocentric system […].

As far as I can tell, this leaves room for the possibility to describe ‘the mind’ (i.e., the theoretical entity that is capable of cognitive processing routines) as emerging from the reciprocal coupling of dynamical systems. On this epistemic view, Markov blankets are the *statistical enablers* of reciprocal coupling. It follows that they cannot be used unequivocally as an argument against the idea that certain cognitive processes can be understood as dynamical, coupled interactions of brain, body, and environment.

However, this line of reasoning does not mean to embrace the original idea of the extended mind hypothesis, which is criticized by Hohwy (2014). In particular, he argues against the *parity principle* originally put forward by Clark and Chalmers (1998, 8):

> If, as we confront some task, a part of the world functions as a process which*, were it done in the head*, we would have no hesitation in recognizing as part of the cognitive process, then that part of the world is (so we claim) part of the cognitive process. (italics in original)

According to Hohwy (2014, 12), this externalist view of cognition is flawed from the perspective of the predictive error minimization framework for functionalistic and methodological reasons:

> […] the PEM-believer who defends extended cognition […] is required to define a plausible evidentiary boundary. This boundary should make it clear that prediction error is minimized for the system including the external object to which cognition is extended, and with respect to hidden causes outside this extended boundary. […] Whereas prediction error can be minimized transiently by systems with all sorts of objects included […], on average and over the long run, it is most likely that the model providing evidence for itself is just the traditional, un-extended biological organism.

Thus, according to Hohwy, the extended mind thesis would only be compatible with the prediction error minimization framework if it were possible to demonstrate that ‘external’ resources are a relevant part of cognitive processing routines over a significantly long time course and are thus on the inside of the ‘evidentiary boundary’. However, this solution is not parsimonious and leads to methodological challenges an ‘internalistic’ or ‘neurocentric’ position is able to avoid. For one would have to stipulate several predictive extended systems, depending on the cognitive task, the ‘external’ resources being involved, and the location of the ‘evidentiary boundary’ (cf. ibid.). This line of criticism does not apply to CI. This is because

> […] cognitive integrationists can accept that there are external resources to aid cognition, as well as a class of actions which have the purpose of simplifying a problem […]. This leaves them free to deny that there are any good grounds for identifying them as cognitive. (Menary 2007a, 49)

According to CI, ‘external’ resources are not themselves part of a cognitive system. Rather, it is the neuronal and bodily interaction with these resources and the application of cognitive norms that characterizes the completion of a cognitive task in a certain socio-culturally structured context. As such, CI is opposed to the parity principle, which is the target of Hohwy’s (2014) criticism. This is because CI is not interested in functional similarities between purely ‘internalistic’ and partly ‘externalized’ cognitive processes. Rather, the epistemic goal of CI is to demonstrate that our neuronal and bodily interaction with ‘external’ resources, such as representational writing systems, transforms and augments the possibilities for efficient cognitive processing routines. It is only from this perspective that we come to acknowledge that we can describe enculturated human organisms as cognitively integrated systems that seamlessly perform cognitive practices by neuronally and bodily interacting with cognitive resources. This, in turn, is one of the most important theoretical insights that inspire EPP.

Earlier in this chapter, I have emphasized that EPP is supposed to be an epistemic, rather than a metaphysical perspective on the investigation of enculturated cognitive processes. The question arises to what extent Hohwy’s (2014) ‘neurocentric’ interpretation of the PP framework can affect EPP. I am inclined to think that Hohwy (2014) almost interchangeably deals with both the metaphysical and epistemic consequences of his interpretation of PP. Here is an example:

> […] *there is a schism* between the prediction-generating models of the brain and the modeled states of affairs in the world. Views of mind and cognition that emphasize openness, extension, embodiment, and enactive coupling into the environment seem to ignore this inferential *conception* of the mind. (Hohwy 2014, 5; my emphasis)

If I am not mistaken, this quotation contains a change of subject. In the first sentence it is argued that the neuronally realized generative Bayesian models and the environment are clearly separated in a *metaphysically* interesting sense. However, the second sentence happens to be concerned with *epistemically* inspired approaches to the mind and how they, in Hohwy’s opinion, fail to acknowledge the metaphysical consequences of the PP framework in their attempts to describe perceptual, sensorimotor, or cognitive phenomena. This is problematic, because this lack of argumentative clarity might imply that there is no clear-cut distinction between metaphysical and epistemic consequences stemming from the PP framework. I think that it is fair to assume that there certainly is an important difference between the question what the mind *is* and how the mind can be *understood* in a theoretical, descriptive manner. Thus, even if Hohwy were right in his assumption that the brain *is* secluded from the non-sensory body and the environment, I do not see any principled reason against the idea that certain cognitive processes are *best understood* by focusing on the dynamic interactions between brain, body, and environment. If this line of reasoning is on the right track, Hohwy's rather extreme, almost Cartesian internalism does not affect the epistemic persuasiveness of EPP.

An important consequence of the EPP approach is that it directly speaks to the emerging debate about the right kind of interpretation of the free energy principle and the prediction minimization framework. On the one hand, Jakob Hohwy (e.g., 2013, 2014) assumes that the PP framework suggests a kind of internalism and 'neurocentrism' of human perception, cognition, action, and attention. In a nutshell, Hohwy (2014, 7) defends the idea that "[t]he mind can be understood in internalist, solipsistic terms, throwing away the body, the world, and other people […]." On the other hand, Andy Clark's (e.g., 2013, 2015a, in progress) interpretation of the PP framework lends much support to the idea that PP "[…] offers a biologically plausible means, consistent […] with as much reliance on external scaffolding as possible, of internally encoding and deploying richly structured bodies of information" (Clark 2015b, 5). Furthermore, Clark (2013a, 195) argues that the PP framework "[…] offers a standing invitation to evolutionary, situated, embodied, and distributed approaches to help 'fill in the explanatory gaps' while delivering a schematic but fundamental account of the complex and complementary roles of perception, action, attention, and environmental structuring." The EPP approach takes this "invitation" seriously by suggesting that the PP framework needs to be complemented by CI and the associated idea of enculturated cognition in order to arrive at a precise and full-fledged description of specific types of cognitive processing routines. Thus, EPP is related to Andy Clark's construal of the epistemic and methodological consequences of PP. It raises serious concerns against the idea that Jakob Hohwy's internalistic interpretation of the PP framework offers a promising route to a conceptually coherent and empirically plausible description of certain cognitive practices. I submit that the EPP description of reading, as it will unfold in the following chapters, will give us good reasons to defend the position that this cognitive practice emerges from the dynamic interaction of neuronal and bodily components with specific resources in the cognitive niche. It is this kind of interaction that possibly would be denied by Hohwy. The remainder of this dissertation can be considered as a lengthy argument for the assumption that the cognitive practice of reading is not an exclusively ‘neurocentric’ affair.

However, it is conceivable that cognitive integrationists raise concerns against EPP. An integrationist might agree that we need a mechanistic description of the neuronal and bodily components which jointly constitute cognitive processes in the close interaction with socio-cultural resources. But she might continue to argue that the performance of cognitive practices is more than just the minimization of prediction error and the optimization of precision estimations (Menary, personal communication). From the perspective of EPP, it must not be denied that human cognitive systems as a whole aim to fulfil cognitive purposes by completing cognitive tasks and that they do so by engaging in cognitive practices. In addition, EPP should not reject the idea that cognitive practices are normatively constrained and that cognitive systems are deeply immersed into a socio-culturally structured environment, which in turn provides these very norms through scaffolded learning. Consequently, EPP is in perfect agreement with the observation “[…] that What? Now sensory predictions *on their own* could not be driving the innovation of NPP [i.e., normative patterned practices], nor could they determine the properties of NPP on their own” (Menary 2015b, 2; my emphasis). However, the important theoretical contribution that the prediction error minimization framework makes is to provide a sub-personal, mechanistic description of the underlying neuronal and bodily sub-processes that is maximally parsimonious, conceptually coherent, and, as we shall see in later chapters, empirically plausible. In addition, PP offers a description of the close interaction of the neuronal and bodily components constituting cognitive practices by depicting this interaction as a mutually constraining interplay of perceptual inferences and active inferences and the sensitive weighting of precision. This is supported by Andy Clark’s (in progress, chapter 8, 22) interpretation of the prediction error minimization framework, where active inferences are considered to be perfectly compatible with an integrationist’s take on cognitive processing routines: “Invoking a bio-external resource, and moving our own effectors and sensors to yield high-quality task-relevant information are here expressions of the same underlying strategy, reflecting our brain's best estimates of where and when reliable, task-relevant information is available."

Furthermore, we have already seen that nothing in the prediction error minimization framework speaks against the idea that enculturated cognitive processing routines require a description that includes a certain degree of dynamicity, reciprocation, and openness. For the foundations of PP, i.e., the free energy principle and the statistical consideration of Markov blankets, are just a specific mathematical application of dynamical systems theory. Understood like this, PP actually lends further support to the idea that the CI "[…] framework is unified by a dynamical systems description of the evolution of processing in the hybrid and multi-layered system […]" (Menary 2015a, 2).

Previously, I have argued that the PP framework offers a mechanistic application of the free energy principle. Even if cognitive integrationists might agree that PP provides important and non-trivial resources for a more fine-grained analysis of the components giving rise to a certain cognitive practice such as reading, they might argue that prediction error minimization is not a (sufficient) mechanistic explanation of the target phenomenon. They might justify this by stating that the current formulations of the prediction error minimization framework are incomplete to the extent that their structural properties, i.e., the properties of the neuronal and bodily realization of first- and second-order statistics, remain (partly) under-determined (Menary, personal communication). This would map onto the distinction between functional and structural decomposition which are both needed in order to arrive at a full-blown mechanistic explanation (cf. Bechtel 2009, 160; Craver & Bechtel 2006, 473). Along these lines, the objection would be that the PP framework remains incomplete to the extent that its progress in functionally decomposing specific processes is not accompanied by sufficient structural specifications.

Even if we agreed with this worry, we could meet it along the following lines: Generally, the PP framework offers fine-grained functional analyses of specific perceptual, sensori-motor, cognitive, and attentional aspects of the target phenomenon. It seems fair to assert that so far, the characterization of the structural properties of the prediction error minimizing system has remained incomplete and awaits further scrutiny by future research. From this it seems to follow that the PP framework should not count as a mechanistic approach. However, this alleged problem can be resolved by arguing that functional analyses should count as mechanistic explanations *in progress*. Following Piccinini and Craver (2011, 284), functional analyses can be characterized as *mechanism sketches*: "[…] functional analyses are *sketches of mechanisms*, in which some structural aspects of a mechanistic explanation are omitted. Once the missing aspects are filled in, a functional analysis turns into a full-blown mechanistic explanation" (italics in original). We can now argue that neuroscientific research has already begun to discover specific structural properties of prediction error minimization. For instance, the functional distinction between error units and representation units has led to the structural distinction between deep pyramidal cells and superficial pyramidal cells, respectively (see chapter 2; cf. Friston et al. 2012, 8; Friston et al. 2014, 434; see also Clark 2013a, 187f; Clark 2016, 39). Another example is the suggestion that the functional workings of the optimization of precision estimations is associated with the structural properties of neurotransmitter systems such as dopamine (cf. Fletcher & Frith 2009, 55; see also Clark 2013a, 190). It is to be expected that more structural properties of prediction error minimizing systems will be specified, which would ultimately lead to a full-blown mechanistic explanation of specific target phenomena such as reading. Hence, the worry that the PP framework might not offer a mechanistic explanation is only warranted if significant scientific and philosophical progress in the investigation of prediction error minimization is not to be expected in the future. Since it seems too early to settle this issue, we should be optimistic that the functional analyses provided by the PP framework will become ever-more fine-grained and continuously enriched by structural analyses of the associated properties.

A related worry could concern the relationship between PP (understood as a framework that aims at providing a mechanistic description and explanation of well-defined target phenomena) and the free energy principle (formulated as a dynamical homeostatic process that constantly engages in the minimization of free energy; Menary, personal communication). In particular, it might be argued that the conceptual relationship (and hence, the heuristic relationship) between PP and the free energy principle as I have developed it is unwarranted. This would be the case, because mechanistic explanations and dynamical systems approaches seem to exclude each other for methodological and epistemic reasons. The main reason for this would probably be that dynamical systems approaches are mainly interested in the temporal dimensions of the interactions of integrated components of specific (coupled) systems. In contrast to the PP framework, dynamicists tend to neglect the question how the specific processes might be neuronally realized (cf. Eliasmith 2009, 139).

Observing this important difference between mechanistic explanations (and mechanism sketches) and dynamicist approaches might lead to the (pre-mature) conclusion that it could be troublesome to argue that the PP framework offers a functional application of the free energy principle to specific cases of enculturated cognitive processing. For current purposes, this conclusion can be avoided by highlighting that the prediction error minimization mechanism and a dynamicist formulation of the free energy principle are complementary because they share the same set of background assumptions while being characterized by non-trivial explanatory and descriptive differences. These background assumptions include the idea that (human) organisms need to resist the second law of thermodynamics and that they need to minimize free energy on various temporal and spatial scales. The relationship, then, between the prediction error minimization mechanism sketch and the dynamicist formulation of the free energy principle is one of complementarity. With this complementarity assumption at hand, we can easily avoid to commit the mereological fallacy of mistaking the dynamics of a component system for the dynamics of the interaction of the human organism with its cognitive niche:

> The dynamical interactions are described as being part of a larger system comprising brain, body, and niche. We can zoom in and focus upon the dynamics of brain or body, but we shouldn't confuse the dynamics of the brain for the dynamics of the overall system. (Menary 2015b, 3)

More generally, "mechanistic decomposition and dynamic modeling are complementary, not opposed" (Kaplan & Bechtel 2011, 443). This is because "[d]ynamical explanations do not provide a separate kind of explanation; when they explain phenomena, it is because they describe the dynamic behavior of mechanisms" (ibid., 440). Thus construed, it seems safe to assume that the differences between mechanistic explanation and dynamical systems approaches do not pose a principled threat to the idea that prediction error minimization is a specific mechanistic application of the free energy principle.

4.7. CONCLUDING REMARKS

These considerations show that EPP is an approach that does conceptual justice to both PP and CI. This is because it adopts the delicate mechanistic descriptions of perception, action, cognition, and attention suggested by the prediction error minimization. At the same time, EPP preserves the theoretical stance on the hybridity, embodiedness, transformativity, and normativity of integrated and enculturated cognitive processes. What EPP adds is the idea that the neuronal and bodily components giving rise to certain cognitive practices can be coherently described in terms of prediction error minimization. At the same time, EPP pays close attention to personal-level features of cognitive practices such as their normative dimension and how they relate to scaffolded learning. The next chapters will show that EPP leads to a fine-grained approach to reading that is conceptually warranted and supported by many empirical results.

PART II

READING AND ITS SUB-PROCESSES

5. VISUAL WORD RECOGNITION

5.1. INTRODUCTION

In the last three chapters, I have outlined the theoretical foundations of the approach to reading to be developed in the following chapters. I will rely on EPP in order to account for both the neuronal and bodily sub-processes giving rise to the phenomenon of interest. Furthermore, I will interpret a vast array of empirical findings coming from neuroscientific, psychological, and psycholinguistic studies investigating certain aspects of reading from the integrative perspective of EPP. In this chapter, I will review and discuss visual word recognition. In chapter 6, I will deal with aspects of sentence processing that go beyond the recognition and identification of single, isolated words. These two components of reading, visual word recognition and sentence processing, will be dealt with on functional and neuronal levels of description. Since I hold the assumption that reading is partly constituted by bodily components, I will be concerned with eye movements in terms of active inference in chapter 7. Finally, cognitive transformation and enculturation are important aspects of reading. Accordingly, chapter 8 will be dedicated to reading acquisition.

Visual word recognition is of crucial importance for the entire reading process. It allows a reader to identify line arrangements on a piece of paper or on a computer screen as meaningful tokens of a writing system. Over the past few decades, much progress has been made in the empirical investigation of the functional, computational, and neuronal processes that might give rise to visual word recognition. Since ongoing research programs in cognitive neuroscience, cognitive psychology, and psycholinguistics are too diverse to be appreciated in their entirety, this chapter will focus on one important, representative debate about the neuronal underpinnings of visual word recognition. This debate concerns the question how reading has become possible in the first place, since this cognitive capacity is far too recent to have evolved on a phylogenetic time scale (cf., e.g., Anderson 2015, 71; Dehaene 2010, 5; Heyes 2012, 2182; van Atteveldt & Ansari 2014, 44). Furthermore, although it has been widely acknowledged that the left ventral occipito-temporal (vOT) area is of crucial importance for the neuronal realization of visual word recognition, there has been less agreement about the overall functional role of this area and the degree of its specialization as a result of successful reading acquisition. Finally, there are two conflicting proposals about the mechanism underlying the interplay between the left vOT area and other cortical regions. The purpose of this chapter is to review and evaluate this debate. This will allow us to arrive at a conception of visual word recognition that is conceptually coherent und empirically plausible. The key claim will be that visual word recognition is best captured in terms of EPP.

5.2. THE LEFT VENTRAL OCCIPITO-TEMPORAL AREA AND NEURAL REUSE

In a series of experiments, Stanislas Dehaene, Laurent Cohen and their colleagues have made a remarkable discovery: neuronal activation in one particular region of the left vOT area is reliably and significantly associated with visual word recognition in adult, non-pathological readers (Cohen & Dehaene 2004; Dehaene 2005, 2010; Dehaene & Cohen 2011; Dehaene et al. 2005; McCandliss et al. 2003; Vinckier et al. 2007). This region, especially the left ventral occipito-temporal sulcus next to the fusiform gyrus, frequently responds to visually presented words regardless of the size, case, and font in which they are made available (cf. Dehaene 2005, 143; McCandliss et al. 2003, 293). This consistent finding has led these researchers to call the left vOT area the *visual word form area* (VWFA), because it crucially contributes to "[…] a critical process that groups the letters of a word together into an integrated perceptual unit (i.e. a 'visual word form')" (McCandliss et al. 2003, 293).

On the basis of several analyses and the results of comparative studies, it is assumed that this area is reproducibly localized across individuals and writing systems:[65] "[…] the same region of the left lateral occipitotemporal sulcus always is activated, to within a few millimetres, whenever literate humans read" (Dehaene & Cohen 2011, 256).[66] Furthermore, it is hypothesized that the VWFA is regionally selective to the extent that "[…] it should be possible to identify patches of cortex that respond exclusively to letters or words, and do not respond at all to stimuli such as faces or objects that do not contain features of letters or words" (Cohen & Dehaene 2004, 468). Independent of the regional selectivity hypothesis (cf. ibid., 467), it has been assumed that the left ventral occipito-temporal sulcus is

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[65] For the ease of exposition, I will focus in this dissertation on alphabetic writing systems. However, I certainly do not deny that other types of writing systems (e.g., syllabic or logographic systems) are equally relevant for research on reading.

[66] See also Cohen & Dehaene (2004, 468) and Dehaene (2005, 134). For similar findings, see also Jobard et al. (2007).

functionally specialized for the recognition and identification of visually presented words. This means to say "[…] that the human brain of literate subjects contains specialized mechanisms for visual word recognition (functional specialization), which map in a systematic way onto the properties of a cortical subregion of the left posterior occipitotemporal sulcus (reproducible localization)" (ibid., 473). According to Dehaene and his colleagues, this does not mean that the left ventral occipito-temporal sulcus is exclusively associated with visual word recognition. It has been acknowledged that this region is also activated in object and face recognition (cf. McCandliss et al. 2003, 294). However, it is held "[…] that this region of the visual system must contain a population of neurons that, as an ensemble, is tuned to invariant stimulus properties and structural regularities characteristic of written words" (ibid.).[67]

This view has been criticized by a number of researchers. For instance, Price and Devlin (2003, 2004) agree that the left vOT area plays a crucial functional role in visual word recognition. But they deny that it is sufficient to consider the function of this region in isolation and to associate this particular region with visual word form recognition only:[68]

> […] although we are not disputing that the left midfusiform area is involved in visual word processing, we believe that it is misleading to label this region the 'visual word form area'. Reading evokes activation in a distributed set of regions […] and activation in one component of the system – the left midfusiform area – is not specific to visual word forms. (Price & Devlin 2003, 479)

Thus, according to Price and Devlin (2003), there are two reasons to deny that the cortical region labelled VWFA is functionally specialized: First, it is misleading to assign a specific cognitive function to one particular area, since the cognitive function is more likely to be associated with the interaction of many cortical areas (cf. Price & Devlin 2004, 478f). Second, since the cortical area under consideration is also associated with cognitive functions other than visual word recognition, it cannot be the case that the left vOT area is functionally specialized in any interesting sense. The last point has been supported recently by a series of analyses conducted by Vogel et al. (2012, 2013, 2014). In their meta-analysis, Vogel et al. (2014) draw on data derived from an fMRI study comparing cortical responses to a set of stimuli including words, pseudowords, nonwords, and Amharic sign strings (Vogel et al. 2012) and from analyses of resting state functional connectivity

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[67] See also Dehaene (2010, 72-74, 76) for a similar point.

[68] For a summary of this discussion, see Schlaggar and McCandliss (2007, 479f).

(RSFC) between the VWFA and other cortical regions across development (Vogel et al. 2013). They conclude that neither the comparison of cortical responses to distinct visual stimuli nor the analysis of RSFC lead to the conclusion that the VWFA (or a sub-component thereof) is functionally specialized:[69]

> In sum, neither functional analyses nor RSFC analyses, including both region specific and large network analyses, indicate the VWFA is used specifically or even predominantly in reading. […] While we suggest that the VWFA has some general visual processing functions, we emphasize that we are not arguing that it is a completely general use visual region. Rather, we contend that the processing performed in the VWFA is related to specific visual properties, which can be used in processing a number of stimuli, but are also very useful for reading. (Vogel et al. 2014, 6)

A synthesis of the approaches to the functional contribution of VWFA to visual word recognition presented by Price and Devlin (2003, 2004) and Vogel et al. (2012, 2013, 2014) leads to a "many-to-many" account of cortical organization. According to this account, a particular cortical region has certain capacities that make it suitable for contributing to the processing of certain stimulus types. At the same time, this cortical region forms part of a larger set of cortical regions whose interaction constitutes a particular neuronal function that can be associated with a cognitive phenomenon (cf. Behrmann & Plaut 2013, 211). Yet, the findings of Dehaene and his colleagues that the VWFA plays a crucial role in the overall visual word recognition process is important and widely acknowledged, although the interpretations of its functional contribution differ.[70]

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[69] In addition to functional specialization, Dehaene (2010) speculates that expertise in visual word recognition might have negative consequences on other cognitive functions associated with visual processing. In particular, he wonders whether "[…] reading acquisition possibly reduces the cortical space available for our other mental activities" (Dehaene 2010, 210). Recent evidence from a longitudinal behavioural study performed with a great number of German-speaking participants suggests that this is unlikely to be the case. In particular, Santi et al. (2015) are interested in the cognitive development as children acquire visual word recognition skills. Their main finding is "[…] that reading and visual processing abilities are both developing in related ways, but reading abilities do not appear to affect the way that students perform on measures of visual processing" (Santi et al. 2015, 11).

[70] Importantly, recent neuroscientific evidence suggests that the left vOT area is not only associated with the visual recognition, but also with the tactile recognition of words. In an fMRI study with congenitally blind participants, Reich et al. (2011) demonstrate that the left vOT area is reliably and significantly activated by words presented in Braille. This has led to the assumption that this area is not solely dedicated to visual processing, but that it needs to be assigned a metamodal function: "This area is therefore 'meta-modal': it may possess a general capacity for identifying shapes, whether visual or tactile, and mapping them onto language areas" (Dehaene & Cohen 2011, 260; see also Dehaene et al. 2015, 237). For an interesting discussion of this issue and the importance of metamodal or "crossmodal plasticity", see Anderson (2015, 54f).

An important motivation for research on the overall function of the left vOT area stems from considerations on the phylogenetic development of visual word recognition.[71] Since writing systems were invented only approximately 5400 years ago, it is unlikely that the ability to read is the result of an evolutionary process (cf. Dehaene 2005, 134; Dehaene 2010, 5; McCandliss et al. 2003, 293). In a nutshell, the crucial question is how visual word recognition is possible given "[…] that the human brain cannot have evolved a dedicated mechanism for reading" (Dehaene & Cohen 2011, 254). This is also referred to as the "reading paradox" (Dehaene 2010, 4). The solution to this paradox proposed by Dehaene and his colleagues is to assume "[…] that plastic neuronal changes occur in the context of strong constraints imposed by the prior evolution of the cortex" as a result of the human organism being exposed to tokens of a certain writing system (Dehaene & Cohen 2011, 254). Specifically, the idea is "[…] that writing evolved as a recycling of the ventral visual cortex's competence for extracting configurations of object contours" (ibid.).

This view, which has been dubbed the *neuronal recycling hypothesis* (cf. Dehaene 2005, 150), suggests that existing neuronal functions associated with visual cognition are 'recycled' for the phylogenetically recent, ontogenetically acquired capacity to recognize visually presented words (cf. Cohen & Dehaene 2004, 468). This 'recycling' is in turn constrained by the overall evolved neuronal architecture and already existing processing mechanisms (cf. Dehaene 2010, 146f; see also Menary 2014, 288; Quercia et al. 2013, 872). This is also acknowledged by Anderson (2010) who contrasts his massive redeployment hypothesis with the neuronal recycling hypothesis, while emphasizing that both hypotheses share the same background assumption:

> Massive redeployment is a theory about the *evolutionary* emergence of the functional organization of the brain, whereas neuronal recycling focuses on cognitive abilities for which there has been insufficient time for specialized neural circuits to have evolved. Both, however, suggest that the functional topography of the brain is such that individual circuits are put to various cognitive uses, across different task domains, in a process that is constrained in part by the intrinsic functional capacities (the "workings" or "cortical biases") of local circuitry.(Anderson 2010, 262; italics in original; see also Menary 2014, 289)

The general idea of *neural reuse* reviewed by Anderson (2010) comprises both evolutionary and ontogenetic-developmental processes. These processes establish

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[71] To emphasize that the region of interest is not exclusively dedicated to visual word recognition, but contributes to other cognitive processes as well, I will abstain from calling it the "visual word form area". Instead, I will employ the neutral anatomical denomination "left ventral occipito-temporal area".

new cognitive functions as a result of neuronal reorganization and the recombination of already existing neuronal resources (cf. Anderson & Finlay 2014, 9). Neural reuse is then defined as “the use of local regions of the brain for multiple tasks across multiple domains” (Anderson 2015, 4). It is likely that this solution to ever new processing challenges in the face of new environments and new cognitive tasks is rendered possible by “[…] a neural ‘search’ mechanism that works to establish functional partnerships between cells and between cortical regions” (Anderson & Finlay 2014, 11; see also Anderson 2015, 58). Specifically, the proposal is that “[a] set of […] neural structures with different *functional biases* (different input-output mappings) would be enough to allow an ongoing process of neural search to identify and consolidate the sets of partnerships that reliably supported skills being acquired during development” (ibid., 12; my emphasis).[72] More recently, Anderson (2015) has developed the *interactive differentiation and search framework* (IDS). This framework is supposed to provide valuable conceptual and empirical tools for the investigation of neural reuse. The motivation behind IDS is to account for both the flexibility and the functional limitations of the (human) brain. Anderson (2015, 74) summarizes the core idea of the IDS framework as follows:

> If the brain possesses mechanisms for functional development that include both the ability to tune local neural structure in response to task-relevant statistical properties in inputs, as well as the ability to perform a ‘search’ for functional partnerships between structural elements at various spatial scales, then it becomes possible to see how systematic, heritable, and relatively consistent functional differentiation in the brain could occur in the absence of targeted modular or mosaic selection.

This line of reasoning can be readily applied to the enabling conditions of visual word recognition and the neuronal function of the vOT area in its ongoing interaction with other cortical areas. This is because the fact that this area is reliably associated with visual word recognition can be explained by its ‘functional biases’ that make it most suitable for fulfilling this function: “(1) a preference for high-resolution foveal shapes; (2) sensitivity to line configurations; and (3) a tight proximity, and, presumably, strong reciprocal interconnection to spoken language representations in the lateral temporal lobe” (Dehaene & Cohen 2011, 256).[73] These ‘functional

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[72] Anderson (2015, 15f) casts the idea that the neuronal reuse of small cortical units is constrained by their functional biases as follows: “[…] local neural structures have a functional bias, a set of dispositional tendencies that capture the set of inputs to which the circuit will respond and govern the form of the resulting output. This notion is sufficient to account for the observations that local structures have multiple but limited uses without committing one to the idea that each circuit does *exactly one* specific thing” (italics in original).

[73] See also Cohen and Dehaene (2004, 473), Dehaene (2005, 147), Dehaene (2010, 294), and Dehaene (2011, 22). This also means to suggest that the historical development of

biases', however, do not preclude that the left vOT area is still engaged in other cognitive processes such as object recognition in skilled adult readers (cf. Carreiras et al. 2014, 93; Dehaene & Cohen 2011, 257; Price & Devlin 2004, 478).[74] Rather, it helps explain why this area is found to be well-equipped for contributing to the overall process of visual word recognition. In sum, then, the neural reuse hypothesis, in combination with the IDS framework, makes an important contribution to answering the question how the recent, culturally established capacity to identify tokens of a writing system is realized, considering the neuronal biases and constraints that are phylogenetically determined.

Taking for granted that the left vOT area crucially contributes to visual word recognition, the question arises which neuronal mechanism might underlie this processing capacity. Dehaene and his colleagues have developed a neuronal model that is considered to answer this question. The *local combination detector model* (LCD) basically assumes that visual word recognition is associated with a bottom-up processing hierarchy, in which increasingly complex information is fed forward from the lateral geniculate nucleus to areas V1 through V4, and finally proceeds from posterior to anterior parts of the left vOT area, including the left ventral occipito-temporal sulcus (cf. Dehaene et al. 2005, 337):[75] "The LCD model thus proposes that words are encoded through a posterior to anterior hierarchy of neurons tuned to increasingly larger and more complex word fragments, such as visual features, single letters, bigrams, quadrigrams, and possibly whole words" (Vinckier et al. 2007, 143f; see also Dehaene & Cohen 2011, 256f). Crucially, an fMRI study reported by Vinckier et al. (2007) that tested the empirical plausibility of the LCD model indicates that the left ventral occipito-temporal sulcus is not a homogenously organized cortical area. Rather, their findings suggest that there is "a gradient-like spatial organization *within* the VWFA" and that there is "a continuous posterior-to-anterior progression of slowly increasing selectivity to higher levels of the stimulus hierarchy" (ibid., 152f; italics in original). Thus, this approach entails "[…] the notion of feed-forward temporal (and structural) modularity, whereby reading is considered

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writing systems was itself subject to already existing neuronal processing capacities of human organisms. That is, "[…] writing systems themselves evolved under the constraint of having to remain learnable and easily recognizable by our primate visual system" (Dehaene 2005, 146; see also Dehaene 2010, 150, 303; Dehaene & Cohen 2011, 254).

[74] See, e.g., Kherif et al. (2011) and Vogel et al. (2012) for recent empirical evidence supporting this point.

[75] For a recent review of this model, see Dehaene (2015, 236).

to rely on a sequence of consecutive brain areas sensitive to a hierarchy of orthographic representations […] that culminates in recognition of a word" (Carreiras et al. 2014, 92). However, the model makes one simplifying assumption that renders it rather unrealistic considering the state of research on the general organization of the human brain (see, e.g., Friston 2005). Dehaene et al. (2005, 338) "[…] only included feedforward connections in the model." However, as the authors go on to admit, "[…] feedback and lateral connections are numerous in the visual system, and probably contribute to shaping the neurons' receptive field, for instance by enforcing probabilistic relations amongst consecutive letters, or by disambiguating letters and bigrams within words […]" (ibid.; see also Dehaene 2010, 160). This assumption has been supported by recent reviews on the neuronal processes underlying visual word recognition. For instance, Carreiras et al. (2014, 91) report that "[t]here is ample evidence that high-level information, such as phonological, morphological, and lexical information, influences very early aspects of the overall visual word recognition process." The absence of feedback connections in the LCD models is, I submit, a major weakness. This is because it does not account for an important and causally efficient component of cortical functioning and neuronal information processing. Furthermore, the LCD model is solely concerned with low-level visual processing that crucially contributes to visual word recognition. It has nothing to say about the interaction of the left vOT area with higher-order cortical areas associated with semantic and phonological processing. However, on a functional level of description, it is suggested that the higher-level processing of visually presented words is associated with two separate pathways, a phonological route and a lexical route (cf. Dehaene 2010, 38), which have been proposed by computational models such as the DRC model (cf. Coltheart 2007; Coltheart et al. 2001),[76] and whose existence appears to be widely supported by neuroscientific

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[76] The DRC model (Dual Route Cascaded model of visual word recognition and reading aloud), which is focused on the computational processes involved in converting a meaningful letter string into speech, suggests that visual word recognition proceeds via two simultaneuously activated, feed-forward routes, the lexical route and the phonological route. The basic idea is summarized by Coltheart (2007, 12f) as follows: "The lexical procedure involves accessing a representation in the model's orthographic lexicon of real words and from there activating the word's node in the model's phonological lexicon of real words, which in turn activates the word's phonemes at the phoneme level of the model. Nonwords cannot be correctly read by this procedure since they are not present in these lexicons […]. […] The nonlexical procedure of the DRC model applies grapheme-phoneme correspondence rules to the input string to convert letters to phonemes. […] It correctly converts nonwords from print to sound, and also regular words (those that obey its grapheme-phoneme correspondence rules)." The DRC model remains neutral on the neuronal realization of its component processes. Still, it is able to simulate a variety of effects

research (cf. Dehaene 2010, 107-112). Yet, it remains an open question how these computationally inspired insights could be integrated with the LCD model and what the features of the interaction between the VWFA, the phonological route and the lexical route might be. As I will show in the next section, there is a viable alternative to the LCD model. This alternative can account for the entire spectrum of the neuronal processes that presumably underlie visual word recognition. Furthermore, it is empirically supported by many results from recently conducted studies.

5.3. The Interactive Account of Visual Word Recognition and Predictive Processing

Price and Devlin (2011) propose to investigate visual word recognition and the crucial contribution of the left vOT area from the perspective of the PP framework. In contrast to Dehaene and his colleagues, they do not assume that the vOT area or any of its sub-components is exclusively dedicated to visual word recognition. Instead, they argue that it is the interaction of the vOT area with other cortical areas that determines its function (cf. Price and Devlin 2011, 246). In agreement with Dehaene and his colleagues, Price and Devlin (2011) assume that neuronal activation in the left vOT area are associated with visual word recognition in an important sense. They offer an Interactive Account (IA) of the neuro-functional contribution of neuronal activation in the left vOT area to hierarchically organized processes that are associated with single-word reading. In line with the general principles of the PP framework, they generally hold the following assumption: “Within the hierarchy, the function of a region depends on its synthesis of bottom-up sensory inputs conveyed by forward connections and top-down predictions mediated by backward connections” (Price & Devlin 2011, 247). In other words, the suggested synthesis equals the prediction error that results from the discrepancy between top-down predictions and bottom-up neuronal information. Applied to the patterns of neuronal activation associated with visual word recognition, this assumption is specified as follows:

> For reading, the sensory inputs are written words (or Braille in the tactile modality) and the predictions are based on prior association of visual or tactile inputs with phonology and semantics. In cognitive terms, vOT is therefore an interface between bottom-up

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observed in behavioural studies on visual word recognition in ‘normal’ and impaired individuals such as developmental dyslexics (cf. ibid., 15, 21f).

> sensory inputs and top-down predictions that call on non-visual stimulus attributes. (Price & Devlin 2011, 247)

Accordingly, the vOT area is supposed to be associated with a distinct level of the hierarchical generative model responsible for visual word recognition mediating between higher-level, language-related predictions and bottom-up visual information. It follows that "[…] the neural implementation of classical cognitive functions (e.g. orthography, semantics, phonology) is in distributed patterns of activity across hierarchical levels that are not fully dissociable from one another" (ibid., 249). This view can be further contrasted with the LCD model by taking Price and Devlin's (2011, 249) stance on the degree of functional specialization of the left vOT area into account: "[…] there is no one-to-one mapping between neuronal activity and the orthography of words such as letters, bigrams, and trigrams. Instead, encoding a visual word is accomplished via a pattern of firing over a population of vOT neurons." This "pattern of firing" is associated with the prediction error resulting from bottom-up sensory information and top-down predictions.

To summarize, IA proposes a neuronal mechanism that is able to demonstrate how linguistic knowledge about phonology and semantics, encoded in top-down predictions derived from a certain hypothesis, causally interacts with bottom-up information. The difference between the top-down prediction and the bottom-up sensory information leads to prediction error. Prediction error, in turn, is associated with significant activation in the left vOT area.[77]

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[77] Intriguingly, this approach has been anticipated by Daniel Dennett (1991, 12) in his construal of prominent connectionist theories of perception developed at that time: "It is widely held that human vision, for instance, cannot be explained as an *entirely* 'data-driven' or 'bottom-up' process, but needs, at the highest levels, to be supplemented by a few 'expectation-driven' rounds of hypothesis testing (or something analogous to hypothesis testing)." This resemblance in theoretical commitments is echoed by Price and Devlin's (2011, 249) remark that IA is continuous with models of parallel distributed processing (PDP). Furthermore, their model of visual word recognition shares basic commitments with McClelland and Rumelhart's (1981) Interactive Activation Model of visual word recognition. In particular, the early connectionist Interactive Activation Model applies the following basic assumption on perception to visual word recognition: "[…] we assume that perception is a fundamentally *interactive process*. That is, we assume that 'top-down' or 'conceptually driven' processing works simultaneously and in conjunction with 'bottom-up' or 'data driven' processing to provide a sort of multiplicity of constraints that jointly determine what we perceive. Thus, for example, we assume that knowledge about the words of the language interacts with the incoming featural information in codetermining the nature and time course of the perception of the letters in the word" (McClelland & Rumelhart 1981, 377f; italics in original). This continuity between connectionist modelling and Price and Devlin's (2011) PP-style approach to visual word recognition fits neatly with Clark's (2014, 235) acknowledgment that predictive systems "[…] combine key features of connectionism, classicism, and dynamicism. They exhibit statistically driven associative learning, support context-senstivie structured encodings […], yet emerge quite naturally from the self-organizing dynamics of prediction error minimization."

This approach has been supported by a number of recently published neuroscientific studies. For instance, Twomey et al. (2011) report an fMRI experiment in which participants perform two lexical decision tasks privileging either orthographical or phonological and semantic processing mechanisms. The results significantly indicate that the strength of the activation pattern in the left vOT area "[…] is influenced by top-down processing of nonvisual properties of the visual stimuli" (Twomey et al. 2011, 1247).[78] Furthermore, the authors conclude that this area "interactively integrates bottom-up visual signals with top-down higher order information that is not present in the visual stimuli" (ibid., 1248).[79]

Another piece of evidence in favour of Price and Devlin's (2011) account of visual word recognition concerns the *word frequency effect* observed in neuroscientific studies. For example, in a parametric fMRI study, Kronbichler et al. (2004, 951) find that the activation strength in the left vOT area is "sensitive to the frequency with which letter strings are encountered by showing decreasing activation in response to increasing frequency."[80] Findings such as these are readily explained by Price and Devlin (2011, 250), who suggest that "prediction error and activation will be less for high than for low frequency words because high frequency words are more familiar, which means their predictions are more efficient because they call on stronger associations between visual and linguistic codes."

Further support for Price and Devlin's (2011) PP approach to visual word recognition comes from a masked/unmasked priming fMRI study reported by Kherif et al (2011). In this study, participants are presented with prime-target pairs, where the primes and targets are either words denoting objects or pictures of objects, leading to a combination of word-word, picture-picture, word-picture, or picture-word. The prime and the target in each prime-target condition are either identical, semantically related, phonologically related, or completely unrelated (cf. Kherif et al. 2011, 105f). The important finding of this study, speaking against Dehaene's and colleagues assumption that the left vOT area is functionally specialized for visual word recognition, is that there is "[…] repetition suppression for conceptually identical relative to non-identical prime-target pairs in both the posterior and anterior LvOT. This was observed irrespective of whether the prime-target pair was within stimulus type and irrespective of whether the primes were masked or unmasked" (ibid., 111).

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[78] I take it that the presumably misleading notion of "nonvisual properties of the visual stimuli" refers to higher-level linguistic representations associated with phonology and semantics abstracting away from the modality in which certain words are presented.

[79] For similar results from an fMRI study involving a phonological task performed on number words and digits, see Hellyer et al. (2011).

[80] For a brief review of studies reporting similar results, see Vogel et al. (2012, 2716).

This significant repetition suppression effect is explained in terms of PP in line with Price and Devlin’s (2011) account of visual word recognition:

> Here, prediction error in LvOT refers to the mismatch between bottom-up inputs in the forward connections and top-down inputs from the backward connections. The mismatch arises because the presentation of the prime sets up a prediction for the response of subsequent inputs, and this prediction is carried by the backward connections from higher to lower levels in the hierarchy […]. Higher LvOT activation can therefore be explained by higher prediction error. This account explains why we observed repetition suppression throughout posterior and anterior parts of LvOT even when the primes had no perceptual similarity with the target […]. (Kherif et al. 2011, 111)

Thus, this study demonstrates on a short timescale, as priming experiments have it, that backward connections causally influence the left vOT area. In this case, the predictions are associated with higher-level conceptual knowledge, independent of the format in which visual stimuli are presented. The strategy to explain the activation level in this area in terms of the size of prediction error accounts for the results derived from the fMRI data in a plausible and coherent way. However, Kherif et al. (2011) focus on the left vOT area as their region of interest (ROI) and do not report activation patterns in other, higher-order cortical areas or their interaction with this ROI. Hence, the question arises whether the top-down influence of higher-order areas on the left vOT area, as postulated by Price and Devlin (2011), is empirically supported and if so, how this influence contributes to the overall process of visual word recognition.

To this end, Schurz et al. (2014) report a dynamic causal modelling analysis on data derived from an fMRI experiment investigating the neuronal activations associated with the processing of visually presented pseudohomophones (i.e., words that have an aberrant spelling, but are phonologically identical with real words) and real words. For the sake of simplicity, their analysis of effective connectivity focuses on the interaction between three ROIs, namely “[o]ne low-level visual area in the occipital cortex, one area in the left vOT, and one higher level language area in the left inferior frontal gyrus” (Schurz et al. 2014, 1670). Importantly, prior research has consistently found that the left inferior frontal gyrus (IFG) is associated with both semantic and phonological processing (cf., e.g., Carreiras et al. 2014, 94; Pammer et al. 2004, 1824). It is further suggested that activation in anterior parts of this area are associated with semantic processing (cf., e.g., Price & Mechelli 2005, 236), while activation in posterior parts are associated with phonological processing (cf., e.g., Cornelissen et al. 2009, 9; Price & Mechelli 2005, 236; Vogel et al. 2013, 231).

The results from Schurz's et al. (2014) fMRI study demonstrate that activation in the left vOT area and anterior and posterior parts of the IFG is higher for pseudohomophones in comparison to words (cf. Schurz et al. 2014, 1675). The effective connectivity analysis conducted by Schurz et al. (2014, 1678) indicates "[…] that bottom-up signaling from the occipital cortex to the left vOT strongly increases for pseudohomophones. In contrast, top-down signaling from the left inferior frontal gyrus to the left vOT did not differ between words and pseudohomophones." The interpretation of these results is that both real words and pseudohomophones are subject to top-down predictions. However, in the case of pseudohomophones, the top-down predictions are not accurate, which leads to pronounced prediction error and thus to a higher activation level in the left vOT area in comparison to the activation level associated with the visual recognition of real words (cf. ibid., 1677).

In addition to lending further empirical support to the idea that there is an important association between the activation level in the left vOT area and the size of prediction error, this study clearly establishes that a higher-level cortical area reliably associated with phonological and semantic processing, namely the left IFG,[81] exerts top-down influence on this area. This influence is associated with predictions concerning the semantic and phonological properties of visually presented words. In a recent MEG study, Woodhead et al. (2014) additionally demonstrate that the left IFG exerts top-down influence on the vOT area already in the first 200 ms after stimulus onset. This emphasizes the crucial functional contribution of top-down predictions to prediction error minimization.

In this vein, an EEG study reported by Bedo et al. (2014) extends these findings by measuring the effective connectivity between the left vOT and a larger number of ROIs. In each trial, the participants are presented with three consecutive letters in isolation followed by a three-letter word. Their task is to decide whether the entire word matches the previously presented sequence of letters (cf. Bedo et al. 2014, 2). The ROIs whose effective connectivity is analysed comprises the left vOT, the dorsal IFG, the ventral IFG, the angular gyrus (AG), the superior temporal gyrus (STG), and the occipital area (cf. ibid., 6). Activation in the AG has been associated with semantic processing in visual word recognition (cf., eg., Price & Mechelli 2005,

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[81] More generally, on the basis of voxel-based analyses of correlations between activation in the left vOT area and left inferior frontal cortex in a semantic decision task, Seghier and Price (2013) report that the interaction these regions can be subdivided into at least three component networks, such that distinct parts of the left inferior frontal cortex appear to interact with distinct component parts of the left vOT area.

236; Vogel et al. 2012, 231; Vogel et al. 2014, 4), while activation in the STG is assumed to be associated with phonological processing (cf. Bedo et al. 2014, 2; Price & Mechelli 2005, 234). The results show that there are strong feedforward and feedback connections between the left vOT and all ROIs over different time courses from 100 to 800 ms after stimulus onset (cf. Bedo et al. 2014, 6). This area is thus "both a source and a receiver of information transfer during word reading in both theta and gamma frequency bands" (ibid.). The researchers interpret their findings in terms of PP by relying on Price and Devlin's (2011) approach. Specifically, Bedo et al. (2014, 8) argue that the two following principles derived from Price and Devlin's (2011) proposal for a neuronal mechanism underlying visual word recognition are confirmed by their results:

> 1) Because of the reciprocal nature of the connections to and from vOT, much of the observed connectivity between vOT and other ROIs should show both feed-forward and feedback signals in the span of time involved in reading a word, and 2) The activation in vOT to word forms should activate – at least partially – semantic and phonological representations simultaneously in high-level language areas. In the present study, we document through connectivity measures the realization of both of these principles.[82]

This study suggests that the left vOT area certainly is "an interface between bottom-up sensory inputs and top-down predictions" (Price & Devlin 2011, 247). It receives top-down predictions associated with phonology and semantics and feeds forward prediction error in order to optimize the associated predictions. More specifically, Bedo et al. (2014) demonstrate that a number of cortical areas, which have traditionally been assumed to be engaged in visual word recognition, are involved in perceptual inference.

In sum, all studies reviewed here provide direct empirical evidence for the plausibility and validity of Price and Devlin's (2011) account of visual word recognition. This is even more striking since these studies employ different measurement techniques (fMRI, EEG, and MEG),[83] different research paradigms, and different methods of analysis. Further evidence that specifies the overall neuronal realization of the hierarchical generative model associated with visual word

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[82] For further details, see Bedo et al. (2014, 9f).

[83] This is important, considering the spatial and temporal limitations of each research technique. While EEG and MEG have a high temporal resolution and a less fine-grained spatial resolution, the opposite applies to fMRI measuring BOLD responses. Furthermore, "[…] the temporal resolution of the blood-oxygen-level dependent (BOLD) response is too slow to unequivocally distinguish between activations that are feedforward versus feedback […]" (Carreiras et al. 2014, 93). This distinction can be reliably made by employing EEG and MEG.

recognition is clearly needed. However, for the time being all of these results are maximally consistent with the PP account proposed by Price and Devlin (2011) and are hardly explainable in terms of a feed-forward hierarchical account as proposed by the LCD model.

5.4. VISUAL WORD RECOGNITION AND ENCULTURATED PREDICTIVE PROCESSING

From the perspective of EPP, Price and Devlin's (2011) account of visual word recognition provides an important attempt to answer the question how the neuronal contribution to visual word recognition might be realized in the human, enculturated brain. If their PP-style account is on the right track, visual word recognition can be approached by describing it in terms of prediction error minimization. As we have seen in the last section, there is much empirical evidence available that renders this position more plausible that the competing LCD model suggested by Dehaene and his colleagues. This evidence also lends further support to EPP. This is because support for a PP-style approach to visual word recognition directly speaks to the more general question how to describe components of this particular enculturated cognitive process on neuronal and functional levels of description. If it is plausible that the neuronal component of visual word recognition, approached as a crucial instance of the entire reading process, is best accounted for by describing it in terms of perceptual inference, this certainly speaks in favour of EPP.

In addition, the idea of *neural reuse* (and its more specific variant, *neuronal recycling*) and the EPP approach can inform each other. Together, EPP and neural reuse lead to a concise answer to the question how culturally developed cognitive practices such as reading could have been rendered possible on both phylogenetic and ontogenetic scales. Recall from section 5.2. that neural reuse is the idea that cortical regions and smaller units of the human brain partake in different neuronal assemblies, depending on their functional biases and the overall neuronal architecture: “[…] individual pieces of the brain, from cells to regions to networks, are used and reused in a variety of circumstances, as determined by social, environmental, neurochemical, and genetic contexts” (Anderson 2015, 36). In evolutionary terms, the functional organization of the human brain may itself be an adaptation. On this construal, “[…] in a functionally differentiated but nonmodular brain, selection pressures might work not to produce particular specializations but rather to stabilize the availability of a diverse mixture of functional properties in the entire brain […]" (ibid., 74). This idea is able to reconcile the alleged tension between the evolutionary trajectory of human organisms and their ability to acquire new, socio-culturally cognitive capacities during ontogenetic development. In the case of visual word recognition, we can assume that there certainly is no evolutionarily determined neuronal circuit exclusively dedicated to the realization of this particular cognitive function. However, there are good reasons to subscribe to the idea that the *general properties* of the human brain that render visual word recognition possible are products of evolution. In particular, these properties concern the functional biases of cortical regions and the existence of a 'neural search' mechanism, as suggested by Anderson's (2015) IDS framework. These evolved neuronal properties, in turn, allow for the dynamic, yet constrained ontogenetic acquisition of new, socio-culturally developed cognitive functions such as visual word recognition. The selection pressure that brought about these special capacities of the human brain might have been a reaction to the increasing complexity of the human environment and its social organization. This socio-cultural development, in turn, might have created the need to find and redeploy new cultural resources to facilitate and drive cooperation and communication. As Anderson (2015, 99) argues, "[…] the brain evolved to manage various organism-environment relationships." This view suggests that we should approach neural reuse not by presupposing a certain kind of 'neurocentrism'. Rather, it is the specific neuronal contribution of a human organism's ongoing *interaction* with resources in its cognitive niche that needs to be accounted for on both phylogenetic and ontogenetic time scales. This is just one of the main theoretical commitments of EPP. In addition, there is a striking resemblance between a cognitive integrationist's take on the continuity and hybridity of human cognitive phenomena and what Anderson (2015, 241) calls "*cooperative connectivity*": "Brain function is about establishing and coordinating neural partnerships across the brain; and adaptive behaviour is a matter of establishing functional partnerships both inside and outside, within and across the body-environment boundary." This suggests that neural reuse is not an end in itself. Rather, this evolved principle of brain organization significantly contributes to an organism's neuronal and bodily interaction with its environment. The bottom line is that neural reuse (and its more specific variant, neuronal recycling) renders the complex neuronal and bodily coordination dynamics efficient and functionally tractable. Even if we focus for heuristic reasons on the specific neuronal contribution to a specific type of cognitive processing – visual word recognition being a case in point here – we should not forget the broader context of the particular neuronal realization of this processing routine.

This also sheds new light on the PP-style account of visual word recognition proposed by Price and Devlin (2011). According to Clark (2016, 150), PP is compatible with neural reuse to the extent that

> [d]istinctive, objectively-identifiable, local processing organizations now emerge and operate within a larger, more integrative, framework in which functionally differentiated populations and sub-populations are engaged and nuanced in different ways so as to serve different tasks (for more on this general multi-use picture, see Anderson, 2010, 2014).

This suggests that PP and the approach to neural reuse supplement each other. While PP's primary focus is on the conditions of (human) perception, action, cognition, and attention in the here and now and across ontogenetic development, neural reuse is mainly interested in the conditions of the phylogenetic history of the neuronal contributions to cognitive functioning. As we have seen in this chapter, the fact that the left vOT area plays a crucial functional role in visual word recognition can be explained in terms of the functional biases of this area and the general cognitive requirements human organisms have to meet. Thus, the principle of neural reuse can contribute to a better understanding of both the possibilities and limitations of neuronal sub-processes that significantly contribute to visual word recognition and other aspects of the reading process. This fits neatly with the overall argument of this chapter that visual word recognition is best described in terms of EPP.

More recently, Dehaene (2014, 324) seems to be inclined to subscribe to the idea that the relationship between neuronal recycling and visual word recognition could be recast in terms of probabilistic Bayesian generative modelling: "Reinterpreted in the light of the Bayesian framework, the neuronal recycling hypothesis boils down to assuming that each brain area, biased by minimal genetic mechanisms, codes for a dedicated set of hypotheses." This view runs danger to simplify the neuronal architecture that is postulated by PP approaches in general and Price and Devlin's (2011) PP-style account of visual word recognition. This is mainly because it does not take into account the presumed neuronal realization of the complex interplay between sensory input, predictions, and prediction error. Furthermore, Dehaene's (2014) tentative adoption of a Bayesian perspective on neuro-functional processing seems to be at odds with the general assumptions made by any PP-inspired account of perceptual, sensorimotor, cognitive, and attentional phenomena: "[…] Bayesian learning may be significantly enhanced by the capacity to consider a vastly larger set of hypotheses formed by a *stochastic 'language of thought'* – nested language-like expressions that recombine the pre-existing basic terms […]" (ibid., 325; my emphasis). It is hard to conceive why he needs to hypothesize that there might be a "stochastic 'language of thought'" that provides the pre-requisite for hypotheses attributed to probabilistic generative models. This seems to re-evoke very conservative representationalist assumptions (e.g., Fodor 1987) that are decisively overcome by the prediction error minimization framework (cf. Clark 2015b, 4). Furthermore, it is not immediately intelligible what a "stochastic 'language of thought'" might look like and how it might be realized in the human brain. For these reasons, Price and Devlin's (2011) account of visual word recognition happens to be more convincing and empirically plausible. In addition, we have just seen that their IA account can be supplemented by considerations on neural reuse and the general adaptive organizing principles of the human brain.

5.5. CONCLUDING REMARKS

In the beginning of this chapter, I have started with the observation that there is converging evidence that the left vOT area is significantly associated with visual word recognition. However, the interpretation of these results in terms of the functional specialization of this area for a specific processing stage in visual word recognition is debated. There are at least two opposed proposals on the neuronal mechanism specifying the functional role of the left vOT area and the neuronal realization of visual word recognition more generally. As I have tried to establish in this chapter, it seems safe to assume that the PP approach to visual word recognition is superior to a feed-forward account as suggested by Dehaene and his colleagues in their LCD model. First, this is because a PP-style account appears to be more parsimonious and to be maximally consistent with many empirical findings. Second, in contrast to theoretical considerations stemming from the LCD model, this account can readily explain empirically established effects such as the word frequency effect or the repetition suppression effect. Third, in contrast to the LCD model, a PP account does not run danger of assuming at least a soft version of functional and neuronal modularity, since it assumes that visual word recognition is a result of neuronal interactions between many cortical areas and not restricted to certain activation patterns in locally circumscribed cortical areas. Furthermore, the

PP account of visual word recognition can be supplemented by the idea that neural reuse figures as a guiding principle of the organization of the (human) brain. As we will see in later chapters, the PP account proposed by Price and Devlin (2011) allows for an approach integrating neuronal sub-processes in terms of perceptual inference and bodily sub-processes in terms of active inference. This seamless integration of distinct, yet highly interactive sub-processes seems to be hardly conceivable from the perspective of the feed-forward LCD model. More generally, the insights obtained from these considerations lead to the conclusion that the EPP framework – informed by Price and Devlin’s (2011) take on visual word recognition – is supported by recent empirical research and allows for an epistemically fruitful application to phenomena associated with visual word recognition.

6. SENTENCE PROCESSING

6.1. INTRODUCTION

The last chapter has been dedicated to the investigation of visual word recognition from the integrative EPP perspective. However, in more natural situations beyond the setting of controlled experimental conditions, words are hardly ever encountered in isolation (cf. Richlan et al. 2014, 2647). Rather, readers are confronted with words presented in syntactically organized, compositional structures, such that the meaning of a word is partly dependent upon the syntactic and semantic context in which it occurs. Accordingly, the functional and neuronal mechanisms underlying sentence processing are supposed to go beyond those underlying the visual recognition of single, context-free words. Empirical results obtained from studies investigating visual single-word recognition can help discover general principles that underlie written language processing, but they are incomplete to the extent that they remain neutral about functional and neuronal processes underlying the successful retrieval of information from sentences (cf. Braze et al. 2011, 417; Constable et al. 2004, 12).[84] The purpose of the present chapter is to investigate sentence processing as far as it concerns reading in contrast to spoken language processing on a neuronal and functional level of description.[85] This will be done by developing a new and parsimonious account in terms of EPP. As we shall see, this new approach to sentence processing is supplementary to the account of visual word recognition and is consistent with many empirical findings. Furthermore, it will turn out that previously disparate and seemingly unrelated findings can be unified by interpreting them from this perspective.

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[84] Research on visual word recognition has been conducted largely independently from research on sentence processing and vice versa. This may be due to methodological commitments and limitations as well as the attempt to focus on a rather fine-grained analysis of sub-processes constituting reading. This chapter is a first attempt to link these two strands of research from a philosophical perspective.

[85] Much research on sentence processing has been based on spoken language processing or has remained rather neutral about the differences between the functional, computational, and neuronal foundations of the processing of syntactically structured written language in contrast to spoken language. However, several fMRI studies have arrived at the conclusion that higher-order processes beyond visual or auditory word recognition are associated with similar neuronal activation patterns (cf. (Braze et al. 2011, 427; Jobard et al. 2007, 798; Shankweiler et al. 2008, 767). Nevertheless, in this chapter I will focus on empirical research that investigates sentence processing in reading only.

6.2. SENTENCE PROCESSING AND PREDICTION ERROR MINIMIZATION

Successful sentence processing depends on multiple factors such as the automatic and fluent application of lexical, grammatical and pragmatic knowledge about possible combinations of words.[86] Additionally, in the case of reading, the recognition and identification of the individual words constituting a sentence is also an indispensable condition for sentence processing. Recently, Fine, Jaeger, and their colleagues have suggested that sentence processing relies on a certain kind of expectation adaptation or prediction optimization. Specifically, Jaeger and Snider (2013, 58) argue that "word-by-word processing difficulty during reading is a function of how expected the word is given preceding context" and that "language processing will be more efficient if comprehenders continuously adapt their syntactic expectations to match the statistics of the current environment […]."[87] Here, the idea is that expert language users and readers automatically learn about and adapt to "the probabilities of syntactic structures" (Fine et al. 2013, 3). The proposed account of *error-based learning* suggests "that the prediction error from recently processed material, which can be interpreted as gradient error signal, affects expectations about upcoming material" (Fine & Jaeger 2013, 579).[88] However, these researchers remain neutral about the functional and neuronal mechanisms underlying error-based learning (cf. Jaeger & Snider 2013, 58). At the same time, they indicate that their account is compatible with PP (cf. Fine et al. 2013, 14; Jaeger & Snider 2013, 58). It seems reasonable to suppose that error-based learning is a fairly general idea, which can be made more concrete by the EPP approach.

Another recent proposal for the compatibility of research on sentence processing and the prediction error minimization framework is presented by Farmer et al. (2013) in their comment on Clark (2013a). They suggest that the principles guiding

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[86] The interplay and mutual dependence of these factors has inspired a class of computational models of sentence processing, namely *constraint-based models*. In contrast to modular, serial models of sentence parsing, constraint-based models rest on the assumption that it is the parallel and interactive computation of lexical, semantic, syntactic, and pragmatic properties of a sentence that renders sentence processing efficient, fast, and successful. For a review, see McRae and Matsuki (2013). Please note also that knowledge about legible combinations of tokens of a representational writing system has a normative dimension. This is because this kind of knowledge is the result of linguistic practices shared by members of a certain language community. Understood this way, sentence processing is subject to cognitive norms.

[87] See also Fine & Jaeger (2013, 579) and Fine et al. (2013, 2).

[88] Similar accounts of sentence processing are presented by Altmann & Mirković (2009) and Levy (2008).

prediction error minimization can be fruitfully applied to language processing in context. In particular, they hold that individuals who process language sub-personally "[…] use internally generated predictions at multiple levels to *explain* the source of the input, and that prediction error is used to update the generative models in order to facilitate more accurate predictions in the future" (Farmer et al. 2013, 211; italics in original). They submit that the PP framework "[…] will unify the literature on prediction in language processing" (ibid., 212). In his reply to Farmer et al. (2013), Clark (2013b, 239) agrees with their approach and emphasizes that "[l]anguage, indeed, is a paradigm case of an environmental cause that exhibits a complex, multilevel structure apt for engagement using hierarchical generative models." The crucial question that will concern us for the remainder of this chapter is how sentence processing can be described in terms of prediction error minimization. To this end, I will review empirical research on certain effects consistently observed in reading experiments that are interested in sentence processing. Furthermore, I propose a unifying account of these effects from the perspective of EPP.

6.3. EMPIRICAL EVIDENCE SUPPORTING ENCULTURATED PREDICTIVE PROCESSING

Over several years, much progress has been made in the identification of brain areas that are reliably associated with sentence processing by employing various tasks, methods, and research paradigms. Consistently, sentence processing has been associated with activation patterns in the left IFG (Broca's area) and several regions in the left temporal cortex, most often in the superior temporal gyrus (STG) and the middle temporal gyrus (MTG; see, e.g., Braze et al. 2011; Brennan & Pylkkänen 2012; Constable et al. 2004; Friederici 2012; Kaan & Swaab 2002). It has been revealed that there are bottom-up–top-down interactions between the left IFG and temporal regions (cf. Friderici 2012, 265; Snijders et al. 2009, 1500f). Friderici (2012, 265) interprets this finding by suggesting that a "[…] function of the posterior IFG might be to deliver syntactic predictions about the incoming information in a sentence to the temporal cortex." If this suggestion turned out to be true, it would support a PP account of sentence processing. The assumption would then be that the hierarchical generative model associated with sentence processing comprises at least the left IFG, associated with high-level predictions about syntactic structures delivered by visual input, and temporal areas, which feed forward prediction error associated with the discrepancy between the predicted syntactic component und bottom-up neuronal information.

6.3.1. SYNTACTIC PRIMING

This line of reasoning is consistent with findings from studies investigating *syntactic priming*, where this is the “facilitation of sentence processing that occurs when a sentence has the same syntactic form as a preceding sentence” (Noppeney & Price 2004, 702).[89] Behaviourally, it turns out that the facilitating effect of the repetition of a certain syntactic structure in the target sentence is associated with a decrease of reading times (cf. C. S. Kim et al. 2013, 10; Noppeney & Price 2004, 703; Weber & Indefrey 2009, 1169). Furthermore, there is neuroscientific evidence that syntactic priming is associated with decreased activations in left-lateralized temporal areas. For instance, in their fMRI study, Noppeney and Price (2004, 705) find that reading sentences in contrast to viewing false fonts as the baseline condition elicits “[…] predominantly left-lateralized activation in the middle and inferior temporal gyri extending into the temporal poles and the hippocampus. In addition, activation was observed in the left inferior and middle frontal gyri.”[90] Crucially, their results indicate that “[…] anterior temporal activation [is] reduced when consecutive sentences are syntactically similar” (ibid., 706). Following up on the assumption introduced in the last chapter that the level of prediction error is associated with the degree of neuronal activation in a critical brain region, this finding can be interpreted by suggesting that there is a decrease of prediction error for primed versus unprimed sentences. This decrease of prediction error could then be associated with a decrease in brain activation observed in the anterior temporal area. It follows that the syntactic priming effect occurs because recent prediction optimization and hypothesis updating informs the selection of future predictions targeted at sensory input. This is because the previously chosen hypothesis renders certain predictions about upcoming syntactic structures more likely than others. Accordingly, their top-down influence is strengthened and competing predictions are cancelled out (presumably by lateral inhibition). If these chosen predictions are sufficiently accurate, the discrepancy between the predicted syntactic structure and the actually

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[89] See also DeLong et al. (2014, 633); Ledoux et al. (2007, 135); and Weber and Indefrey (2009, 1164). For a review, see Tooley and Traxler (2010).

[90] Subsequent studies (Jobard et al. 2007; Zempleni et al. 2007) also found significant activation patterns in the left middle and inferior temporal gyri. They thus provide support for Noppeney and Price’s (2004) finding that these cortical regions play a crucial role in sentence processing.

given sensory input indicating that structure will be reduced in comparison to unprimed conditions, thus leading to reduced prediction error. The minimal time frame provided by the set-up of syntactic priming experiments would thus allow for significant neuronal and functional effects to become measurable. However, these effects should be pervasive and render sentence processing successful and efficient on larger time scales.[91] This is consistent with Clark's (in progress, chapter 1, 31) more general considerations on priming effects:

> […] the active role of the top-down generative model accommodates all manner of priming effects, and makes architectural sense both of the prevalence of backward neural connectivity and of apparent functional differences between the forward and backward connections – differences that reflect, PP suggests, the divergent functional roles of prediction-error signaling and probabilistic prediction […].

Indirect evidence for this line of reasoning comes from an EEG experiment investigating the electrophysiological correlates of syntactic priming reported by Ledoux et al. (2007). In this experiment, participants read pairs of sentences containing a temporarily ambiguous verb, which serves either as the past participle introducing a reduced relative clause or as the past tense verb being part of a main clause. While the first sentence either contains a reduced relative clause or consists of a main clause, the target sentence always contains a reduced relative clause (cf. Ledoux et al. 2007, 136f). Comparing the prime-target condition with the control condition of processing syntactically dissimilar pairs of sentences, it turns out that "[t]he difference we observed in the ERP waveforms were manifest as a reduced positivity" (ibid., 140). This reduced positivity is associated with the syntactic priming condition and is interpreted to reflect the P600 (cf. ibid.). This is an event-related potential (ERP) that is localized in posterior parts of the cortex and associated with syntactic ambiguity resolution (cf. van Gompel 2013, 2). Thus, this study can be taken as evidence for a local decrease of brain activation and the associated prediction error in syntactic priming conditions.

6.3.2. AMBIGUITY RESOLUTION

In addition to syntactic priming, the resolution of syntactic or semantic ambiguities in sentence processing has been the target of several studies. The general reasoning behind these studies is that the processing of ambiguous sentences is assumed to

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[91] A similar point is made by Jaeger & Snider (2013, 60f) who assume "[…] the prediction error associated with a syntactic prime to depend on all experience prior to a sentence, including, in particular, recent experience with the statistics of the current environment."

be more difficult than the processing of unambiguous sentences. Furthermore, it is assumed that experienced readers should sub-personally entertain predictions about the frequencies with which certain ambiguities are resolved in a particular way. Behaviourally, it is expected that this should be reflected in reading times. This is exactly what Fine et al. (2013) find in two consecutive experiments. In these experiments, participants read sentences containing verbs that are statistically more likely to be the main verb than the past participle introducing a relative clause.[92] However, in both experiments, this frequency distribution is reversed. The most important finding from the two experiments is that in the course of the experiments, participants increase the speed with which they read previously infrequent, syntactically ambiguous sentences. The researchers take this as evidence for the suggestion "[…] that readers are capable of adapting to *relative* frequencies (or probabilities) of syntactic structures in the current linguistic environment" (Fine et al. 2013, 11; italics in original). This suggestion can be interpreted from the EPP perspective by assuming that predictions encode probability distributions of certain syntactic structures and the frequencies with which they occur. However, these predictions are optimized as a result of preceding prediction error minimization. On a personal level of description, this should lead to a decrease in processing difficulty with regard to previously infrequent (or unlikely) syntactic structures. This is reflected in the reliable reduction of reading times.

However, ambiguity resolution in sentence processing should also be associated with specific neuronal activation patterns across brain regions in contrast to the processing of unambiguous sentences. This is what Snijders et al. (2009) report. In their fMRI study, they investigate the resolution of word-category specific ambiguities in sentences and use the processing of syntactically unstructured sequences of words as their control condition. In the main task, participants read Dutch sentences containing words that can either be used as a verb or as a noun depending on the syntactic context (cf. Snijders et al. 2009, 1494). In one condition, the critical words are temporarily ambiguous and in the other condition the words are used in a syntactic context that clearly indicates that the critical word must figure as a verb or a noun, respectively. The first critical finding is that in the sentence

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[92] To illustrate this, here are examples of each sentence type making up the material employed in this study. The examples are taken from Fine et al. (2013, 2). Temporarily ambiguous verb that figures as the main verb: "The experienced soldiers … warned about the dangers before the midnight raid." Temporarily ambiguous verb that introduces a relative clause: "The experienced soldiers … warned about the dangers conducted the midnight raid."

condition, brain activation in left IFG and in the left posterior middle temporal gyrus (LpMTG) is significantly increased in contrast to the control condition (cf. Snijders et al. 2009, 1500). This is in line with previously presented evidence from other studies indicating that these brain regions are reliably associated with sentence processing. More importantly, the second finding is that the activation pattern in LpMTG is increased for ambiguous in contrast to unambiguous sentences (cf. ibid.). This is consistent with the finding from Noppeney and Price (2004) discussed earlier and suggests that across tasks and paradigms, the MTG might be a crucial brain region for conveying prediction error signals in syntactic processing contexts to higher cortical levels such as left IFG, and might in turn receive prediction signals from this brain region. Similarly, in their fMRI study investigating lexical semantic ambiguity resolution in a homograph reading task, Zempleni et al. (2007, 1275f) find that "[t]he majority of the activated voxels are located in the left hemisphere, in the inferior frontal gyrus (BA 45/44) and in the left inferior/middle temporal gyri (BA 20/37)." However, their results also indicate significant brain activation in the right homologues of these brain regions (cf. ibid.). Focusing on the more significant activation pattern in the left hemisphere, Zempleni's et al. (2007) results lend further support to the idea that there is a close interaction between the left IFG and specific parts of the temporal cortex in the processing of syntactically ambiguous sentences. Once again, it seems safe to assume that EPP can easily account for this insight. On this construal, predictions about a certain syntactic structure are associated with activations in left IFG, which exert top-down influence on lower-level areas in the temporal cortex. These areas in turn feed forward prediction error signals to LIFG, thus 'explaining away' the discrepancy between syntactic predictions and bottom-up prediction error.

6.3.3. SYNTACTIC COMPLEXITY

More generally, several fMRI studies have investigated the influence of syntactic complexity on sentence processing. Syntactic complexity is understood as the statistically assessable occurrence of certain comparatively infrequent syntactic structures, which manifests itself in significant behavioural and neuronal differences across types of syntactic structures.[93] For instance, a study reported by Constable et

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[93] Braze et al. (2011, 417) define the notion of "differences in complexity" as follows: "The term refers to empirically well-established cases in which one grammatical type takes reliably longer and/or causes more errors than a closely-related different grammatical type."

al. (2004) approaches processing differences with regard to sentences containing relative clauses that either refer to the grammatical subject or to the object of the main clause (cf. Constable et al. 2004, 13).[94] These types of syntactic structures are presented both visually and auditorily, since the researchers are also interested in cross-modal differences. It turns out that the more complex (or less frequent, less expected) syntactic structure, which contains an object relative clause, elicits comparatively more neuronal activation in left IFG, STG, and MTG than subject relative clauses across modalities (cf. ibid., 18f). Similar results are obtained from previous fMRI studies investigating sentence complexity (Keller et al., 2001; Michael et al., 2001). Interestingly, Constable et al. (2004, 19) report that "[…] other sites within angular gyrus and SMG [supramarginal gyrus] demonstrated complexity effects for printed sentences only" (ibid., 19). This can be related to findings reviewed in the last chapter on visual word recognition. In cases of single-word reading, the angular gyrus has been reliably associated with semantic processing (cf. Bedo 2014, 6; see also Price & Mechelli 2005, 236; Vogel et al. 2012, 231; Vogel et al. 2014, 4). Similarly, previous research has also indicated that the supramarignal gyrus is involved in visual word recognition and effectively connected to the left vOT area (cf., eg., Behrmann & Plaut 2013, 214). Together, these insights lead to the assumption that the processing of syntactically complex sentences involves a number of interacting brain areas in inferior frontal, superior/medial temporal, inferior parietal, and occipito-temporal areas. This interaction is best and parsimoniously explained in terms of EPP. From this perspective, the hierarchical generative model associated with sentence processing in reading is realized (at least) in the brain areas just mentioned, such that the multiple functional levels of the hierarchy correspond to levels located in these brain areas contributing to prediction error minimization. The idea would then be that prediction error associated with neuronal activation in the left vOT area is fed forward to inferior parietal, middle/superior temporal and inferior frontal regions. At the same time, in sentence processing the vOT area would receive top-down signals from these higher-order cortical areas which are associated with lexical, semantic, and syntactic predictions.

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[94] To illustrate this, here are examples of each sentence type provided by Constable et al. (2004, 13): "(1) The biologist – who showed the video – studied the snake. [subject relative clause] (2) The biologist – who the video showed – studies the snake. [object relative clause]"

6.4. TOP-DOWN INFLUENCE ON LOWER-LEVEL CORTICAL AREAS

This line of reasoning can be supported by other studies that explicitly investigate the impact of higher-level on lower-level cortical areas and the associated sub-processes of sentence processing. There is increasing evidence, mainly coming from electrophysiological recordings, that higher-level predictions exert top-down influence on lower levels of the processing hierarchy. For instance, DeLong et al. (2005) report an EEG experiment that investigates the impact of the expectability (estimated by cloze probabilities) of a certain noun following an indefinite article ('a' or 'an', depending on the first letter/onset of the following noun) on the amplitude of the N400 ERP. The N400 is a negative electrophysiological signal whose "[…] amplitude is sensitive to word frequency, repetition and concreteness, among other factors" (DeLong et al. 2005, 117). The researchers report that the "[…] N400 amplitude decreased (became less negative) as noun cloze probabilities increased." Furthermore, "[s]imilar to the nouns, the more contextually unexpected an indefinite article was, the more negative the ERP amplitude between 200-500 ms post-word onset (N400)" (ibid., 119). These results are interpreted as evidence for the assumption that sentence processing involves "probabilistic predictions of which specific words will come next" (ibid.).

Being interested in form-based probabilistic expectations about upcoming words in English, Farmer et al. (2006) performed a corpus analysis of the likelihood with which a certain word is a member of a specific syntactic category depending on its phonological form. They demonstrate that both nouns and verbs share reliably more phonological properties with its category members than with words belonging to the other syntactic category (cf. Farmer et al. 2006, 12204). Reporting the results from four subsequent behavioural reading experiments investigating the impact of *phonological typicality* of both nouns and verbs on written language processing, Farmer et al. (2006, 12207) arrive at the conclusion that there is "[…] a systematic relationship between the sound of a word and whether it is used as a noun or a verb." Furthermore, they submit "[…] that adults are sensitive to such phonological typicality both when reading isolated words aloud and when comprehending ambiguous and unambiguous sentences" (ibid.). This can be taken as evidence for the assumption that prevalent exposure to written language, in addition to spoken language, results in the persistent acquisition of knowledge about probability distributions of linguistic tokens and their properties, which are in turn used to predict, and ultimately to 'explain away', visually presented linguistic input.

Further evidence for this comes from an MEG study reported by Dikker et al. (2010), which follows up on Farmer's et al. (2006) insights. Investigating electrophysiological responses to syntactic categories, they find a main effect of the M100 amplitude for category violations. The M100 ERP indicates "activity generated in visual cortex at 100 to 130 ms" after stimulus onset (Dikker et al. 2010, 629). In this study, the participants read sentences containing a noun that is either expected or unexpected depending on the syntactic context (cf. ibid., 631). It turns out that "the MEG visual M100 response was sensitive to form typicality" (ibid., 632). The interpretation of this result put forward by Dikker et al. (2010, 632) is "[…] that the brain uses prior syntactic context to predict not only a word's syntactic category […], but also form features that are probabilistically associated with the predicted category." This result goes beyond the empirical evidence reviewed so far. This is because it suggests that neuronal responses to expectation violations are not only located in higher-order cortical regions or regions most tightly associated with visual word recognition (i.e., the left vOT area), but also in the lower-level occipital visual cortex. From the perspective of PP, this is hardly surprising. If this approach and its mechanistic explanation of neuronal functions are not mistaken, prediction error minimization occurs at all cortical levels. It follows that prediction error, which is associated with increased neuronal activation in critical brain areas should also be detectable at low-level sensory cortical areas. These low-level cortical areas, being part of a hierarchically organized generative model realized in the human brain, receive predictions from higher-order cortical areas, which are associated with linguistic processing proper, via a top-down cascade spanning multiple levels. This is perfectly in line with the neuro-functional structure suggested by the prediction error minimization framwork and the mutual interaction of multiple levels and the ongoing, dynamic propagation of top-down predictions and bottom-up prediction error. This is in line with Farmer's et al. (2013, 212) claim that "[l]inguistic context is used to generate expectations about form-based properties of upcoming words, and these expectations are propagated to perceptual cortices […]." Certainly, this is a result of a system's ongoing exposure to compositional, syntactically structured sentences, which ideally leads to ever more accurate estimations of probability distributions feeding into predictions about sensory input indicating linguistic causes. At the same time, these estimations and the resulting predictions are context-sensitive and render successful, flexible, and efficient sentence processing possible.

6.5. SENTENCE PROCESSING AND ENCULTURATED PREDICTIVE PROCESSING

As we have just seen, there is much evidence available that directly speaks to the question how sentence processing is realized in the human brain. This evidence supports the idea that sentence processing is a matter of prediction error minimization. In this case, prediction error minimization concerns several linguistic dimensions. These dimensions include syntactic, semantic, and phonological properties that constrain the ways in which well-formed sentences can occur. The degree of familiarity of a certain kind of syntactic structure conveyed by visually presented input directly influences the accuracy of the associated sub-personally computed predictions on multiple time scales. We have seen that this observation is supported by research using syntactic priming paradigms. However, it is conceivable that this effect extends beyond these highly experimentally constrained settings and is a pervasive feature of sentence processing more generally. Understood as a vital aspect of the entire reading process, sentence processing is part of this cognitive practice and requires the human organism to have achieved a sufficient degree of expertise in the fluent and dynamic interaction with tokens of an (alphabetic) writing system. This also means to have a great amount of (implicit) knowledge about the relational properties of language. It is this knowledge that informs the predictions that are neuronally realized in the brain of an enculturated human organism. This kind of sentence processing is coalesced with the visual word recognition processing regime discussed in the last chapter. Understood like this, the neuronal realization of reading amounts to the seamless integration of visual word recognition and sentence processing routines in the enculturated, expert, non-pathological reader. On this construal, the success and efficiency of EPP-style sentence processing is congruent with the full-fledged comprehension of the meaning (i.e., the set of semantic properties) conveyed by syntactic structures.

The associated complex neuronal procedures require the fine-tuned interplay of many cortical areas that realize the predictive processing hierarchy associated with fluent and dynamic sentence processing. As we have seen in the previous sections, there is now much empirical evidence available that speaks in favour of this account. Importantly, the EPP framework is able to unify these different and disparate strands of research for the first time. It achieves this by accounting for several experimentally observed features of sentence processing while describing them parsimoniously in terms of predictive processing routines performed by enculturated human organisms.

6.6. CONCLUDING REMARKS

In this chapter, I have dealt with sentence processing in reading. Extending and supplementing assumptions I have made in the previous chapter on visual word recognition, I have argued that many complementary, yet to date rather unrelated empirical findings can be unified by describing sentence processing in terms of EPP. By reviewing and discussing many studies on syntactic priming, ambiguity resolution, syntactic complexity effects, and top-down influences on lower-level cortical responses, I have suggested that these diverse effects associated with successful, efficient, and dynamic sentence processing are best captured by interpreting them from the perspective of EPP. If this approach is on the right track, sentence processing will avail itself as a highly complex, ongoing realization of prediction error minimization. This complex cognitive procedure is rendered possible by the enculturation of human organisms in their linguistically structured cognitive niche.

However, so far my considerations seem to suggest that both visual single-word recognition and sentence processing are an internal, exclusively neuronally realized affair. But such a conclusion would be premature, if not completely mistaken. For reading is constituted by both neuronal and bodily sub-processes which mutually influence each other over time. To show that this actually is the case, the next chapter will be dedicated to the indispensable functional role of eye movements in reading.

7. EYE MOVEMENTS IN READING

7.1. INTRODUCTION

In chapter 4, I have outlined the EPP approach. I have argued that this theory integration gives rise to a highly promising perspective on the neuronal and bodily sub-processes constituting reading. In particular, the emphasis on bodily components in terms of bodily manipulation and active inference is of vital importance for a complete account of reading. In this chapter, I will argue that eye movements play an indispensable functional role in reading. The epistemic goal of this chapter is to present empirical results from investigations of eye movements in reading and to interpret them from the perspective of EPP. It will turn out that pervasive effects associated with specific eye movement patterns in close interaction with lexical processing routines can be fruitfully interpreted in terms of bodily manipulation, the minimization of prediction error, and the optimization of precision estimations through active inference. In the first part of this chapter, I will present the basic properties of eye movements in reading and their close connection to the allocation of attention. Second, I will elaborate on the EPP account of bodily manipulation and active inference by conceptually relating it to eye movements. Third, I will present major effects of eye movements in reading elucidated by empirical research. I will interpret these effects in terms of bodily manipulation and active inference.

7.2. BASIC PROPERTIES OF EYE MOVEMENTS IN READING

When we process tokens of a writing system, our eyes constantly move. This is because the acuity of the retina (and hence of the visual field) is limited. Eye movements bring the visual stimuli into a position relative to the retina where they can be processed in an optimal fashion (cf. Dehaene 2010, 13; Rayner 1998, 374; Rayner et al. 2007, 85). The visual field is subdivided into "the foveal region (2 degrees in the centre of vision), the parafoveal region (extending from the foveal region to about 5 degrees on either side of fixation), and the peripheral region (everything beyond the parafoveal region)" (Rayner 2009, 1459). Crucially, acuity is best in the fovea, decreases significantly in the parafovea and is almost lacking in the peripheral region (cf. ibid.). It follows that "[…] the purpose of eye movements in reading is to place the to-be-processed text in the fovea, where it can be most easily identified" (Rayner et al. 2007, 85; see also Rayner 1998, 374; Rayner 2009, 1459; Rayner et al. 2001, 46; Reichle & Reingold 2013, 1).[95] This is achieved by alternations of saccades and fixations. Saccades are oculo-motor activities (eye movements in the proper sense) and last for 20 to 40 ms on average (cf. Rayner et al. 2001, 46; Rayner et al. 2007, 80). The saccadic latency, i.e., the time it takes to initiate and execute a saccade, amounts to approximately 175 to 200 ms in expert readers (Rayner 2009, 1458f). During saccades, which usually span seven to nine letter spaces (cf. Rayner 1998, 375), "vision is suppressed" whereas "cognitive processing does continue" (Rayner 2009, 1458). In contrast, during fixations, which take 200 to 250 ms on average (cf. Choi et al. 2014, 1; Rayner 1998, 375; Rayner et al. 2001, 46; Reichle & Reingold 2013, 1),[96] "new information is acquired from the visual array" (Rayner 2009, 1458). Importantly, the unit of analysis in all cases is the word. This results from the implicit background assumption that in normal cases, eye movements are not directed at letters or bigrams, but at words as a whole. Depending on the visual and lexical properties of the word to be processed, it is either fixated only once or refixated. As we shall see, the duration und number of fixations per word varies as a function of the visual and lexical features of the words to be processed. If a fixated word has not been successfully processed in first passing, a regression, i.e., a backward saccade, is initiated. Regressions vary in length depending on processing difficulty and "occur about 10-15% of the time in skilled readers" (Rayner 2009, 1460).[97] In alphabetic writing systems such as English, at the end of each line of the text the eyes have to move to the leftward side of the line below. These movements are called return sweeps (cf. Findlay & Gilchrist 2003, 84f; Rayner 2009, 1460).

Eye movements are initiated and executed on the basis of sub-personally computed 'decisions' on their timing ('when') and location ('where'; cf. Rayner & Reingold 2015, 107). Importantly, "there is typically no correlation between how long the eyes remain fixated and how far they move" (Rayner 2009, 1468). The saccadic span, that is, the distance between the current fixation and the landing position of the next

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[95] However, as we will see in the course of this chapter, parafoveal vision does influence the processing routines associated with reading.

[96] Similar estimations of the duration of saccades and fixations and of the average span of saccades are presented by Findlay & Gilchrist (2003, 85); Gilchrist et al. (1997, 130); Quercia et al. (2013, 871); Rayner (2009, 1460); and Rayner et al. (2006, 242). These approximated data refer to the processing of tokens of alphabetic writing systems such as those employed for English, French, German, and Dutch.

[97] See also Rayner (1998, 375); Rayner et al. (2001, 46); Rayner et al. (2006, 352); and Rayner et al. (2007, 80).

fixation, “is strongly influenced by low-level cues provided by word length and space information” (ibid., 1469). In contrast, the timing of saccades is dependent on “lexical properties of the [currently] fixated word (ibid.).[98] This computational distinction is associated with a neuronal distinction. The ‘when’ decision is assumed to be correlated with visual processing located in the ventral pathway, while the ‘where’ decision is assumed to be correlated with neuronal activities in the dorsal pathway (cf. Heinzle et al. 2010, 820; see also Engbert et al. 2005, 781).

Before moving on to a more in-depth discussion of the constitutive role that eye movements are assumed to play in reading, it is reasonable to briefly mention the commonalities and differences of eye movements in reading and other visual processing tasks. In visual search, for example, the saccadic span tends to be wider than in reading (cf. Rayner 2009, 1482). Furthermore, fixations are considered to be of a longer duration in comparison to reading (cf. Rayner 1998, 397). This might be due to the fact that the spatial array for the completion of a certain visual search task is usually not as restricted as in the case of reading, where the properties of the representational media, such as a page in a book or a computer screen, prescribe a rather dense spatial array. Similarly, in scene perception “[f]ixation durations […] tend to be longer than those in reading, and saccade size tends to be larger” (Rayner 2009, 1476). Obviously, eye movements in reading, visual search, and scene perception share the basic principles of an ongoing alternation between saccades and fixations.[99] In all three cases, “how much information is processed on any fixation […] varies as a function of the task” (ibid., 1485). Furthermore, eye movement patterns are partly determined by the complexity of the visual array and the purpose for which visual processing routines are performed (cf. ibid.). This should suffice to establish that eye movements in reading have specific properties and show certain effects to be discussed later in this chapter that differentiate them from eye movements contributing to other types of cognitive processing routines.

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[98] The same distinction is also made by Pollatsek et al. (2006, 8); Rayner and Raney (1996, 246); Rayner and Well (1996, 507); and Rayner et al. (2007, 89).

[99] For a more extensive comparison, see Rayner (1998, 396-404). Importantly, the similarities of eye movements across tasks might be partly explained in terms of the *neural reuse* (cf. Anderson 2010, 2015; Dehaene 2010) of cortical structures underlying the initiation of oculomotor activities. This is suggested by Heinzle et al. (2010, 818) who argue that the ‘recycling’ of the frontal eye field, which contributes to the initiation of saccadic eye movements, might be one crucial factor in allowing the visual system to execute phylogenetically recent, culturally determined eye movements targeted at tokens of an (alphabetic) writing system.

7.3. EYE MOVEMENTS IN READING AND THE DIRECTION OF ATTENTION

Fixations are tightly associated with the direction of attention, such that “in complex information processing tasks such as reading, the link between the two is probably quite tight” (Rayner 1998, 375). Over the past years, several computational models of eye movements in reading have been proposed.[100] The outstanding difference between the two most influential models, the E-Z Reader model (Pollatsek et al. 2006; Reichle et al. 2013) and the SWIFT model (Engbert et al. 2005), concerns the assumptions they make on the allocation of attention. The proponents of E-Z Reader assume that attention is allocated in a serial fashion (Pollatsek et al. 2006, 39), thereby emphasizing its tight connection with eye movements. In contrast, SWIFT is based on “a parallel mechanism of attention during reading” (Pollatsek et al. 2006, 778), according to which “all words are processed in parallel because of the assumption of a processing gradient” (ibid., 798). To date, both models seem to be equally qualified to simulate human eye movement behaviour in reading and to generate novel predictions for empirical research. Therefore, additional comparisons of empirical data with computational simulations are needed in order to decide whether attention is allocated strictly serially, in parallel, or both, where the latter possibility might depend on specific processing demands. For conceptual reasons to be presented in the course of this chapter and in line with E-Z Reader, I shall assume that fixations are connected with the allocation of attention in a rather serial fashion. This assumption is also supported by Heinzle’s et al. (2010) cortical model of eye movements in reading. It puts the neuronal function of the frontal eye field (FEF), which is part of the dorsal pathway, centre stage and is based on converging results from empirical research demonstrating that “[t]he FEF is the key area for the cortical control of saccadic eye movements and attentional signals” (Heinzle et al. 2010, 809). This model successfully simulates the neuronal mechanism that presumably generates eye movements, implements certain effects that have been established in behavioural research over the past few decades, and does justice to the functional role of neuronal components in the generation and execution of eye movements. Therefore, if we assume that there exists a co-occurrence of saccadic movements and attention due to the same underlying neuronal mechanism, it follows that attention is directed serially, simply because eye movements are by necessity serially ordered. Thus, this model lends additional support to the idea that fixations as a result of saccadic movements are tightly associated with the serial

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[100] For a concise review, see Rayner and Reichle (2010, 793f).

allocation of attention. After having presented the main properties of eye movements in reading and how they presumably relate to attention, I will now turn to the interpretation of their function from the perspective of EPP.

7.4. EYE MOVEMENTS IN READING, BODILY MANIPULATION, AND ACTIVE INFERENCE

In chapter 2, I have presented the theory of CI and its associated notion of a cognitive practice. Reading, or so I have argued, is a paradigm case of cognitive practices, such that instances of reading can be defined as the "culturally endowed bodily manipulations of informational structures" (Menary 2012, 150). In the case of reading, eye movements fulfil the functional role of bodily manipulation, thereby partly constituting the entire cognitive process.[101] This assumption can be significantly enriched by describing bodily manipulation in terms of active inference. Recall from earlier chapters that the PP framework proposes that prediction error is minimized by the system's ongoing engagement in both perceptual and active inference. Active inference helps minimize prediction error by initiating bodily movements that bring about the verification of a certain prediction. Eye movements are just a special case of active inference (cf. Friston et al., 2012).[102] This is suggested by Hohwy (2013, 166), who argues that "[s]accades are moments in active inference, which then occur very frequently and at very fast time scales […]. This would lead to very rapid and automatic switching between updating hypotheses and selectively sampling the world to test those hypotheses."[103] Similarly, Clark

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[101] Of course, it is likely to be the case that other types of bodily manipulation are involved in reading, such as slight head movements or adjustments of representational media achieved by hand movements. However, to my knowledge there is no empirical research that has tested this rather intuitive assumption, so that I exclusively focus on eye movements in this chapter.

[102] More generally, Friston et al. (2012, 9) suggest that "[s]accadic eye movements are a useful vehicle to illustrate active inference about salient features of the world because they speak directly to visual search strategies and a wealth of psychophysical, neurobiological, and theoretical study […]." At the same time, however, the reverse descriptive and explanatory strategy is reasonable as well: By reframing both results and desiderata from research on eye movements in reading and (other visual processing tasks) in terms of PP, new insights into the mechanism presumably underlying the initiation and execution of eye movements in reading can be achieved and, ideally, new empirically testable predictions can be generated.

[103] In this vein, Hohwy (2013, 80f; my emphasis) also points out that "[c]onditional on the evidence attained in action (for example, *as one's eyes move around*) a given hypothesis can increase its posterior probability. Through action, already selected hypotheses can be made much more reliable in the sense that they minimize prediction error very efficiently." In addition, Clark (2016, 184) describes the alternation between perceptual inference (visual perception) and active inference (oculo-motor activities in terms of saccades and fixations)

(2016, 70) argues that "[…] a sequence of saccades to locations expected to deliver high-precision information of the kind predicted by some specific perceptual hypothesis (and not predicted by nearby rivals) provides excellent evidence that the hypothesis is correct […]."[104] Thus, eye movements can be described by assuming that they are an instance of first-order statistics in terms of active inference working in tandem with perceptual inference. However, eye movements also play an important role in second-order statistics, as already implied by Clark. This is because active inference helps minimize prediction error by rendering sensory input more precise (more certain and reliable), thereby increasing the neuronal influence (the synaptic gain) of certain error units within the processing hierarchy. This direct link between eye movements and optimization of precision expectations is also suggested by Clark (2016, 82):[105] "The generative model, by including estimates of current precisions and of the precisions that would result from visual saccades and other actions, directly entrains swathes of information-gathering behaviours." It follows that eye movements in general, and in reading in particular, play a double role in minimizing prediction error. First, they directly contribute to sampling the visual array in such a way that predictions can be directly tested against sensory evidence. Second, the precision of prediction error signals (i.e., the synaptic gain on the associated error units) resulting from these oculo-motor activities are increased. This is just another way of expressing the functional role of attention on the construal of the prediction error minimization framework. Recall that the allocation of attention is equal to the "optimization of precision expectations in hierarchical predictive coding" (Hohwy 2013, 70).

Considering eye movements, this means that active inferences will be targeted at a certain location if there is a high likelihood that this location will provide precise information that will help minimize prediction error, based on prior predictions. This fits neatly with the approach to eye movements in reading and the allocation of attention presented in the previous section. In the light of the prediction error

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as follows: "Visual perception is […] constantly conditioned by visuomotor action, and visuomotor action is constantly conditioned by visual perception."

[104] This means that, in the long run, "[…] the only hypothesis that can endure over successive saccades is the one that correctly predicts the salient features that are sampled" (Friston et al. 2012, 16).

[105] Although tokens of a writing system are generally rendered to result in more precise sensory input in comparison to other sources (a natural scene, for example), there is still some variability that needs to be taken into account. Just consider how the quality of print or the distribution of pixels on a computer screen can influence the ease or difficulty of visual processing.

minimization framework, the close relationship between eye movement patterns and the allocation of attention turns out to be a matter of precision estimation by actively inferring causes of visual effects. That is to say that the alternation between saccades and fixations can be described in terms of serially directed attention to locations that promise to provide precise information, which in turn verify (or alter) the currently highest weighted prediction, thereby minimizing prediction error.

In sum, I argue that the notion of bodily manipulation can be enriched by assuming that active inference can be treated as its mechanistic underpinning. Furthermore, it has turned out that existing approaches to the link between eye movements in reading and the direction of attention can be theoretically framed by relating them to assumptions provided by the prediction error minimization framework. In what follows, I will apply these theoretical insights to the interpretation of empirically established effects associated with specific eye movement patterns in reading.[106]

7.5. EYE MOVEMENT EFFECTS IN READING

Friston et al. (2012, 18) state with regard to research on eye movements in reading that “[h]uge amounts of data are available (including corpus studies) and [that] it would be interesting to see how the current framework could explain robust effects in reading.”[107] This is the purpose of this section. In addition, it will serve to provide direct empirical support for the assumption that eye movements in terms of bodily manipulation and active inference play an indispensable functional role in reading.

Before discussing specific effects that are established in empirical research on eye movements in reading,[108] I will point to certain parameters that give rise to the

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[106] This is perfectly in line with Findlay and Gilchrist’s (2003, 101) conjecture that “[i]t might be profitable to think of the system [responsible for the visual processing of linguistic input] as a hierarchy, recognising that low-level factors and high-level factors are involved. Demonstration of the influence of a high level variable need not imply that low-level factors are not important and vice versa.” This interdependence of high- and low-level factors can be expressed by assuming that they are realized in a prediction error minimizing, hierarchically organized generative model.

[107] A first step in this direction has been taken by Levy et al. (2009). Relying on a probabilistic model of Bayesian inference, they argue that “[…] key elements of language comprehension can be viewed as instances of rational behavior through probabilistic inference: perceptual input obtained from eye movements is recruited jointly with grammatical knowledge to produce evidential inferences about linguistic form and structure, which in turn play a role in guiding subsequent eye movements” (Levy et al. 2009, 21089).

[108] Earlier research has relied on the implicit background assumption that eye movements are binocularly coordinated, such that the landing and launch positions as well as the coordination in time are approximately the same for both eyes (cf. Rayner 2009, 1462). However, recent studies indicate that this is unlikely to be the case. For example, a study conducted by Blythe et al. (2006, 3905), which compares binocular eye movement patterns

empirical detection of these very effects. First, consider measurements of *fixation duration*. Depending on the design and the purpose of a certain eye-tracking study, single fixation duration, first fixation duration, gaze duration, and total fixation duration are likely to be analyzed. First fixation duration concerns the duration of the first fixation that a certain target word receives, independent of how many times this word is fixated in total. If the target word receives one and only one fixation, this will be reported by the single fixation duration. Gaze duration reports the total fixation duration with respect to a target word, whereby this value does not include refixations as a result of regressions. In contrast, total fixation duration reports the overall time spent on fixating a certain target word, and this value does include the time spent on refixating a word after a regression has been executed (cf. Juhasz & Rayner 2003, 1313; Rayner & Well 1996, 505).

Second, consider estimates of *word skipping*. Word skipping occurs when a certain target word is not directly fixated, yet cognitively processed (cf. Rayner 2009, 1471; Rayner et al. 2001, 46). In fact, "[…] many words are skipped so that foveal processing of each word is not necessary" (Rayner 1998, 375). The sub-personally computed 'decision' to skip a word is directly influenced by the result of neuronally realized lexical processing routines. Furthermore, the properties of the words themselves constrain the likelihood with which a word is assumed to be skipped. On average, "[…] content words are fixated about 85% of the time, while function words are fixated about 35% of the time" (Rayner 2009, 1461; see also Rayner 1998, 375). As we will see, word skipping is an important parameter of visual word processing routines.

Third, word skipping is directly linked to advantages stemming from *parafoveal preview*. This notion refers to the phenomenon that "[…] the word to the right of fixation (i.e., the parafoveal word) is completely identified prior to its fixation. In most cases when this occurs, the parafoveal word is skipped" (Rayner et al. 2007, 87; see also Rayner 1998, 381; Rayner et al. 2011, 514). However, if a word is not skipped as a result of parafoveal pre-processing, the so-called *parafoveal preview benefit* applies: "A preview of the word to the right [of the current fixation] reduces fixation

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in children and adults provides evidence that "[…] during reading, the positions of the two eyes are more than one character apart, and the eyes are aligned to within one character space on a numerical minority of fixations." However, the authors conclude "[…] that the visual system can, under normal circumstances at least, tolerate a certain amount of disparity between two differing patterns of retinal stimulation during reading" (ibid.)." Furthermore, the authors do not find any correlation between mismatched binocular coordination and the word frequency effect (cf. ibid., 3907), so that this finding does not seem to have a major impact on overall visuo-lexical processing patterns.

duration on this word when the eyes move there with the next saccade" (Kliegl & Engbert 2005, 133).[109] In these cases, the benefit of a valid parafoveal preview amounts to a reduction of overall processing time "of the order of 30-50 ms" per parafoveally previewed word (Rayner 2009, 1466).[110]

The stable effects numerously reported by eye-tracking studies are highly correlated with each other (cf. Juhasz & Rayner 2003, 1312). For the ease of exposition, however, I will try to disentangle them as much as possible. Generally, the background assumption of all research dedicated to eye movements in reading is that "lexical variables" have a major impact on specific eye movement patterns (cf. Rayner et al. 2006a, 243; Rayner et al. 2007, 89). In addition, "visuomotor variables" are also assumed to have a significant influence on eye movement patterns and these variables "[…] refer to the visual characteristics of the text and to limitations in the planning and execution of eye movements" (Drieghe et al. 2004, 80). It is reasonable to distinguish effects that primarily concern the word-level from those that are more important at the level of the processing of entire sentences or even larger units (cf. ibid., 81). In what follows, I will first discuss a pervasive effect occurring at the word level, namely the *word frequency effect*. Second, I will discuss the *predictability effect*, which is an often replicated effect relevant at the level of sentence processing.

7.5.1. THE WORD FREQUENCY EFFECT

First, consider the *word frequency effect*. This notion refers to the phenomenon "that the frequency of a fixated word influences how long readers look at the word" (Rayner 1998, 376). Generally, it is an often replicated result "[…] that readers look longer (first fixation, gaze, and single fixation duration) at low-frequency words than at high-frequency words […]" (ibid., 387f).[111] This is also indicated by the overall processing times (cf. Juhasz & Rayner 2003, 1312). In addition, the more frequent a word is, the more likely it is to be skipped (cf. Drieghe et al. 2004, 81).[112] For

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[109] See also Drieghe et al. (2004, 80); Rayner (1998, 374); Rayner et al. (2007, 87); and Rayner et al. (2011, 514).

[110] A potential problem stemming from the parafoveal preview effect is that it remains unclear how this phenomenon is related to the allocation of attention. More research is certainly needed to investigate this relationship.

[111] See also Ashby et al. (2005, 1066); Juhasz and Rayner (2006, 847); McDonald & Shillcock (2003, 648); and Rayner and Raney (1996, 246).

[112] See also Rayner (1998, 387), Rayner (2009, 1471) and Rayner et al. (2011, 515).

instance, in a study using 144 German sentences from the Potsdam Sentence Corpus, Kliegl et al. (2004) investigate the frequency effect next to other effects to be discussed in the next sub-section. Two groups of participants, young and older adults, are asked to read these sentences matched for high- and low-frequency, word class, and word length (cf. Kliegl et al. 2004, 267f). The results, irrespective of age group, indicate that "[w]ord skipping […] increased with frequency" (ibid., 271f); furthermore, all measures of fixation duration mentioned above "decreased with frequency" (ibid., 272).

Similarly, Rayner and Raney (1996) report a study in which the frequency effect in reading is compared to its occurrence in a task dedicated to the search for specific target words. In both cases, the materials are short narrative texts; "[…] half of the passages contained an HF [high-frequency] target word and half contained an LF [low-frequency] target word for any given subject" (Rayner & Raney 1996, 246). The results significantly demonstrate that "[…] in the reading condition subjects were more likely to skip the HF target word than to skip the LF target word; they fixated on the HF words 83% of the time and on the LF words 89% of the time ($t(15) = 2.17$, $p < .05$)" (ibid., 247). A similar effect could not be observed for the visual search condition. Considering fixation durations in the reading condition, it turns out that the average first fixation duration for high-frequency words is shorter than for low-frequency words (248 milliseconds vs. 273 milliseconds) and that the average gaze duration for high-frequency words is also remarkably shorter than for low-frequency words (272 milliseconds vs. 325 milliseconds) (ibid., table 1). In comparison, in the visual search task no significant differences in either first fixation duration or gaze duration could be found.

A summary of these studies should suffice to show that word frequency has a significant effect on fixation duration, fixation location, and skipping probabilities. However, it is also important to mention at least one important variable whose effect on eye movement patterns is usually correlated with word frequency, namely word length (cf. Drieghe et al. 2004, 81; Juhasz & Rayner 2003, 1313). This is considered to be the case because "[…] high-frequency, familiar (i.e., easy) words tend to be shorter than low-frequency, unfamiliar words" (ibid.). In addition, empirical studies suggest that both fixation duration and the likelihood with which a word will not be skipped "[…] increase with word length and decrease with word frequency" (Kliegl et al. 2004, 263).[113]

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[113] For empirical results demonstrating this mutual influence of word length and word frequency on skipping, see Kliegl & Engbert (2005). Beside word length, there are other

The word frequency effect is theoretically interesting because it directly speaks to the EPP approach and its emphasis on the importance of bodily manipulation and active inference for a coherent description of reading. This effect is direct empirical evidence for the idea that it is the coordination of bodily and neuronal sub-processes that gives rise to the cognitive practice under scrutiny here. It is in line with the hybrid mind thesis and the manipulation thesis. This is because the neuronal processes associated with the estimation of the frequency of a given word directly influence eye movement patterns. Vice versa, it is the generation and execution of eye movements that directly influence neuronal processing routines. This interpretation can be spelled out in more detail by referring to active inference. The word frequency effect can be approached by assuming that word frequency is associated with predictability. On this construal, high-frequency words are associated with accurate predictions based on previous learning trajectories. This decreases the need for the effortful testing of these predictions through active sampling of the visual stimulus array. This would result in shorter fixation durations and higher word skipping probabilities. In contrast, low-frequency words are possibly associated with comparatively inaccurate predictions, which increase the necessity to carefully test the most likely prediction against sensory evidence. This results in longer fixation durations and lower skipping probabilities for low-frequency words. Furthermore, low-frequency words can be assumed to provide very precise ('newsworthy') visual information, so that they lead to an increase of the allocation of attention (indicated again by fixation duration and fixation location). As a result, it seems reasonable to suppose that the word frequency effect is an important demonstration of the close coordination of bodily and neuronal components that give rise to the cognitive practice of reading. This can be fully appreciated by interpreting empirical results from the EPP perspective.

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variables that are also considered to co-vary with word frequency, such as subjective *word familiarity* and the *age of acquisition* of certain target words (cf. Juhasz & Rayner 2003). In particular, it is suggested that both word familiarity and age of acquisition (both being estimated by subjective ratings) certainly contribute to overall word frequency as stated by statistical corpus analyses. However, it is likely that these variables also independently contribute to observable effects (cf. ibid., 1316f). It is an open question for further empirical research and computational modeling to investigate the relationship between these factors in greater detail.

7.5.2. THE PREDICTABILITY EFFECT

At the level of sentence processing, the *predictability effect* is a phenomenon that has been empirically established and multiply replicated in research on eye movements. This effect basically refers to the phenomenon that “words that are predictable from prior context are read more quickly and are less likely to be directly fixated than are unpredictable words” (Ashby et al. 2005, 1066; see also White et al. 2005, 466). When the relationship of contextual predictability and word skipping probability is considered, it turns out that “[w]ords that are highly predictable from the preceding context are skipped more often than words that are not constrained […]” (Drieghe et al. 2004, 81; see also Rayner 2009, 1471; Rayner et al. 2011, 514). The influences of contextual predictability on both fixation durations and word skipping probabilities has been established by several empirical studies, two of which I will summarize briefly.

First, in the study by Kliegl et al. (2004) already mentioned, the effect of contextual predictability is also tested. The results indicate that “[…] predictability increased word skipping and decreased the associated multiple-fixation probability for corpus and target words” (Kliegl et al. 2004, 276). The higher the predictability of a word is, the lower is the probability that this word will be fixated several times in first-pass reading or as a result of a regression. However, “[…] first pass reading effects of predictability were observed only for single-fixation and gaze durations of target words” (ibid., 277). Considering second-pass reading probabilities in the context of predictability, it turns out that total reading time is more significantly influenced by predictability probabilities than gaze duration (cf. ibid). The explanation for this is straightforward: “These results are consistent with the expectation that low-predictable words were a primary target of regressive movements because differences between gaze duration and total reading time reflect the time spent in refixations” (ibid.).

Second, Rayner et al. (2011) report a study in which they investigate the effect of contextual predictability on fixation duration and skipping probability. The materials, consisting of pairs of sentences, are matched for word length and have been tested in a norming study, which additionally established the statistically determined cloze probabilities of predictability (cf. Rayner et al. 2011, 517f). The second sentence of each pair contains a target word that is either high or low in predictability.[114] The

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[114] Here are examples of sentences for the high- and low-predictability conditions:

results indicate "[…] that word predictability had a strong effect on both skipping and fixation time on target words independent of the length of the target word" (ibid., 522). In particular, "[…] readers looked at low-predictable words longer than high-predictable words" (ibid., 521). This effect was significant for first fixation duration (+ 11 ms), single fixation duration (+13 ms), gaze duration (+18 ms), and total reading time (+33 ms) (cf. ibid.). Considering skipping probabilities, it turns out that these are significantly influenced by the contextual probabilities of the target words (cf. ibid.). In summary, both studies suggest that the predictability effect is a pervasive phenomenon characterizing eye movements in sentence processing. Furthermore, they indicate that the predictability of target words embedded in a constraining context directly influences both fixation durations and skipping probabilities.[115]

The interpretation of the predictability effect from the perspective of EPP is straightforward. As in the case of the word frequency effect, it provides direct empirical evidence for the crucial interplay of bodily components (in terms of bodily manipulation) and neuronal components. On the one hand, the execution of eye movements directly influences neuronal sub-processes by making available new sensory information. On the other hand, neuronal sub-processes (in terms of neuronally realized predictions of upcoming words) constrain the generation and execution of eye movements (in terms of bodily manipulation). This interpretation can be made more concrete, once again, by relying on the EPP framework.[116] At the level of sentence processing, the system is supposed to generate predictions of upcoming words. An increase of the accuracy of the selected prediction leads to a decrease of overall influence of active inference on the minimization of prediction error. This makes sense, since linguistic context can be supposed to constrain the selection of good predictions concerning the visual evidence for a certain word. In contrast, the more unlikely it is that the selected prediction will be verified, the more

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"Example 1. Gary had become a compulsive liar. He just couldn't seem to tell the *truth* about anything. (Predictable target)
Example 2. Gary had some mental health issues. He just couldn't seem to tell the *truth* about anything. (Unpredictable target)" (Rayner et al. 2011, 518; italics in original).

[115] For similar results, see Rayner and White (1996) and White et al. (2005).

[116] McDonald and Shillcock (2003) interpret the strong influence of contextual predictability by emphasizing the crucial functional role of concurrently generated predictions. Although they do not directly refer to Bayesian probabilistic models implemented in the human brain or to PP, their position is perfectly compatible with the line of reasoning presented here: "We suggest that the remarkable efficiency of reading is due, at least in part, to the on-line formation of predictions about upcoming words. The statistical properties of the linguistic environment offer a viable source for these predictions" (McDonald & Shillcock 2003, 651).

important it is for the system to engage in active inference. Active inference allows to sample the visual array in such a way that the resulting prediction error can propagate up the hierarchy so as to modify or replace the selected prediction. On this construal, fixation durations on unpredicted target words would report the intensity of precision optimization in terms of attention allocation, since the unpredictability of visually available linguistic input makes it necessary for the system to increase the precision (the synaptic gain) on specific error units. That is to say that the certainty in specific predictions, the selection of the saccadic target location, and the fixation duration on these targets mutually constrain and influence each other. This in turn depends on the visual evidence of the underlying linguistic causes. This should suffice to illustrate that the delicate interplay of neuronal and bodily sub-processes is easily accounted for by EPP.

7.6. EYE MOVEMENTS IN READING AND ENCULTURATED PREDICTIVE PROCESSING

The last section has indicated that two of the most pervasive eye movement effects in reading, the word frequency effect and the predictability effect, can be easily accounted for from the perspective of EPP. More generally, the idea that eye movements can be described in terms of bodily manipulation and active inference finds additional support in recent empirically inspired approaches. If the PP interpretation of eye movements is on the right track, oculo-motor activities and neuronal processing routines closely work together in their mutual attempt to minimize prediction error. This is in line with Rayner and Reingold's (2015) *direct cognitive-control hypothesis*. The idea is "that lexical and linguistic processing of the fixated word produces an immediate fixation-by-fixation adjustment of the timing of the saccade which terminates the fixation" (Rayner & Reingold 2015, 107). This hypothesis is supported by neuroimaging and eye-tracking studies that are interested in the time course of neuronal activation patterns associated with visual word recognition and sentence processing and in the timing of saccades. For example, Reichle and Reingold (2013) interpret their results of a meta-analysis of the time course of the retina-brain lag, visual encoding, and lexical processing in favour of the direct cognitive control hypothesis. By taking parafoveal preview into account, they argue "that lexical processing is sufficiently rapid to permit direct control of the decisions when to move the eyes during reading, but that such control also requires a substantial amount of lexical processing from the parafovea"

(Reichle & Reingold 2013, 5). This can serve as evidence for the idea that high-level predictions cause the initiation and execution of eye movements understood in terms of active inference. In this case, the predictions associated with the lexical properties of the visually presented linguistic input induce the alteration of this very sensory input. This also depends on the precision to be expected from the sensory input that will have become available as a result of active inference. Thus, the plausibility of the direct cognitive control hypothesis lends further support to the idea that it is the close interaction of perceptual and active inference and the hybridity of certain cognitive processes that bring about the entire reading process.[117] This idea shares the general approach to reading with Quercia's et al. (2013, 869) remark that two seemingly distinct processing stages involved in reading are actually interdependent and influence each other over time:

> The first corresponds to the different steps involved in the ocular capture of the word's image, which is the start of cerebral analysis in the occipital cortex. The second represents the different cognitive phenomena that permit the identification of and then represent and make sense of the word just read. The constant interdependence between these phenomena, notably during the oculomotor phase of reading, makes this separation artificial.

Hence, if the close interaction of eye movements and neuronal sub-processes gives rise to reading, it is reasonable to provide an account that does justice to this fact. This is exactly the concern of the EPP approach to reading.

I have suggested in the last chapter that many successful attempts to interact with cohesive and coherent linguistic structures represented by tokens of a writing system automatically give rise to the comprehension of the semantic properties represented by these structures. If this suggestion is on the right track, there is no need to postulate a mysterious meaning-generating process that is additive to more basic, lower-level processing stages. Rather, comprehension is the natural result of the flexible and dynamic alternation of perceptual and active inference and the system's ongoing attempt to optimize its precision estimations. In this sense, it is reasonable to argue that "[m]eaning is a physical phenomenon that, for example, is

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[117] In this context, there appears to be an interesting resemblance of the EPP approach to reading and Popper's (1977, 45) speculations about the action-orientedness and hypothesis-involving character of visual perception: "However, the neurophysiology of the eye and that of the brain suggest that the process involved in physical vision is not a passive one, but consists in an active interpretation of coded inputs. It is in many ways like problem solving by way of hypotheses. (Even the inputs are already partially interpreted by the receiving sense organ, and our sense organs themselves may be likened to hypotheses or theories – theories about the structure of our environment, and bout the kind of information most needed and most useful to us.)"

transiently and episodically generated by an information-processing system tied into an active sensorimotor loop” (Metzinger 2003, 113). This loop, however, is tacitly and automatically constrained by the manipulative and interpretative norms that govern the ways in which literate members of a linguistic community meaningfully communicate with each other.

An implicit background assumption that has inspired many studies investigating eye movements in reading is that the distinctive eye movement patterns observed in these studies play an indispensable functional role in the entire reading process. This is in line with the hybrid mind thesis and the idea that both perceptual and active inference are necessary to engage in efficient and successful enculturated prediction error minimization. The crucial functional role of eye movements can be backed up by taking Gillchrist’s et al. (1997) case study into account. They report the case of an individual who is congenitally unable to perform any eye movements because of “extraocular muscular fibrosis resulting in ophthalmoplegia” (Gilchrist et al. 1997, 130). In order to overcome this deficit that would usually prevent her from reading, the individual performs head movements. The head movement patterns closely resemble eye movement patterns in non-pathological enculturated readers. This provides evidence for the necessity of *some* kind of bodily manipulation of cognitive resources in reading. Since the individual is unable to perform eye movements, this type of bodily manipulation is replaced by another compensatory strategy.

However, the congenital inability to perform eye movements is just one possibility of the impediment of genuine active inference in reading. Another possibility would be the existence of obstacles that concern the cognitive resource to be manipulated. This possibility is investigated by Schotter et al. (2014). In particular, they are interested in the question how the rapid serial visual presentation (RSVP) method affects the efficiency of the entire reading process. In RSVP, “[…] readers do not make eye movements (a natural part of reading), but rather, words are presented briefly one at a time, in the center of the screen, in sequential order” (Schotter et al. 2014, 1). This method has been recently employed for smartphone apps and is thus a consequence of the advent of new information-delivering technologies (cf. ibid.). The material employed in this study was comprised of ambiguous and unambiguous sentences presented in the RSVP fashion. Importantly, because of the sequential presentation of the stimuli, participants are precluded from the possibility to make regressions if these are required as a result of initially incomplete processing success. The main finding is that RSVP leads to a reduction of the success rate of sentence processing, which is approached in terms of a reduction of overall sentence comprehension: “[…] our data showing the relationship between regressions and reading comprehension are the most compelling evidence suggesting that reading without the ability to reread parts of the text, when necessary, decreases comprehension accuracy” (ibid., 8). Thus, if individuals are prevented from making a certain type of eye movements, i.e., regressions, their overall processing success significantly decreases. In terms of EPP, the interpretation of this study is that a limitation of possible types of bodily manipulation and active inference leads to a significant limitation of the success rate of the performance of this cognitive practice. This result shows that the delicate and dynamical interplay of neuronal and bodily components can go astray if one of the components is negatively affected. Furthermore, this study can also illustrate to what extent conceptual and empirical research can respond to recent technological advancements and possibly make suggestions for the future development of representational media.

There is also an important methodological consequence following from EPP. If it is correct to say that reading emerges from the interaction of eye movements and neuronal sub-processes in the spirit of the hybrid mind thesis and the manipulation thesis, then this should be taken into account in empirical investigations of reading and its constitutive sub-processes. Richlan et al. (2014) and Choi et al. (2014) have taken first steps into this direction. Both studies investigate the feasibility of combined fMRI and eye-tracking experiments in reading research. In particular, Richlan et al. (2014, 2655) “us[e] self-paced eye movements as markers for hemodynamic brain responses” in order to arrive at a more fine-grained measurement of brain activation associated with certain stages of sentence processing. In addition, Choi et al. (2014, 2) compared three conditions, namely normal, pseudoword, and consonant string-nonwords text reading in order to “[…] investigate the nature of the networks activated when participants read naturally via eye movements, compared to pseudo-reading controls.” This study suggests that the combination of fMRI and eye-tracking in the investigation of reading processes yields important data concerning the co-ordination of eye movements, their neuronal initiation, and the neuronal sub-processes pervasively associated with visual word recognition and sentence processing (cf. ibid., 10). Both studies are good news for the EPP approach. This is because they provide an idea how the fine-grained and dynamic interaction of neuronal and bodily components, or of perceptual and active inference in terms of PP, can be more directly investigated given the recent advancements of neuroimaging and eye-tracking technologies. It is this technological progress that ultimately allows the development of new methodologies in order to test hypotheses that previously were beyond reach of concise experimental investigation. For instance, the joint contribution of neuronal sub-processes (perceptual inference) and eye movements (active inference) in cases of syntactic ambiguity resolution could be directly investigated by employing a method combining fMRI and eye-tracking. In this case, the hypothesis would be that syntactically ambiguous words would be refixated at least once and that the neuronal activation pattern in critical brain regions such as the left vOT area would peak at the point in time between the first and the second fixation of the critical word. Call this the *ambiguity resolution hypothesis*. The reverse pattern would be expected to be observed with regard to the word frequency effect. In this case, the prediction would be that the frequency of a word is diametrically opposed to the likelihood of being fixated and of being associated with a pronounced neuronal activation of the left vOT area and other lower-level areas contributing to the elicitation of prediction error. Call this the *frequency effect hypothesis*. This hypothesized direct interplay of perceptual and active inference in reading can be hoped to be further investigated by future empirical research.

7.7. CONCLUDING REMARKS

This chapter has attempted to show that eye movements play an indispensable functional role for reading. They enable and constrain the processing of tokens of a writing system in multiple ways. This has been illustrated by referring to empirical results concerning the word frequency effect and the predictability effect. In addition, these effects strongly suggest that eye movements in turn are constrained by neuronal sub-processes having to do with lexical processes at the word and sentence level. This evidence for the crucial interplay of bodily and neuronal components lends direct support to the hybrid mind thesis and the manipulation thesis. Furthermore, it has turned out that the hybridity of reading can be analysed by assuming that prediction error minimization is the right kind of mechanism underlying the flexible and yet constrained coordination dynamics of neuronal and bodily processing routines. EPP provides the conceptual tools to interpret results from empirical research and assumptions derived from computational modelling in a new, conceptually coherent, and parsimonious way.

8. READING ACQUISITION

8.1. INTRODUCTION

In the last chapters, I have investigated the basic sub-processes of reading, namely visual word recognition, sentence processing, and eye movements. Supported by a great amount of empirical evidence, I have argued that each of these sub-processes can be best described in terms of EPP. So far I have only dealt with reading in adult expert readers, who have already acquired the competence to read fluently, automatically, and efficiently. However, a crucial question is how reading becomes possible in the first place, since it is unlikely that the human brain has evolved for this fairly recent culturally established cognitive practice (cf. Dehaene 2011, 20).[118]
The question that concerns us now is which neuronal and bodily changes need to occur in order to allow a child (or an adult) to become an expert reader. In this chapter, I will attempt to outline an answer to this question. Specifically, I will argue that learning to read is an instance of enculturation. That is, learning to read involves the transformation of cognitive capacities by altering the constituting neuronal and bodily components as a result of the close interaction with a certain (alphabetic) writing system. Furthermore, I will argue that this transformation can be best explained in terms of PP on a sub-personal level of description.

8.2. READING DEVELOPMENT AND THE ACQUISITION OF COGNITIVE NORMS

In chapter 2, I have reviewed Menary's theory of CI. As I have tried to establish in previous chapters, this theory is most suitable for a thorough description of the interaction between neuronal and bodily sub-components giving rise to reading. Furthermore, the conceptual framework provided by this theory helps account for the acquisition of culturally acquired, yet biologically determined cognitive skills such as reading. This is because CI emphasizes the transformation of cognitive functions as a result of the exposure to writing systems, next to other culturally established types of representation. Put differently, "[c]ognitive transformations occur when the development of the cognitive capacities of an individual are sculpted by the cognitive and social niche of that individual" (Menary 2010b, 572). This is exactly what the

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[118] Recall from chapter 5 that this is also referred to as the *reading paradox* (cf. Dehaene 2010, 4). For similar points, see also Brem et al. (2010, 7939); Ben-Shachar et al. (2011, 2387); Parviainen et al. (2006, 6052); and Heyes (2012, 2182).

notion of *enculturation* refers to: it is the process by which cognitive abilities are augmented as a result of acquiring expertise over a cognitive practice within a certain social-culturally shaped context. One crucial aspect of learning to perform a cognitive practice is the acquisition of the relevant cognitive norms, where this class of norms "govern[s] manipulations of external representations, which aim at completing cognitive tasks" (Menary 2010a, 238). In the case of reading, these norms concern the recognition and identification of tokens of a certain writing system. In alphabetic writing systems, important cognitive norms are derived from the so-called *alphabetic principle*, where this principle amounts to the "mapping [of] written units onto a small set of elements – the phonemes of a language" (Rayner et al. 2001, 33; see also Snowling 2000, 87). Specifically, the correspondence of graphemes to phonemes puts culturally established, normative constraints on the ways in which individual letters (or combinations thereof) are related to phonological units. The normative scope of these correspondences is best illustrated by differences across languages and orthographies. As pointed out by Ziegler and Goswami (2006, 430), "[i]n some orthographies, one letter or letter cluster can have multiple pronunciations (e.g. English, Danish), whereas in others it is always pronounced in the same way (e.g. Greek, Italian, Spanish)."[119] This shows that the degree of consistency or transparency of *grapheme-phoneme correspondences* is subject to arbitrary stipulations by a linguistic, literate community employing a specific orthographic system (cf. van Atteveldt & Ansari 2014, 45f). These stipulations are normative insofar as they constrain the ways in which combinations of letters are pronounced and in which written words are related to spoken words. The acquisition of this normative knowledge needs "explicit instruction in the alphabetic principle" (Rayner et al. 2001, 57).[120] Furthermore, this kind of normative knowledge influences the process of reading acquisition *per se*: "[…] the process of literacy acquisition is influenced by the phonology and orthography of the language in question" (Morken et al. 2014, 3). The acquisition of these norms is socially structured and dependent upon the cooperation of experts and novices. This fits neatly with Menary's (2013b, 361) following assumption:

> Manipulative norms and interpretative norms apply to inscriptions of a public representational system and are never simply dependent on an individual. Indeed, it is the individual who must come to be transformed by being part of the community of representational system users.

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[119] This phenomenon is also known as *orthographic depth*. For a recent review, see Richlan (2014).

[120] See also Dehaene (2010, 219); Dehaene (2011, 26); and Frith (1985, 307).

Acquiring knowledge about grapheme-phoneme correspondences, especially in an inconsistent orthography such as English, puts demands not only on the novice, but also on the teachers who assist her to learn these correspondences. This is because the teachers, being experts in reading, need to break down their automatic identification and recognition skills in order to be able to teach the novice the norms underlying the relationship between graphemes and phonemes. As Sterelny (2012, 145) points out more generally, "[e]xpert performance is often rapid and fluent, without obvious components. Learning from such performance is difficult. It becomes much easier if the task is overtly decomposed into segments, each of which can be represented and practiced individually." In the present context, the most successful strategy of teaching grapheme-phoneme correspondences has turned out to be *phonics instruction* (cf. Rayner et al. 2001, 31f):[121] "[…] teaching methods that make the alphabetic principle explicit result in greater success among children trying to master the reading skills than methods that do not make it explicit" (ibid., 34).

This goes along with teaching novices that spoken language consists of phonemes. That is, children's reading acquisition is dependent upon, or at least co-develops with *phonological awareness*, where this is understood as "[…] the ability to perceive and manipulate the sounds of spoken words" (Castles and Coltheart 2004, 78). The *metalinguistic awareness* that spoken language consists of phonemes must be explicitly acquired and allows the novice to learn that these units correspond to letters or combinations thereof. It is still debated whether phonological awareness is a prerequisite for learning to read or whether it is co-emergent with basic letter decoding skills.[122] However, as suggested by Castles and Coltheart (2004, 104), "[…] it may not be possible for phonemic awareness to be acquired at all in the absence of instruction on the links between phonemes and graphemes." Thus, it seems safe to assume that phonological awareness clearly facilitates the ability to relate graphemes to phonemes.

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[121] This is contrasted with *whole-word instruction*, in which "[…] a sight vocabulary of 50 to 100 words is taught initially. Subsequently words are also learned as wholes, although not necessarily out of context" (Rayner et al. 2001, 31f). The reasoning behind this method is that it is more promising to teach the novice that the primary function of words is to convey meanings, not their relationship to spoken language. As a result, it is assumed that the association of graphemes to phonemes will develop almost automatically once the novice comes to acknowledge that there is a systematic relationship between the meaning of written words and spoken words. However, as pointed out by Rayner et al. (2001, 67) and Dehaene (2010, 225-228), this method has been proven rather unsuccessful.

[122] See Castles and Coltheart (2004), for a review.

There are other components of meta-linguistic awareness that influence the successful application of norms governing alphabetic writing systems. Beginning readers are already proficient speakers of their native language and are able to fluently apply syntactic, semantic, and pragmatic norms in their everyday conversations. However, they usually lack the explicit insight that utterances are made up of sentences and that sentences are constituted by the combination of words (cf. Frith 1985, 308; Rayner et al. 2001, 35). To novices, these basic properties must be made explicitly available in order to put them in the position to apply the knowledge about it automatically and fluently at later stages of reading acquisition. Furthermore, novices need to be acquainted with the convention, which is fairly obvious to expert readers, that alphabetic writing systems are decoded from left to right and from the top to the bottom of a page. These normative aspects contributing to advances in processing tokens of an alphabetic writing system are summarized by Dehaene (2011, 26):

> In brief, all aspects of the alphabetic code must be patiently explained to children: that words are made of letters or graphemes; that graphemes map onto […] phonemes; that letters should be decoded from left to right; that the spatial left-to-right organization corresponds to the temporal order in which they are uttered; and that by changing their spatial order, one can compose new syllables and words.

The acquisition of normatively constrained knowledge of these aspects of alphabetic representational writing systems is assumed to proceed in a specific order. This is suggested by Uta Frith’s (1985) influential three-phase model of reading acquisition. According to this model, the process of becoming a proficient reader is comprised of the subsequent acquisition of logographic, alphabetic, and orthographic skills (Frith 1985, 306).[123] In the first phase, specific words are unsystematically identified as a whole on the basis of their visual properties (cf. ibid.), “as though they were objects or faces” (Dehaene 2010, 200). It is only in the second phase that alphabetic skills are acquired. These alphabetic skills amount to the ability to apply knowledge about grapheme-phoneme correspondences in the sense introduced earlier. That is, “[i]t is an analytic skill involving a systematic approach, namely decoding grapheme by grapheme. Letter order and phonological factors play a crucial role” (Frith 1985, 306). The transition from the logographic phase to the alphabetic phase is assumed to be based on metalinguistic, especially phonological awareness (cf. ibid., 308). Finally, on the basis of alphabetic skills, proficiency in orthographic skills can be developed. These skills “[…] refer to the instant analysis of words into orthographic

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[123] For comprehensive summaries, see Morken et al. (2014, 2) and Snowling (2000, 64f).

units without phonological conversion” (ibid.). That is, once the conversion of graphemic into phonological units has reached a certain stage of automaticity and fluency, words can be recognized without explicitly associating them with their relata in spoken language, as it is the case in expert readers. As pointed out by Dehaene (2010, 204) in his comment on Frith’s (1985) model, from this phase onwards “[…] reading time is no longer determined primarily by word length or by grapheme complexity. Rather, it becomes increasingly influenced by how often a word is encountered […].” That is, in this phase the more basic alphabetic skill of applying grapheme-phoneme correspondences becomes so automatic that words are rapidly recognized as a whole, such that word frequency, and not word length becomes the primary factor influencing the fluency of visual word recognition. It is important to emphasize that Frith (1985, 309) raises the hypothesis “[…] that a breakthrough to the next phase of development would only occur if there is a merging of the old and new strategy.” Accordingly, the transition from one phase to the other is characterized by a combination of already possessed and recently acquired skills that allow the beginning reader to become ever more efficient in recognizing words.

These basic personal-level components of the acquisition of reading skills provide the cognitive norms necessary for the development of reading. It is these norms that govern the successful manipulation of tokens of an alphabetic writing system and need to be established by social interaction between learners and teachers. Furthermore, the unique properties that characterize cohesively and coherently structured written language are made accessible to the novice to allow her to cognitively interact with this cognitive resource in normatively approved ways. In the case of written language, these properties are concrete manifestations of the alphabetic principle and other metalinguistic principles. In the course of reading instruction, these properties become more salient to the individual, because the individual has been learning how to apply the required set of cognitive norms.

This fits neatly with the *extended expertise model* proposed by Menary and Kirchoff (2013). Recall from chapter 1 that this model rests on the idea that expertise is the result of “the transformation of abilities through development and learning” (Menary & Kirchoff 2013, 2). In the case of reading acquisition, the stages of transformation are illustrated by Frith’s (1985) three-phase model and the emphasis on the ability to retrieve phoneme-grapheme correspondences along with the development of metalinguistic awareness. However, expertise is also extended in the sense that it “[…] is extended across a group working collaboratively to some end” (ibid.). Applied to reading acquisition, this means that a certain orthographic system is widely distributed across a certain literate community and that this community has established formal schooling and explicit instruction methods to bring about the transformations necessary for the development of expertise in reading. In sum, the personal-level features of reading acquisition lend support to the idea that cognitive practices are dependent upon the acquisition of the relevant cognitive norms. Furthermore, they emphasize the validity of the extended expertise model. Vice versa, the conceptual tools provided by this model help interpret and contextualize these features of reading acquisition in a coherent way.

More generally, the changes associated with reading acquisition as detectable on a personal level of description can serve as a paradigm case for the scaffolded learning hypothesis. This is because it is due to the scaffolding by teachers and caregivers and due to the institutionalization of specific learning environments that human organisms are able to acquire the specific ability of reading in their highly structured cognitive niche.

According to CI, cognitive functions are profoundly transformed in the course of the socio-culturally scaffolded development of cognitive practices. This suggests that we should pay close attention to the neuronal and bodily transformations brought about by the acquisition of a certain cognitive practice. In the case of reading acquisition, there is emerging evidence suggesting that both neuronal processes and eye movement patterns significantly change in the course of cognitive development. In the next two sections, I will review the relevant empirical literature and interpret them from the perspective of EPP. This will serve to approach the fine-grained details of enculturation in the case of reading.

8.3. READING ACQUISITION AND NEURONAL TRANSFORMATION

One crucial aspect of cognitive transformation is LDP (cf. Menary 2015a). Recall that this notion refers to the phenomenon that the socially structured acquisition of new skills brings about both structural and functional changes in the associated cortical circuitry. Indeed, in the case of reading acquisition, there is unequivocal evidence pointing to "[…] plastic changes in brain function that result from the acquisition of skills" (Ansari 2012, 93). By the same token, Ben-Shachar et al. (2011, 2397) emphasize that "[…] culturally guided education couples with experience-dependent plasticity to shape both cortical processing and reading development."

This suggests that basic personal-level developmental stages throughout reading acquisition correspond to cortical changes.

As Schlaggar & McCandliss (2007, 477) point out, the application of knowledge about grapheme-phoneme correspondences in novice readers “[…] implicates the formation of functional connections between visual object processing systems and systems involved in processing spoken language.” Similarly, Dehaene et al. (2015, 234) “[…] hypothesize that the core brain systems whose function is partially reoriented or ‘recycled’ when learning to read are involved in early vision, letter analysis and their reciprocal interconnections.” The left vOT area appears to play a crucial role in establishing these connections. This is suggested by a significant increase of activation in this area as a result of exposure to visually presented words in beginning readers across different research paradigms and methodologies employing fMRI (e.g., Ben-Shachar et al. 2011; Gaillard et al. 2003; Olulade et al. 2013). For instance, in a longitudinal study investigating event-related fMRI signals, Ben-Shachar et al. (2011) find increasing activation in the left occipito-temporal sulcus associated with the processing of visually presented words. Similarly, Olulade’s et al. (2013, 144) findings from an fMRI study comparing neuronal activation associated with single-word reading in novice readers and adult expert readers suggest that there are “gradients of word-selectivity in the left occipito-temporal cortex (but not in the right hemisphere) for both pediatric and adult groups”. However, their findings, refining the VWFA hypothesis put forward by Dehaene and his colleagues, also imply that “[…] word-selective regions in the adults occurred at a more anterior location and extended into more anterior regions within the VWFS [visual word form system] than in children, suggesting the utilization of more anterior regions for word processing with age-related advanced reading skills” (ibid., 140).

However, Turkeltaub’s et al. (2003) study seemingly contradicts these results. Instead of finding an increase of activation within the left vOT area associated with progress in reading acquisition in their 6- to 22-year-old participants, these researchers report that the “[…] development of ventral extrastriate pathways toward their mature lateralized state occurred exclusively through developmental decreases in the right hemisphere” in homologue areas (Turkeltaub et al. 2003, 769). However, this finding can be interpreted as being consistent with the previously mentioned evidence. This is because this decrease in the right homologue of the left vOT area is possibly significantly related to the latter’s pronounced functional role in emerging visual word recognition.

From the perspective of Anderson's (2015) IDS framework introduced earlier, the results reported by Olulade et al. (2013) and Turkeltaub et al. (2003) can be easily accounted for. The assumption here is that the spatial differences of neuronal activation in literate participants and beginning readers represent learning-induced cortical changes. They could be the result of an active search process, where this is understood as "[…] the rapid testing of multiple neural partnerships to identify functionally adequate options" (Anderson 2015, 58). Vice versa, Olulade's et al. (2013) and Turkeltaub's et al. (2003) results lend support to the hypothesis that, if the IDS framework were on the right track, "[…] we would expect the learning process to be characterized by an initial increase in both the distribution and degree of brain activity as various neural partnerships were tested; that activity would then slowly subside as the proper functional partnerships were consolidated" (ibid., 63).

So far, I have only been concerned with neuronal transformations in the left vOT area associated with reading acquisition in children. It should at least be mentioned that the human brain appears to be plastic enough for reading acquisition also being possible in adults (cf. Dehaene et al. 2015, 235). This has been demonstrated by a study conducted by Dehaene et al. (2010) testing adult Portuguese-speaking illiterates, reading beginners, and literates who acquired reading skills in childhood.[124] The results from their fMRI study suggest that the left vOT area shows a significant activation pattern in reading in contrast to control tasks, even in participants who have acquired basic reading skills in adulthood.[125]

Another line of evidence for the crucial importance of cortical changes being localized in the left vOT area comes from two longitudinal ERP studies investigating the left occipito-temporal N1 effect occurring "between 150 and 250 ms" after stimulus onset, where the N1 is assumed to be "[…] sensitive to print, with larger amplitudes over the left hemisphere for alphabetic than for nonalphabetic stimuli" (Brem et al. 2010, 7939). Maurer et al. (2006) investigate the N1 in German-speaking children at two time points, before and after they have started learning to read, and compare visual word recognition with symbol string processing which serves as control task. Their findings suggest that there is a significant N1 ERP at the second time point in comparison to the first (Maurer et al. 2006, 755):

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[124] For a similar study, see Carreiras et al. (2009).

[125] See Dehaene (2011, 23f), for a review of this study.

> Their N1 maps in response to words had become much stronger than those in response to symbol strings, and had developed distinct occipitotemporal N1 topographies. This N1 specialization had not yet been present in the same children just before entering school as nonreading kindergartners (Maurer et al. 2005) […].

In a recent EEG study, Eberhard-Moscicka et al. (2015) extend this result by finding a similar N1 effect not only at a group level (as it is the case in the Maurer et al. (2006) study), but also at an individual level in German-speaking first-graders. In particular, their "[…] study demonstrates the presence of print tuning in the first year of reading acquisition and its development at an individual level" (Eberhard-Moscicka et al. 2015, 116). Furthermore, the results of this study indicate that the presence of the N1 effect in first-graders is a significant predictor of overall reading performance (cf. ibid., 114).

Furthermore, in a combined fMRI and ERP study, Brem et al. (2010) investigate the effect of children's engagement with a computer-based game that trains sensitivity to grapheme-phoneme correspondences on BOLD signals and the N1 at three time points. They find that "the learning of letter-speech sound correspondences in young, nonreading kindergarten children results in an initial sensitization to print in specific areas within the occipito-temporal cortex" (Brem et al. 2010, 7942). Importantly, both Maurer et al. (2006) and Brem et al. (2010) point out that the activation levels within the left vOT area do not develop in a linear fashion. Rather, Maurer's et al. (2006, 756) comparison of their results obtained from their child participants with an adult control group indicates that "[i]nstead of a linear increase with more proficient reading, the development is strongly nonlinear: the N1 specialization peaks after learning to read in beginning readers and then decreases with further reading practice in adults following an inverted U-shaped developmental time-course." In this vein, Brem et al. (2010, 7942) interpret their results by suggesting that "[t]he emergence of print sensitivity in cortical areas during the acquisition of grapheme-phoneme correspondences is in line with the inverse U-shaped developmental trajectory of print sensitivity of the ERP N1, which peaks in beginning readers […]."[126] This is in line with the findings from Ben-Shachar's et al. (2011, 2396f) longitudinal fMRI study which indicates changes of neuronal activation within the left occipito-temporal sulcus (LOTS):

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[126] See Eberhard-Moscicka et al. (2015, 107f), for a review. In addition, Parviainen et al. (2006, 6059) report an MEG study with Finnish children at the beginning of reading acquisition, which indicates that an "[…] increase in phonological skills was accompanied with a decrease in the amplitude of the left occipito-temporal letter-string-sensitive response, which thus approached adult values."

> The active region within LOTS first grows (between ages 7 and 9 approximately) and then shrinks (after the age of 13) until it reaches adult levels around age of 15 years […]. […] We interpret the size reduction observed in older children as reflecting the ability to process the same visual stimulus with fewer resources, that is, increased efficiency […].

Similarly, Olulade et al. (2013, 140) report that their “[d]irect between-group comparison for words greater than false-fonts using whole-brain analysis yields greater activation for children than adults in the occipito-temporal cortex […].”

How can these rather surprising findings be interpreted and related to the progressively acquired personal-level reading skills discussed earlier in this chapter? Price and Devlin (2011, 248) provide an answer to this question by interpreting findings like these in terms of their PP account of visual word recognition. They suggest the following explanation of the non-linear development of activation within the left vOT area:

> In pre-literates, vOT activation is low because orthographic inputs do not trigger appropriate representations in phonological or semantic areas and therefore there are no top-down influences […]. In early stages of learning to read, vOT activation is high because top-down predictions are engaged imprecisely and it takes longer for the system to suppress prediction errors and identify the word […]. In skilled readers, vOT activation declines because learning improves the predictions, which explain prediction error efficiently […].

That is, this PP account presupposes that the level of activation within the left vOT area is dependent upon the general establishment and refinement of a generative model comprising both lower-level areas associated with visual processing and higher-level cortical areas associated with language processing. The activation level in the left vOT area does not represent “[…] an experience-dependent change in selectivity in the VWFA for newly learned words after training, indicating that the trained words were added to the orthographic lexicon”, as Glezer et al. (2015, 4971) argue. Rather, it should be associated with the degree of accuracy of top-down predictions in the face of bottom-up signals. This is supported by various studies demonstrating that higher-level activations in cortical areas associated with language processing are also present in beginning readers. For example, Turkeltaub et al. (2003, 772) report that “[a]ctivity in the left ventral inferior frontal gyrus increased with reading ability and was related to both phonological awareness and phonological naming ability. […] Brain activity in the anterior middle temporal gyrus also increased with reading ability”, where this area is associated with semantic processing. Similarly, Gaillard et al. (2003) report activation in the middle temporal gyrus, which is frequently associated with semantic processing in expert readers (e.g., Bedo et al. 2014, 2; Price & Mechelli 2005, 236; Vogel et al. 2013, 231; Vogel et al. 2014, 4). Furthermore, they report significant activation patterns in left IFG, which is associated with both phonological and semantic processing. Similarly, Dehaene et al. (2010) report increases in activation in a wide range of areas within temporal and frontal cortex that have been consistently associated with phonological and semantic processing in expert readers and in individuals processing spoken language. Importantly, the results of this study with late-literate adults suggest that “literacy refines spoken language processing by enhancing a phonological region, the planum temporale, and by making an orthographic code available in a top-down manner” (Dehaene et al. 2010, 1364). More generally, Olulade et al. (2013, 139) report that “[…] whole-brain analysis revealed activation in traditional left-hemisphere language areas for both adult and pediatric samples when contrasting real words with fixation, and to a lesser extent when real words were contrasted with false-fonts.” This indicates that the basic differences between novice and expert readers does not lie in higher-level phonological and semantic processing routines, but in the fluent and automatic application of phoneme-grapheme correspondences and the retrieval of semantics from visually presented words. Unfortunately and to the best of my knowledge, there are no studies that more directly investigate the effective connectivity of brain areas associated with visual word recognition. Such studies could potentially lend further direct support to the idea that learning to read is associated with the formation and refinement of a generative model realized in the human brain. However, indirect evidence for the validity of this idea comes from Parviainen’s et al. (2006, 6058) MEG study, which indicates at least functional connectivity between two lower-level and one higher-level cortical area: “The covariation between the occipital visual feature and occipitotemporal letter-string activation and between the occipitotemporal and sustained left temporal letter-string activations implies functional connectivity between these three areas in perception of visual words […].”

In sum, there is much evidence for the plausibility of Price and Devlin’s (2011) approach to reading acquisition, although additional evidence is clearly required. For instance, future studies could investigate the interaction between the left vOT area and higher cortical areas associated with phonological processing in phonological decision tasks conducted with beginning readers in comparison to advanced and expert readers. Such studies would also help test and refine the development of alphabetic skills as assumed by Frith (1985), Rayner et al. (2001), and others.

Furthermore, future studies interested in the neuronal underpinnings of reading acquisition could also investigate more explicitly the top-down and bottom-up connections between the vOT area and higher-level cortical areas associated with semantic processing by employing similar research paradigms used for the investigation of visual word recognition in adults.

However, assuming that Price and Devlin's (2011) approach to reading acquisition in terms of PP is empirically plausible, how can it be conceptually enriched? Recall from chapter 4 that, within the PP framework, learning a new skill such as reading is just a special case of overall prediction error minimization. On this construal, learning to read means to become increasingly efficient in predicting linguistic, visually presented input as a result of long-term exposure to types of this input and the optimization of predictions through perceptual and active inference. This can be fully acknowledged once we take Andy Clark's (in progress, chapter 9, 20) notion of *path-dependent learning* into account. Path-dependent learning, recall, is the scaffolded acquisition of a culturally developed skill, such that the novice is exposed to highly structured, systematically organized classes of stimuli she needs to process. As should have become clear in the previous section, this is just the case in reading acquisition (e.g., Frith 1985). The careful instruction in relating graphemes to phonemes, metalinguistic awareness, and the normatively constrained alphabetic principle provides the environmental conditions for progressively more efficient prediction error minimization. The signals delivered by this highly structured learning environment are estimated as being precise, such that the synaptic gain on error units reporting the discrepancy between (still imprecise) predictions and prediction error is high. As learning to read proceeds, the predictions become more precise and the overall influence of prediction error shows a relative decrease. This line of reasoning is supported by Price and Devlin's (2011, 248) following suggestion: “At the neural level, learning involves experience-dependent synaptic plasticity, which changes connection strengths and the efficiency of perceptual inference.” Understood this way, LDP and the associated neuronal transformations can be understood as being realized by prediction error minimization and the optimization of precision estimations in the context of path-dependent learning. The left vOT area plays an important functional role in having a pronounced influence on overall prediction error minimization associated with visual word recognition in novices and advanced readers.

8.4. READING ACQUISITION AND BODILY TRANSFORMATION

Since EPP subscribes to the hybrid mind thesis, it seems natural to assume that reading acquisition also is associated with the transformation of bodily sub-processes, which functionally contribute to the cognitive practice of reading. In terms of PP, this assumption leads to the suggestion that it is not only the optimization of perceptual inference that is causally relevant for reading acquisition, but also the adaptability of active inference that allow for ever more efficient sub-personally employed strategies of 'explaining away' incoming sensory input.

Recently, it has become possible to investigate eye movements in beginning readers by employing eye-tracking methodologies. Converging evidence suggests that beginning readers make more fixations, saccades, and regressions. Furthermore, they exhibit longer fixation durations and smaller saccade amplitudes than proficient and expert readers (cf. Joseph & Liversedge 2013, 3; Rayner et al. 2001, 46). More specifically, these tendencies are assessed in a longitudinal eye-tracking study reported by Huestegge et al. (2009). They measure eye movements during an oral reading task in second and fourth graders of a German primary school. Additionally, they assess overall reading skills and oculo-motor behaviour beyond reading (cf. Huestegge et al. 2009, 2949). Their results indicate that the fourth graders, in comparison to the second graders, show a decrease of fixation duration, gaze duration, total reading time, refixations, and saccadic amplitudes (cf. ibid., 2956). Huestegge et al. (2009, 2958) attest the younger, less proficient readers a "[…] refixation strategy, with initial saccade landing positions located closer to word beginnings." Similar to Huestegge et al. (2009), Seasseau et al. (2013) report a longitudinal study comparing the performance of 6- to 11-year-old children in a reading task and a visual search task. In line with the empirical evidence already mentioned, their results indicate that "[w]ith age, children's reading capabilities improve and they learn to read by making larger progressive saccades, fewer regressive saccades and shorter fixations […]" (Seasseau et al. 2013, 6). Furthermore, their results indicate that the eye movement patterns employed in reading and in visual search diverge with increasing reading proficiency (cf. ibid., 9).

An explanation of these results in terms of EPP is straightforward. In beginning readers, the predictions initiating active inference occurring in a highly-structured linguistic environment are inaccurate and imprecise, such that the generation and execution of eye movements in terms of active inference is not as efficient as it is the case in expert readers. By the same token, the inaccuracy and imprecision of the currently selected prediction makes it necessary to sample the visually available linguistic environment more thoroughly. This explains the "refixation strategy" and the execution of comparatively more saccades. As reading skills improve, resulting from increasingly efficient prediction error minimization through perceptual inference as suggested in the previous section, the accuracy of predictions becomes more optimal. This allows for more efficient active inference. More efficient active inference, in turn, allows for more efficient perceptual inference, since both types of inference mutually influence each other over time. This line of reasoning is supported by Huestegge's et al. (2009, 2957) claim informed by the results of their study "[…] that only linguistic, not oculomotor skills were the driving force behind the acquisition of normal oral reading skills." Furthermore, the results from simulations of eye movement behaviour in beginning readers using the E-Z Reader model reported by Reichle et al. (2013, 142f) "[…] suggest that most of the variance in reading ability stems from differences in language processing skill, with very little or none variance being due to differences in the basic mechanics of programming and executing eye movements." Thus, the increase of efficiency of eye movements in beginning readers does not result from an increase of oculo-motor capabilities *per se*, but works in tandem with higher-level linguistic knowledge encoded in predictions, which are associated with representations in higher-order cortical areas. As a result, the improvement of active inference in the course of reading acquisition is nothing but another aspect of path-dependent learning. This highlights that learning to read does not only result in neuronal, but also in bodily transformations. It turns out that reading acquisition is not only realized by LDP, but also by a genuinely bodily type of development and adaptation to acquired, culturally afforded processing needs. This is what I call *learning driven bodily adaptability* (LDBA). In the case of reading acquisition, we are confronted with a particular sub-type of LDBA which I dub *learning driven oculo-motor adaptability* (LDOA).

8.5. READING ACQUISITION AND ENCULTURATED PREDICTIVE PROCESSING

We have just seen that reading acquisition is a matter of a threefold process of cognitive transformation. First, beginning readers need to acquire the cognitive norms required for the successful and efficient manipulation tokens of an (alphabetic) writing system. Second, brain areas associated with the to-be-acquired cognitive function need to be structurally and functionally transformed. Third, eye movement patterns need to be adapted to their contribution to the to-be-acquired cognitive function. For the ease of exposition, it is possible to disentangle these three components of cognitive transformation, which ultimately give rise to the ever more efficient performance of the cognitive practice of reading. However, the more realistic picture is that these three components interact and mutually reinforce each other over time. This becomes obvious once we consider the constraints on the acquisition of cognitive practices such as reading:

> Learning is constrained by existing cortical biases and it is enabled by environmental interaction, but the environment is not an open ended and undifferentiated sequence of input, it is carefully structured and presented by caregivers and educators – it acts as a developmental channel with its own constraints. (Menary 2014, 297)[127]

By the same token, the relationship between the learning environment and the possibility space of bodily interaction with this environment is also subject to constraints. In the case of reading acquisition, the carefully structured visual presentation of words to the beginning reader is subject to norms that govern reading instruction (e.g., the adherence to phonics instruction). This is what I call *instructive norms*. Additionally, the adaptability of eye movement patterns to the requirements of reading is constrained by the specific properties of eye movements more generally (e.g., the alternation between fixation and saccades, the time course of the initiation and execution of saccades, etc.). The developmental trajectory of bodily components contributing to a certain cognitive practice is realized by LDBA. This provides us with the necessary conceptual tools to complement the notions of scaffolded learning and LDP. Recall that, according to Menary (2015a, 8), "[c]ognitive transformations result from our evolved plasticity and scaffolded learning in the developmental niche." If we take the integrationist's hybrid mind thesis and the manipulation thesis seriously, we should add that cognitive transformation is the result of the mutual interaction of scaffolded learning, LDP, and LDBA (or, more specifically, LDOA in the case of reading acquisition). As we have seen in the

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[127] The more general idea that neuronal sub-processes are constrained by functional biases and adaptive to the (socio-cultutally shaped) environment of the associated human organism as a whole resonates in Clark's (1997, 87) approach to cognition which suggests that "[t]he biological brain is, it seems, both constrained and empowered in important and sometimes non-intuitive ways. It is constrained by the nature of the evolutionary process – a process that must build new solutions and adaptive strategies on the basis of existing hardware and cognitive resources. And it is empowered […] by the availability of a real-world arena that allows us to exploit other agents, to actively seek useful inputs, to transform our computational tasks, and to offload acquired knowledge into the world."

course of this chapter, this is perfectly in line with many empirical results and experimental observations.

The idea that learning is constrained by environmental, neuronal, and bodily factors fits neatly with Clark's (in progress, chapter 9, 20) notion of *path-dependent learning*. Recall that path-dependent learning is the idea that prediction error minimizing systems are selectively exposed to sensory input that is structured, ordered, salient, and informative. This path helps the novice acquire a sufficient degree of expertise in her interaction with a certain cognitive resource. Understood like this, path-dependent learning is subject to socio-culturally shaped cognitive norms that constrain the ways human organisms can interact with this cognitive resource and to instructive norms on the side of the teacher. At the same time, path-dependent learning does justice to the possibilities and limitations human organisms are provided with. As we have seen in the previous sections, this is just the case in reading acquisition. Here, the possibilities and limitations concern 1. the functional biases of to-be-reused cortical regions (such as the left vOT area) and LDP;[128] and 2. the constraints posed on eye movement patterns and LDOA. The prediction error minimization framework, working in tandem with the cognitive integrationist's approach to enculturation and cognitive transformation, provides the conceptual tools to interpret, contextualize, and unify a vast set of empirical data. At the core of this innovative move is the idea that the process of enculturation can be described in terms of the continuous optimization of perceptual and active inference and the associated precision estimations on a sub-personal level of description. However, it is of vital importance to appreciate that the description of this kind of prediction error minimizing path-dependent learning needs to be complemented by the careful personal-level scrutiny of the conditions under which scaffolded learning is rendered possible.

The types of explicit instruction and scaffolded learning we have been considering are instances of what Kline (2015) calls "direct active teaching". This is the idea that

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[128] It is for this reason that reading acquisition is an interesting target phenomenon in its own right for researchers interested in neural reuse and Anderson's (2015) IDS framework. In particular, this framework "[…] sees learning to read as an especially good candidate for understanding the nature of the neural search process at the level of large-scale recruitment of neural systems. This is due both to the irreducibly cultural nature of the task and the recency of the emergence of this practice but also because of its crucial importance to learning and development more generally and the devastating impact of the various disorders of reading that we are just beginning to understand" (Anderson 2015, 306). We will be concerned with the latter issue in the next chapters.

teaching is “[…] characterized by (1) manifestation of *relevant* information by the teacher to the pupil and (2) interpretation of this manifestation in terms of knowledge content by the pupil” (Kline 2015, 8; italics in original). Kline develops a taxonomy of several types of teaching, most of which are almost ubiquitous in many animals other than humans. In addition to ‘direct active learning’, this taxonomy includes teaching by 1. “social tolerance”; 2. “opportunity provisioning”; 3. “stimulus or local enhancement”; 4. and “evaluative feedback” (cf. ibid., 7f).[129] The interesting result of Kline’s large-scale review of the psychological, anthropological, and ethnographic investigation of teaching in different species and cultures is that ‘direct active teaching’ only occurs in humans, while the other types of teaching are pervasive phenomena in many species (cf. ibid., 38). According to Kline (2015, 16), the reason for this

> […] is that ours is the only species in which it is adaptive […]. I argue this is because humans (and only humans) evolved in the ‘cultural niche’, such that our species depends to a great degree on cumulative cultural adaptation too complex for any one individual to create on his or her own, which coevolved with species-specific cultural capacities (Boyd, et al. 2011). If this is the case, then direct active teaching may be a derived form of teaching that co-evolved with culture, for the purpose of transmitting hard-to-learn cultural adaptations.

Accordingly, the particular ways in which human organisms pass on important cognitive skills to the next generation are shaped and constrained by the cognitive niche that is inter-generationally created, maintained, and refined.[130] In turn, ‘direct active teaching’ could be an adaptation that is suitable for the efficient transmission of information and the relevant cognitive norms that concern the interaction with evolutionarily recent, genuinely cultural cognitive resources. If this line of reasoning is on the right track, reading could serve as a good example of “hard-to-learn cultural adaptations” whose acquisition requires ‘direct active teaching’ in terms of explicit reading instruction that is in line with instructive norms.

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[129] See Strauss et al. (2014, 39) for a diverging taxonomization of teaching in humans across the lifespan. Another interesting point to note about Kline’s (in press) interdisciplinary framework for the investigation of teaching is that it is consistent with the continuity thesis defended by cognitive integrationists. This is because it is interested in “[…] the adaptive design and evolutionary origins of teaching behaviour, by providing a unifying approach through which to study the form, function, and prevalence of different teaching behaviors across human and nonhuman populations” (Kline 2015, 17). On this construal, teaching is a specific type of social interaction with its own evolutionary trajectory. Thus, the genuinely human type of teaching, namely ‘direct active teaching’ is continuous with other types of teaching found in the animal kingdom.

[130] This is consistent with Sterelny’s (2003, 173) notion of “downstream epistemic engineering”. This is the idea that “[…] agents modify the informational character of their environment and sometimes the environment of their descendents” (ibid., 147).

In sum, it turns out that reading acquisition can be consistently approached by employing the conceptual tools provided by EPP. To my knowledge, this is the first attempt to describe the personal-level features, the functional and structural cortical changes, and the oculo-motor changes associated with reading acquisition from a unifying perspective while doing justice to a vast array of theoretical and experimental insights. In a nutshell, reading acquisition is a paradigm case of enculturation which is best described by analysing the contributing factors of cognitive transformation in terms of prediction error minimization, neural reuse, LDP, LDOA, and the specific features of scaffolded learning.

There is nothing in the EPP approach to reading acquisition that would disagree with the statement that "[i]t looks like PP can provide models of some of the fundamental processing principles at work at the sub-personal neural level, but it is not obvious that it would *replace* the roles of LDP and neural redeployment as the mechanism of transformation" (Menary 2015b, 4; my emphasis). The EPP perspective does not indicate that LDP and neural reuse could be substituted (partially or completely) by relying on prediction error minimization and the optimization of precision estimations. Rather, EPP suggests that these mechanistic principles should be *complemented* by a PP-style description. This gives us the right kind of conceptual resources to account for the multiplicity of the sub-personal level changes associated with reading acquisition. In this sense, the consideration of PP certainly

> […] adds another string to the bow of our understanding of how the brain exhibits the plasticity required for cognitive transformation. In that case it provides extra explanatory depth to the account of enculturation, but only as part of a much broader explanatory framework. (ibid., 6f)

In summary, then, the EPP perspective on reading acquisition submits that human organisms become enculturated by becoming expert readers. Enculturation is constrained by neuronal and bodily biases and the ways human organisms can interact with their cognitive niche. The cognitive niche, in turn, provides the targets and means of enculturation. Human organisms acquire the cognitive practice of reading because they are immersed into a specific socio-cultural environment. In addition, human organisms can become expert readers because their brains and bodies are apt to being transformed in both biologically and culturally constrained ways.[131]

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[131] In the next chapters we will see that cognitive processes associated with reading can go astray if any of these conditions is not met.

8.6. CONCLUDING REMARKS

The purpose of this chapter has been to develop a unificatory theoretical approach to reading acquisition. It has turned out that EPP is most suitable for a careful investigation of the cognitive transformations associated with reading development. By doing conceptual justice to the culturally constrained ways in which normative, arbitrarily stipulated features of a certain (alphabetic) writing system influence reading acquisition, it has become possible to interpret psychological approaches to personal-level components that strongly influence successful reading acquisition. In addition, the description of reading instruction in terms of scaffolded learning and its principle of path-dependent learning leads to a conceptually consistent consideration of the ways in which the cognitive skills necessary for successful reading acquisition are passed on to novices. Furthermore, the cognitive transformations corresponding to the development of reading skills could be spelled out by relying on the EPP framework. By describing both the neuronal and bodily transformations in the light of efficiency gain in perceptual and active inference and by highlighting the importance of path-dependent learning, it has become possible to provide a conceptually coherent and empirically plausible sketch of components of reading acquisition on a sub-personal level of description. Taken together, this suggests that reading acquisition truly is a case of enculturation.

PART III

READING DISORDERS

9. DEVELOPMENTAL DYSLEXIA

9.1. INTRODUCTION

In chapters 5, 6, and 7, I have developed an approach to reading in adult, non-impaired individuals. I have reviewed and discussed empirical results and theoretical insights coming from cognitive neuroscience, cognitive psychology, and psycholinguistics and I have interpreted them from the perspective of EPP. By considering visual word recognition, sentence processing, and eye movements from this integrative perspective, I have offered a new approach which attempts to show how each of these sub-processes contributes to reading. Specifically, I have offered a new perspective by suggesting that reading is constituted by delicate interactions of neuronal and bodily components at multiple levels of analysis. Furthermore, I have argued that these interactions are partly determined by the socio-cultural context in which they emerge. In chapter 8, I have elaborated on these ideas by presenting a new approach to reading acquisition. This approach highlights the interplay of neuronal transformation (LDP), bodily transformation (LDOA), and the realization of path-dependent learning. At the same time, I have been concerned with the normative dimension of reading acquisition in the spirit of Menary's account of enculturation and the associated notion of scaffolded learning.

However, there are many cases in which reading acquisition fails (developmental dyslexia), the capacity to read is mostly lost (pure alexia), or in which specific aspects of reading performance are impaired (high-functioning autism). These cases will be the topic of the chapters to follow. They are interesting in their own right. This is because they give intriguing insights into the complexity and fragility of reading. Furthermore, in the context of this dissertation, considerations of developmental dyslexia, pure alexia, and reading performance in high-functioning autism are rewarding. They will help elaborate on the approach to reading developed so far. Furthermore, they will continue to establish the epistemic advantages of approaching reading from the perspective of EPP.

In the last chapter, I have argued that reading acquisition is a paradigm case of enculturation and I have described the neuronal and bodily transformations necessary for becoming a skilled reader. Yet, there are many cases in which these transformational processes (partly) fail. In particular, there is a phenomenon that is characterized by failures in the cognitive development towards fluent, automatic, and efficient visual word recognition and sentence processing. This phenomenon is called *developmental dyslexia*. It is defined "[…] as reading achievement below the expected given a person's chronological age, measured intelligence, and education" (Castles et al. 2010, 426).[132] It is further "[…] characterized by significant difficulties in learning to decode print" (Vellutino & Fletcher 2007, 364).

The purpose of this chapter is to describe important aspects of developmental dyslexia, to review the relevant psychological and neuroscientific literature and to interpret findings on this developmental disorder in the light of EPP. I will proceed by reviewing the state of research on a personal level of description in the next section. After that, the next two sections will be dedicated to the neuronal and bodily impairments that are assumed to underlie developmental dyslexia. The overall claim of this chapter will be that this disorder is a good test case for the validity of the EPP framework. This is because it helps further specify the conditions under which 'normal' reading acquisition can be said to occur. Furthermore, I will argue that the EPP framework is capable of providing a convincing approach to developmental dyslexia by uniting initially disparate empirical findings.

9.2. APPROACHES TO DEVELOPMENTAL DYSLEXIA ON A PERSONAL LEVEL OF DESCRIPTION

As indicated by the definition of developmental dyslexia quoted above, individuals suffering from this disorder are of average or high intelligence. Typically, they do not show significant deficits beyond reading and spelling. There has been a long-standing debate about the causes of this disorder. By now, it has become clear that developmental dyslexia is genetically inheritable, such that children of dyslexic parents are more likely to be affected (cf. Schlaggar & McCandliss 2007, 491; Shaywitz & Shaywitz 2005, 1301; Shaywitz et al. 2008, 458). However, since reading acquisition is complex and constituted by the interaction of several sub-processes, it remains unclear how the behavioural profiles and the neuronal and bodily manifestations of developmental dyslexia ultimately relate to the identification of specific genomes that might be responsible for its heredity.[133] Furthermore, the

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[132] For similar definitions, see Blau et al. (2010, 869); Boets (2014, 501), Ramus et al. (2003, 841); Richlan (2012, 1); Shaywitz et al. (2002, 101); Shaywitz & Shaywitz (2005, 1301); Silani et al. (2005, 2453); Temple et al. (2003, 2860); and Vagge et al. (2015, 1).

[133] As pointed out by Dehaene (2010, 254), several genomes that might carry information related to the phenotypic expression of dyslexia have been identified: "By crossing genetic information with the results of a great many cognitive tests, six vast regions of the human genome, on chromosomes 1, 2, 3, 6, 15, and 18, were 'linked' to dyslexia."

search for the chromosome set associated with the onset of this disorder is complicated by inter-individual differences of dyslexic profiles and the interaction of inherited dispositions with the culturally scaffolded acquisition of reading. As pointed out by Vellutino and Fletcher (2007, 377), "[…] individual differences in reading ability result from complex interactions between naturally endowed cognitive abilities underlying the ability to learn to read on the one hand, and literacy experiences and instruction on the other." Considerations such as these lead Castles et al. (2010, 430) to suggest that "[…] there is no single cause of developmental dyslexia and it is likely that multiple factors interact in complex ways to impair reading acquisition." This suggestion is important for two reasons. First, it points out that even if the exact chromosome set associated with developmental dyslexia were discovered, it would leave many questions unanswered. Perhaps the most important question would concern the interaction of genetic disposition and phenotypic manifestation. Second, this suggestion raises the question whether there is a core deficit that is associated with developmental dyslexia and if so, whether this deficit can be considered as a prominent cause (amongst others) of the pervasive difficulties observed in dyslexics.

Several proposals have been presented in attempting to account for the neuro-cognitive cause(s) of developmental dyslexia. These proposals have assumed deficits in visual or auditory processing or a neuronal impairment being attributable to the cerebellum or the visual magnocellular pathway (for reviews, see Castles et al. 2010, Ramus et al. 2003). However, there is now a broad consensus that a deficit in phonological processing is a pervasive phenomenon that occurs in the majority of cases of developmental dyslexia.[134] This phonological deficit is considered to affect the dyslexic's ability to acquire the capacity to apply grapheme-phoneme correspondences: "Speech sounds are poorly represented or processed by children with developmental dyslexia, and this makes it difficult for them to associate those sounds with their corresponding letters when learning to read in an alphabetic system such as English" (Castles et al. 2010, 427; see also Araújo et al. 2012, 79).[135] In the last chapter, we have seen that the emergence of phonological

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[134] This is not to say that dyslexic individuals never suffer from visual or auditory processing deficits or aberrant functioning of the cerebellum or the magnocellular pathway. However, it seems reasonable to suppose that the phonological deficit characterizes many cases of dyslexia, which might in certain cases co-occur with other deficits assumed by these alternative proposals.

[135] See also Dehaene (2010, 239); Georgiewa et al. (2002, 5); Morken et al. (2014, 1); Ramus et al. (2003, 842); Richlan (2012, 1); Richlan et al. (2010, 2); Snowling (2000, 104); and Vellutino and Fletcher (2007, 367, 377).

awareness is a crucial factor of successful reading acquisition. It is precisely this factor that appears to be impaired in dyslexic individuals (cf. Shaywitz & Shaywitz 2005, 1302). Although some developmental dyslexics might show subtle difficulties in the processing of spoken language (see, eg., Snowling 2000, 34f), it is the metalinguistic phonological awareness or the ability to represent phonemes *as phonemes* that appears to be affected.

As a result, the acquisition and application of the alphabetic principle is impaired and leads to lifelong difficulties in visual word recognition or “an orthographic coding deficit”, as van der Mark et al. (2011, 2426) put it.[136] Understood like this, “[d]yslexia thus appears to be a reading deficit that can be reduced to a problem with single-word recoding, which is itself due to an impairment in grapheme-phoneme conversion” (Dehaene 2010, 239). This view is in line with the following assumption put forward by Shaywitz and Shaywitz (2005, 1302): “The phonological deficit is domain-specific; that is, it is independent of other, nonphonologic abilities. In particular, the higher order cognitive and linguistic functions involved in comprehension, such as general intelligence, reasoning, vocabulary […], and syntax […] are generally intact.” This suggests that even though the basic deficit characterizing developmental dyslexia seems to be rather restricted to the retrieval of grapheme-phoneme correspondences and their relation to the alphabetic principle, it has a major impact on the processing of visually presented words that occur either in isolation or in in syntactic context.[137] A consequence of this is also that the consistency and transparency of phoneme-grapheme correspondences in a

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[136] According to Frith’s (1985, 324) three-phase model of reading acquisition, which I have reviewed in the last chapter, developmental dyslexia is characterized by an impaired transition from phase 1 (logographic skills) to phase 2 (alphabetic skills): “*Classic developmental dyslexia* is the failure of alphabetic skills. It corresponds to arrest at phase 1 in the normal developmental sequence. One explanation of the failure that is favoured by a number of recent studies is in terms of a disorder of the phonological system” (italics in original).

[137] To date, the specific status of the idea that developmental dyslexia is characterized by a cognitive impairment that concerns the application of phonological knowledge is still a matter of debate (see, e.g., Boets 2014; Castles & Friedmann 2014; Dehaene 2014). As Castles and Friedmann (2014) convincingly show, developmental dyslexia is a rather heterogeneous phenomenon. They hypothesize that “[…] [i]f reading is in fact a complex skill, involving the co-ordinated functioning of a number of processes, one would expect dyslexia to present in a number of different forms” (Castles & Friedmann 2014, 272). They support this hypothesis by showing that the scientific literature on dyslexia suggests the existence of many sub-types of developmental dyslexia. These sub-types clearly need to be distinguished from the type of dyslexia that manifests itself by a pronounced impairment concerning the fluent application of grapheme-phoneme correspondences (i.e., *developmental phonological dyslexia*; cf. ibid., 272f). For the remainder of this chapter, I will be concerned with this particular sub-type of developmental dyslexia. However, it should be kept in mind that dyslexia is a fairly complex and heterogeneous condition that comes in different degrees and forms.

certain orthography has an impact on the reading-specific performance of dyslexic individuals. Recall from the last chapter that phoneme-grapheme correspondences are normative and vary across languages and alphabetic writing systems. This makes it reasonable to suppose that the transparency and consistency of a certain orthographic system might be a dependent variable of the severity of reading impairment in dyslexics (cf. Pollack et al. 2015, 7f). Evidence for this comes from a cross-linguistic and cross-orthographic study by Paulesu et al. (2001), which investigates the performance of Italian, English, and French dyslexic adults in word recognition and phonological tasks. Their interpretation of the results is straightforward:

> […] a phonological processing deficit is a universal problem in dyslexia and causes literacy problems in both shallow and deep orthographies. However, in languages with shallow orthography, such as Italian, the impact is less, and dyslexia has a more hidden existence. By contrast, deep orthographies like that of English and French may aggravate the literacy impairments of otherwise mild cases of dyslexia.[138] (Paulesu et al. 2001, 2167)

This suggests that the manifestation of developmental dyslexia is dependent upon the linguistic environment to the extent that the cognitive norms that need to be acquired and applied are variable across languages and orthographies. More generally, the notions of enculturation and cognitive transformation help account for the behavioural profiles of developmental dyslexia. This is because they are suitable for specifying the conditions under which reading acquisition is impaired. In 'normal' cases, learning to read proceeds by the child's immersion into a highly structured, linguistic, and literate environment. Furthermore, the child is explicitly instructed in phonological awareness, the alphabetic principle, and grapheme-phoneme correspondences. If all goes well, the non-impaired novice will finally become an expert reader as a result of cognitive transformation and scaffolded learning. She will then apply the relevant cognitive norms fluently and automatically while performing the cognitive practice of reading. In cases of developmental dyslexia, however, specific stages of enculturation are rendered (partially) unsuccessful due to the underlying phonological deficit. In turn, this impairs the acquisition of the alphabetic principle and the application of grapheme-phoneme correspondences, understood as a set of cognitive norms. Yet, dyslexic individuals will be able to

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[138] For a similar account of differences in the manifestation of dyslexia across linguistic and orthographic systems see Shaywitz et al. (2008, 457f). In this vein, Castles and Friedmann (2014, 274) suggest that "[o]nce the characteristics of each type of dyslexia and the relevant aspects of each orthography are known, it is possible to predict how each dyslexia will be likely to manifest in each orthography."

acquire at least some cognitive norms if they are exposed to appropriate reading instruction and if they enjoy an adequate amount of scaffolded learning. Specifically, it is widely assumed that "[…] remediation of the phonological weakness leads to the amelioration of the decoding and word-reading weaknesses in dyslexia […]" (Shaywitz et al. 2008, 454).[139] This suggests that scaffolded learning and adequate instruction are capable of bringing about cognitive transformations and help enculturate not only 'normal', but also congenitally impaired individuals, at least to a certain degree. The ways in which dyslexic individuals are instructed and remediated by teachers and care-givers might depart from the pervasive instruction methods employed in teaching 'normal' individuals how to read. This suggests that the instructive norms employed by teachers might be partially dependent on the specific characteristics and profiles of the individuals who receive reading instruction. However, it should not be forgotten that developmental dyslexia is a life-long impairment, which manifests itself in variable degrees of severity across individuals: "[…] although dyslexic children will improve their accuracy, deficient fluency continues to be a concern at all grade levels […]" (Shaywitz et al. 2008, 466).

In the EPP framework, cases of developmental dyslexia can be considered as representing a specific type of enculturation, which I call *dysculturation*. Dysculturation may be defined as an incomplete process of enculturation which results in deficient cognitive processing routines that involve the interaction with cognitive resources. The resulting cognitive deficits may be caused by neuronal or bodily developmental deviations or a combination of both. Dysculturation also refers to the possible development of strategies that help compensate for congenital cognitive deficits. It should also be clear that dysculturation is not an all-or-nothing phenomenon. It comes in different degrees and requires the fine-grained investigation of distinct, yet certainly related manifestations of dysculturated cognitive processes.

These considerations lead to the question how the phonological core deficit and the deficits associated with visual word recognition can be accounted for on a neuronal level of description. Furthermore, it is of interest how the neuronal transformations occurring in dyslexic individuals learning to read can be approached and related to

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[139] Similarly, Snowling (2000, 196) submits "[...] that the most effective teaching methods for dyslexic readers combine reading instruction and phonological awareness training."

those transformations ascribed to ‘normal’ novices. This is the purpose of the next section.

9.3. DEVELOPMENTAL DYSLEXIA AND IMPAIRED NEURONAL TRANSFORMATION

As pointed out in the last section, the majority of cases of developmental dyslexia is characterized by at least two impairments. First, dyslexics show a phonological awareness deficit. Second, dyslexic individuals suffer from an ‘orthographic coding deficit’, which prevents them from automatic and fluent visual word recognition. This leads to the hypothesis that both deficits are associated with aberrant patterns of brain activation in dyslexics in comparison to ‘normal’ individuals.

This hypothesis has been confirmed by several brain imaging studies investigating the neuronal underpinnings of dyslexic reading impairments in children, adolescents, and adults. In Paulesu’s (2001, 2167) combined behavioural and PET study already mentioned in the last section, the results of the PET experiment suggest that “[r]educed activation in the left middle, inferior, and superior temporal cortex and in the middle occipital gyrus was the robust universal feature of dyslexia for word reading in the three language groups.” In a follow-up investigation of grey matter structures which employs voxel-based morphometry analysis on the same data set, Silani et al. (2005, 2458) find that there is “a structural disorganization of the cortex with both reduction and increases of ‘grey matter’”. Taken together, these results suggest that dyslexic impairments are associated with hypoactivation and aberrant grey matter organization especially in temporal cortical areas, which are usually associated with phonological processing in reading (cf. Silani et al. 2005, 2459). Furthermore, in their magnetic source imaging study of dyslexic children, Simos et al. (2000, 814) find that, in addition to hypoactivation in temporal areas, parietal areas usually involved in visual word recognition also show a reduced activation pattern in comparison to ‘neurotypical’ control participants: “Regions that showed marked hypoactivation included the posterior part of the superior temporal gyrus and the left parietal lobule (angular and supramarginal gyri), which are known to play a crucial role in word recognition and reading.” They interpret this finding to suggest “[…] that developmental dyslexia, especially when associated with marked phonological processing difficulties, is linked to a functional deficit in the brain mechanism that supports phonological analysis of print” (ibid., 815). In addition, their findings indicate that right-hemisphere homologues of temporo-parietal brain areas typically involved in visual word recognition are recruited in dyslexic children (cf.

ibid., 814). This is in line with the results from Shaywitz's et al. (2002) large-scale fMRI study comparing brain activation patterns in dyslexic and 'normal' children during word and pseudo-word reading. They assume that "[…] the right hemisphere sites may represent the engagement of brain regions that allow the poor reader to use other perceptual processes to compensate for his or her poor phonologic skills" (Shaywitz et al. 2002, 108; see also Shaywitz & Shaywitz 2005, 1307).[140] A likely interpretation of this recruitment of right-hemisphere regions, which are not involved in visual word recognition in 'typically' developing children, is that it is associated with "compensation effects" as a result of early reading remediation focusing on a behavioural alleviation of deficits in dyslexic children (Dehaene 2010, 259):

> After rehabilitation for dyslexia, brain activity often increases in several regions of the right hemisphere, at locations symmetrical to those of the normal reading circuit. It seems likely that in the presence of left-hemisphere impairment, equivalent regions of the right hemisphere take over.[141] (ibid.)

A similar explanatory strategy is also chosen for the relative increase in activation in left inferior frontal regions in dyslexic individuals. For instance, in a combined fMRI and EEG study with German dyslexic children, who perform a reading task that employs words and pseudo-words as stimuli, Georgiewa et al. (2002) find that the left IFG (Broca's area) is significantly more activated in dyslexics than in control participants. The authors' interpretation of this finding is as follows: "On the basis of the 'phonological' function of this brain region, the hyperactivation of Broca's area in dyslexics, in comparison to controls, could reflect an increasing effort concerning phonological coding" (Georgiewa et al. 2002, 7). Dehaene (cf. 2010, 246f) takes this as further evidence for the assumption that the increased recruitment of certain brain areas in dyslexic individuals, such as the left IFG, is a means of compensation for neuronal impairments.[142] However, this stands in contrast to other findings

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[140] Relatedly, Araújo et al. (2012, 87) report that their comparison of ERPs derived from an EEG experiment with dyslexic and 'normally' developing pre-adolescent children who perform implicit reading tasks leads to the conclusion that "[…] the control readers tended to show a lateralized pattern with relatively greater left than right negativity; in contrast, the dyslexic group did not show any lateralization effect."

[141] This is also suggested by fMRI studies investigating the effects of remediation programs on patterns of neuronal activation in dyslexic children (e.g., Temple et al. 2003) and adults (e.g., Eden et al. 2004).

[142] In this vein, Morken et al. (2014) report an fMRI study in which Norwegian dyslexic and 'neurotypical' control participants are tested in reading long words, short words, and entire sentences. Their main finding is "[…] that the dyslexia group generally displayed cortical hyperactivations during reading tasks as compared to the typical group, especially in more taxing conditions. Furthermore, the difference between the groups increased with increasing processing demands" (Morken et al. 2014, 9). However, since both the dyslexic and control group have received intense reading instruction and remediation, Morken et al. (2014, 11) tentatively argue that this pervasive hyperactivation of cortical regions associated with visual

suggesting that the left inferior frontal gyrus is not hyper-, but hypoactivated in dyslexics. In an fMRI study investigating German-speaking dyslexic adolescents who perform a phonological decision task on short and long words, pseudohomophones, and pseudowords, Richlan et al. (2010) find that dyslexic participants do not show a significant increase of activation in inferior frontal regions (pars opercularis and pars triangularis) in the pseudoword condition in comparison to the word condition, which is observed in the control participants (cf. Richlan et al. 2010, 8). This is interpreted as "[…] absent responsiveness to increased sublexical reading demands in phonological inferior frontal gyrus (IFG) regions" (ibid., 9). Intriguingly, a supplementary finding is obtained for the left vOT area: "[…] dyslexic readers did not show the pseudoword-length effect of the nonimpaired readers in left OT sulcus regions which correspond to the VWFA" (ibid., 7). Furthermore, dyslexic participants "[…] also showed reduced activation of this region compared to nonimpaired readers" (ibid.).[143]

A significant hypoactivation of the vOT area in dyslexic individuals in comparison to a 'neurotypical' control group has also been found by other studies. For instance, in a longitudinal study investigating the occipito-temporal N1 ERP associated with visual word recognition, Maurer et al. (2007) compared German-speaking dyslexic participants with a control group before and after initial reading instruction at school. The main result of this study is that "[o]ver the course from kindergarten to 2nd grade the increase in N1 specialization with reading training was not significant for the dyslexic children. This strongly contrasted with the highly significant increase in those children who learned to read normally" (Maurer et al. 2007, 3207). This trend seems to be continued at later stages of the cognitive development of dyslexics. Araújo et al. (2012) report an EGG study which compares the sensitivity to visually

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word recognition and sentence processing could possibly be explained by assuming "[…] that the training could have supported the development of compensatory mechanisms, contributing to the picture of hyperaction seen in our results." If this were true, the alleged contradiction between oberserved cortical hypo- and hyperactivation in dyslexics could be resolved by assuming that the hyperactivation in some (majorly right-hemispheric) cortical regions represents a neuronal compensation strategy for hypoactivations in other cortical regions usually contributing to visual word recognition and sentence processing. This, in turn, would suggest that LDP is at play not only in 'normal' cognitive development, but that this propensity of the human brain significantly contributes to compensatory strategies in cases of (congenital) neuronal impairment. In order for these compensatory strategies to emerge, however, scaffolded learning in terms of intensive reading instruction and remediation is certainly required.

[143] See Pollack's et al. (2015, 6) meta-analysis of 'normal' and impaired readers for a similar result.

presented words, pseudowords, consonant sequences, and symbol sequences as reflected in ERP signals obtained from dyslexic and ‘normally’ developing pre-adolescent participants. Their main result is that “[i]n the dyslexic group, the N1 response did not show the letter-processing sensitivity found in normal readers. In contrast to control readers, the N1 peak was attenuated […]” (Araújo et al. 2012, 85). This significant hypoactivation of left occipito-temporal areas as observed in younger and pre-adolescent children appears to remain significant as dyslexic individuals reach adulthood. McCrory et al. (2004) demonstrate in their PET study that these areas are under-activated both in visual word recognition and picture naming for their adult dyslexic participants (cf. McCrory et al. 2004, 265). They interpret this result as suggesting that “the neurological deficit in this region is an emergent property of the interaction of multimodal (in this case visual and phonological) information” (ibid.). A similar result has also been reported for dyslexic children by van der Mark et al. (2009).[144] In their fMRI study, the dyslexic participants and a control group perform a phonological decision task on several classes of linguistic stimuli similar to those employed in Richlan’s et al. (2010) study. Van der Mark et al. (2009, 1948) interpret their findings as follows: “We were able to demonstrate that multiple regions along the posterior-to-anterior axis of the VWF-system are affected, rather than just its well-known core area (i.e., the VWFA proper).”

Performing additional analyses on the data set obtained from this study, van der Mark et al. (2011) investigate the functional connectivity of the left vOT area to cortical areas widely assumed to be associated with phonological processing. The reasoning behind this analysis is that, given that dyslexic individuals suffer from both a phonological and an ‘orthographic decoding deficit’, this should be reflected in the underlying connectivity of associated brain regions. In fact, van der Mark’s et al. (2011, 2433) analyses confirm this hypothesis: “The group comparison revealed that children with dyslexia showed a focal reduction of ROI-specific functional connectivity between the VWFA and two major components of the language network: (i) the left inferior parietal lobule and (ii) the left inferior frontal gyrus.” They interpret their results as indicating that the hypoconnectivity of the left vOT area with

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[144] In addition, in a study comparing neuronal activation patterns associated with the processing of Dutch visually presented letters and speech sounds, Blau et al. (2010) also find reduced activation of the fusiform gyrus located in the left vOT area for the dyslexic children participating in their study (cf. Blau et al. 2010, 877). However, since the unit of analysis is the processing of single letters and graphemes, it remains unclear whether this result can be applied to an impairment of the application of grapheme-phoneme correspondences as occurring in entire words.

these areas, which are associated with phonological processing in 'neurotypical' individuals, accounts for the specific deficits observed in dyslexics (cf. ibid.). In this vein, Boets (2014, 501) argues "[…] that the phonological representations *per se* may be intact in individuals with dyslexia, but the ability to access them is impaired." This leads him to assume that there is "a dysfunctional fronto-temporal connection in dyslexia" that is thought to occur in dyslexic children, adolescents, and adults alike (ibid.). Evidence for this comes from a recent fMRI study with dyslexic and non-dyslexic adults which produced data for a functional connectivity analysis (Boets et al. 2013). The main finding derived from this analysis is "[…] that a dysfunctional connection between frontal and temporal language areas impedes efficient access to otherwise intact representations of speech sounds, thus hampering a person's ability to manipulate them fluently" (Boets et al. 2013, 1254).

Considering these different strands of evidence for impaired neuronal processes in developmental dyslexia, the crucial question is whether these results can be accounted for in a unifying and parsimonious way. I would like to suggest that the EPP framework has the right kind of conceptual resources for this task. In terms of prediction error minimization, Price and Devlin (2011, 248) propose that the impairments observed in developmental dyslexia can be accounted for as follows: "In developmental dyslexics, abnormally low vOT activation and reduced functional connectivity between vOT and other language areas are consistent with failure to establish hierarchical connections and access top-down predictions, perhaps because of a paucity of phonological knowledge […]." Put differently, the suggestion here is that perceptual inference in developmental dyslexics is impaired as a result of the aberrant activation and functional connectivity of cortical areas being crucial for visual word recognition in both novice and expert readers.[145] This view is supported by the empirical findings presented so far in favour of a hypoactivation of the left vOT area and its poor connectivity with other, equally under-activated cortical areas being associated with phonological processing. Similarly, functional

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[145] It would be interesting to see whether the brain regions under consideration do not only show a deficit in functional connectivity, but also in effective connectivity. To the best of my knowledge, there are no studies available so far that investigate the hypothesis that developmental dyslexics show a deficit of effective connectivity of crucial brain regions in comparison to 'normal' control participants. However, Cao et al. (2008) report that children with reading difficulties show a decrease of effective connectivity of the left IFG, the left inferior parietal lobule, and the left fusiform gyrus with increased processing demands in a rhyme judgment task when compared to control participants (cf. Cao et al. 2008, 99). Since it remains unclear whether the participants with a reading difficulty have been diagnosed to suffer from developmental dyslexia or a related deficit with a different aetiology, the significance of this study for the current purposes remains unclear.

hypoconnectivity has been observed in the left arcuate fasciculus, which connects temporal and frontal areas being associated with phonological processing (cf. Boets et al. 2013, 1254). In addition, Richlan's (2012, 4) interpretation derived from his meta-analysis of recent fMRI studies investigating patterns of brain activation in dyslexic individuals points into the same direction: the "[…] findings on reduced early left OT engagement in young dyslexic readers may reflect a form of disconnection between visual and phonological representations."[146]

Price and Devlin's (2011) proposal can be refined by following their general assumption that the level of activation in the left vOT is associated with the magnitude of prediction error. Given the phonological deficit that affects visual word recognition in developmental dyslexia, the hypoactivation of the left vOT area could be explained by the insufficient availability of any relevant top-down predictions. If higher cortical areas associated with phonological processing are impaired and do not (sufficiently) generate top-down predictions attempting to 'explain away' bottom-up signals, it is not surprising to find significant hypoactivation in both the vOT area and temporal, parietal, and inferior frontal brain areas associated with phonological processing. In addition, given the 'orthographic coding deficit' and given that this deficit is most likely to be associated with an impairment of the left vOT area, the higher-order cortical areas associated with phonological processing hardly receive precise prediction error. Thus, they cannot reliably optimize hypotheses about the linguistic causes of sensory evidence. Here, the idea is that the severity of the phonological deficit observed in developmental dyslexia increases as a result of poor bottom-up prediction error signals informing higher levels of the hierarchical generative model.[147] In short, the suggestion is that it is both the top-down prediction

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[146] For an elaboration on this suggestion, see Richlan (2014, 8). Interestingly, he predicts that the hypoactivation of the left vOT area observed in dyslexic individuals should not show significant differences depending on the orthographic depth of a certain alphabetic writing system the dyslexics are confronted with: "In the Interactive Account, the left ventral OT underactivation exhibited by dyslexic readers is interpreted as failure to establish hierarchical connections and access top-down predictions. As top-down predictions from phonology and semantics play an important role in reading irrespective of OD [orthographic depth], the left ventral OT activation pattern is expected to be similar in deep and shallow orthographies." Future empirical research needs to test this prediction and to relate it to the behavioural manifestations of developmental dyslexia reviewed earlier in this chapter.

[147] While I see these two strands of malfunctioning, one stemming from deficits in higher-order phonological representations and one stemming from deficits in bottom-up signalling, as interactive and mutually reinforcing each other, Dehaene (2010, 247) considers them to reflect two distinct, yet not necessarily exclusive possibilities: "The disproportionate difficulties in phonemic awareness complicate the acquisition of the alphabetic principle. These problems, in turn, impact the left letterbox area, which is unable to acquire visual expertise for written words. All this explains why a second, derivative drop in activation is observed in this region. This scenario, however plausible, is debatable. The possibility

and the bottom-up prediction error signal associated with the ever more efficient development of fluent and automatic visual word recognition that is impaired in developmental dyslexics. This is likely, given the state of research reviewed earlier. Furthermore, this line of reasoning is supported by a direct comparison of 'neurotypical' and dyslexic beginning readers. In 'neurotypical' novices, phonological awareness, the acquisition of the alphabetic principle, and reading acquisition can be depicted as co-developing on both behavioural and neuronal levels of description. This should also be the case in dyslexic novices to the extent that the behavioural manifestation of the phonological deficit and the 'orthographic coding deficit' co-develop while the individual is instructed in the alphabetic principle and in grapheme-phoneme correspondences.

Developmental dyslexia is philosophically interesting because it presents a good example of cases in which scaffolded, path-dependent learning (partially) fails. This is due to an impairment of the neural circuitry (and the associated generative model) necessary for successful reading acquisition. That is, in cases of developmental dyslexia, prediction error minimization in terms of perceptual inference can never become optimal and efficient, because the hierarchical generative model associated with visual word recognition cannot become sufficiently established. Furthermore, the interplay between top-down predictions and bottom-up prediction error signalling is not well-balanced, because the associated brain areas and their connectivity are impaired. However, many developmental dyslexics acquire at least some skills in visual word recognition, but their reading performance will never become as efficient, fluent, and automatic as that of 'non-impaired' individuals. Dyslexic individuals are equally exposed to a socio-culturally structured environment that provides path-dependent learning and scaffolding more generally construed. These individuals might receive reading instruction that is even more intense and goal-directed than that offered to 'normally' developing novices. But since the neuronal mechanism usually guaranteeing successful reading acquisition is impaired, remediation is only partly successful. This directly speaks to cognitive transformation considered on a neuronal level of description. In developmental dyslexia, LDP is only partly evident. This is because the neuronal transformations usually associated with successful reading acquisition are insufficient to the extent that the functioning

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remains that the occipito-temporal cortex itself, the future site of 'the brain's letterbox', is directly impaired in some children."

of crucial lower- and higher-level brain areas and their connectivity are not effectively changed in the course of reading acquisition. However, as I have already mentioned in this section, it has been observed that right-hemispheric homologues of brain areas associated with non-impaired phonological processing and visual word recognition proper are recruited in developmental dyslexics. This speaks in favour of the assumption that the brain is plastic enough to allocate alternative resources, which could be considered as a case of *compensatory learning-driven plasticity* (cLDP).

However, cognitive transformation is not only constituted by neuronal changes, but also by the transformation of the bodily components allowing for the efficient performance of a cognitive practice such as reading. In the last chapter, we have seen that eye movement patterns change in the course of reading acquisition and become ever more efficient as 'normal' individuals learn to read. Given the genuine properties of LDOA in individuals learning to read, it is likely that developmental dyslexics show aberrant eye movement patterns in reading tasks in comparison to 'normally' developing individuals. This hypothesis will be evaluated in the next section.

9.4. DEVELOPMENTAL DYSLEXIA AND IMPAIRED BODILY TRANSFORMATION

So far, there have been only a few studies that have investigated eye movement patterns in dyslexic individuals while performing reading tasks. However, these studies converge on the insight that "[i]n general, compared to age-matched control readers, dyslexics' eye movements in word, pseudoword, or sentence reading are characterized by more and longer fixations, shorter saccades, and more regressions" (Bellocchi et al. 2013, 455).[148] Furthermore, developmental dyslexics across all ages have a lower single-fixation rate and a lower word skipping rate than control participants (cf. ibid.). This is demonstrated by Hutzer's and Wimmer's (2004) eye-tracking study with German-speaking dyslexic children and an age-matched control group (mean age: 13.5 years). They compare the eye movement patterns in a "passage reading and pseudoword reading task" (cf. Hutzler & Wimmer 2004, 236). For the two tasks taken together, the results suggest that "[d]yslexic readers exhibited more fixations of longer duration and also more regressions", although "[…] the proportion of these regressions in relation to the total number of

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[148] Similarly, Quercia et al. (2013, 872) report that dyslexic readers generally tend to exhibit more fixations, more saccades, and more regressions.

fixations was small" (ibid., 238f). Furthermore, the skipping rates of the dyslexic participants are significantly lower in comparison to the control participants (cf. ibid.).[149] Similar results are reported by Trauzettel-Klosinski et al. (2010) who investigate eye movement patterns in dyslexic and 'normally' developing German children (mean age: 9.5 and 9.6 years, respectively). The task is to read aloud two short texts that differ in statistically assessed difficulty. The main finding is that the dyslexic participants make more saccades per word and more regressions in comparison to the control group. In addition, the dyslexic participants exhibit shorter saccade amplitudes and significantly longer fixation durations (cf. Trauzettel-Klosinski et al. 2010, 685f). This general trend is also reported by de Luca et al. (2013) who studied eye movements in Italian-speaking dyslexic and age-matched control children in a reading aloud task with short texts as material (mean age: 11.9 and 11.6 years, respectively). In contrast to Hutzler and Wimmer (2004), they find "[n]o significant difference […] for fixation duration" between the dyslexic and the control group (de Luca et al. 2013, 8).[150] However, they report that "[…] children with dyslexia showed a slow and fragmented reading pattern characterized by many fixations, smaller forward saccade amplitude and a higher percentage of regressions with respect to typically developing readers" (ibid., 9). In this vein, a recent study which compares the eye movement patterns of dyslexic and 'normally' developing Italian children performing a text reading task demonstrates that the dyslexic participants make significantly more saccades and regressions than the control group (cf. Vagge et al. 2015, 6).

Although these studies differ with regard to the employed materials and tasks, the overall tendency of eye movement patterns is fairly similar: it suggests inefficiency with regard to almost all parameters in dyslexic individuals. Furthermore, all studies mentioned above lead to the conclusion "[…] that the alteration of eye movement does not depend on oculo-motor dysfunction but is secondary to a defect in the visual processing of linguistic material" (Vagge et al. 2015, 7).

Based on the assumption that the severity of impairments affecting dyslexic individuals is partly influenced by the consistency and transparency of phoneme-grapheme correspondences in a certain orthographic system, as suggested by

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[149] Unfortunately, the researchers do not report the saccade amplitudes observed in both dyslexic and control participants for this experiment.

[150] This finding might be partly explained by referring to the difference between silent reading and reading aloud with regard to eye movements. It is known that reading aloud leads to longer fixation durations (cf. Rayner 1998, 375; Rayner 2009, 1459), such that this might result in an alignment of dyslexic and 'normal' participants.

Paulesu et al. (2001), it would be interesting to investigate whether this assumption can be supported by comparative studies testing eye movement patterns in dyslexic individuals across orthographic systems that are either transparent (such as German and Italian, which are involved in the eye-tracking studies reported here), or opaque (such as English and French). My hypothesis is that the effects of aberrant eye movement patterns are more pronounced in these latter cases. Call this the *orthography-dependent dysculturated eye movements hypothesis*. To the best of my knowledge, no studies have been conducted to test this hypothesis yet. However, Bucci et al. (2012) report several properties of eye movements in 10- to 12-year-old French dyslexic children. In comparison to 'normally' developing children matched for chronological age (group 1) and reading age (group 2), dyslexic children show more fixations, longer fixations, and more regressions (cf. Bucci et al. 2012, 4). Yet, the reported data and the methodology of the study do not allow for a direct comparison with the other eye-tracking studies mentioned above. Trauzettel-Klosinski et al. (2010) attempt to compare their results derived from dyslexics struggling with the German orthographic system with results from earlier studies investigating dyslexia in English participants. Although this type of post-hoc comparison is neither reliable nor significant, the general trend seems to be that "[t]he number of fixations/word was higher in English-speaking readers, even in our control children" (Trauzettel-Klosinski et al. 2010, 689). Furthermore, the tentative conclusion is that "[…] most authors have reported a higher percentage of regressions (19-36%) in English-speaking readers" in comparison to the eye movement parameters of German dyslexic children (ibid., 688). If these considerations were on the right track, they would support the hypothesis that the eye movement patterns of English dyslexics are characterized by more saccades and regressions in comparison to dyslexics struggling with a transparent orthography such as Italian or German. However, it is desirable to conduct an eye-tracking study directly comparing dyslexics' eye movement profiles in both transparent and opaque orthographies by controlling for inclusion criteria, mean age, task difficulty, and measurement technology.

In terms of PP, the overall trend represented by the empirical evidence suggests that active inferences are far from being optimal. They are too slow and too fragmentary to allow for efficient prediction error minimization in dyslexic individuals. This is reasonable, given that the top-down predictions generated by the hierarchical model associated with visual word recognition are inaccurate and imprecise and thus incapable of initiating optimal active inference. As a result, the active, visual engagement with the linguistic environment, understood as an attempt to minimize prediction error and to optimize precision expectations, is characterized by longer fixations, more fixations, shorter saccade amplitudes, and more regressions in dyslexic individuals in comparison to 'normally' developing readers. This, in turn, reinforces the impairments affecting perceptual inference. Again, path-dependent learning is comparatively unsuccessful, since developmental dyslexics are congenitally impaired in visual word recognition.

This also speaks to cognitive transformation and the associated aspect of LDOA. In the last chapter, we have seen that the efficiency of eye movement patterns increases with the successful progression of reading acquisition in 'normally' developing individuals. In contrast, dyslexic individuals are impaired in acquiring the competence to bodily manipulate tokens of an alphabetic writing system. Thus, the bodily component of cognitive transformation remains under-developed, which works in tandem with an under-development of neuronal transformation. However, the aberrant eye movements observed in dyslexic individuals also suggest that these individuals employ a compensation strategy. In particular, their almost excessive eye movements can be interpreted as an attempt to exaggerate the bodily manipulation of the cognitive relevant cognitive resource in order to compensate for the poor functioning of the genuinely neuronal components associated with visual word recognition. This would be a good example of what I would like to call *compensatory learning-driven oculo-motor adaptability* (cLDOA). In terms of the prediction error minimization framework, the system is forced to perform active inferences in a rather dissipative way, because it needs to compensate for poor or inaccurate and imprecise top-down predictions in its ongoing endeavour to infer the (linguistic) hidden causes of its sensory input.

In sum, developmental dyslexia is a good test case for the interaction and interdependence of perceptual and active inference in terms of PP and for the close connection of the transformation thesis and the hybridity thesis defended by CI.

9.5. DEVELOPMENTAL DYSLEXIA AND DYSCULTURATED PREDICTIVE PROCESSING

The cases of developmental dyslexia discussed in the previous section suggest that both neuronal and bodily sub-components of reading are significantly impaired in dyslexic individuals. However, these individuals show certain (sub-personally realized) compensation strategies as indicated by several lines of empirical evidence derived from neuro-scientific and eye-tracking studies. Taken together, this accumulative evidence suggests that developmental dyslexia is a paradigm example of dysculturation. This is because the typical processes of enculturation characterized by LDP, LDOA, and scaffolded learning (including the principle of path-dependence) are far from being successful. This does not mean that individuals diagnosed with developmental dyslexia are not able to read at all. Rather, developmental dyslexia comes in many varieties and degrees and is, like 'normal' reading acquisition, subject to a developmental trajectory from early childhood through adulthood. Furthermore, many developmental dyslexics are exposed to specific reading instruction and remediation programs which help them acquire at least some degree of competence. As we have seen, this competence is often associated with cLDP and cLDOA, which highlights the degree of flexibility of both neuronal and oculo-motor processing routines. From the perspective of EPP, both the dysfunctional and compensatory properties of dyslexic reading performance can be readily described in terms of prediction error minimization. The reduced accuracy and precision of top-down predictions, impairments associated with the propagation of prediction error signals, and the poor functional connectivity of crucial brain areas lead to inefficient perceptual inference. Because of the attenuation of perceptual inference, higher-level predictions cannot be appropriately updated and optimized. In turn, this makes it necessary for the system to perform active inferences (in terms of eye movements) to an almost excessive degree to compensate for the inefficiency of perceptual inference. This kind of cLDOA happens to be the best strategy for the system to acquire useful sensory information. However, this sensory information is only partially functionally beneficial. This is because the entire generative model is poorly connected and fails to propagate precise top-down predictions and precise bottom-up prediction error signals in a seamless and efficient fashion. Even in cases in which neuronal compensatory strategies take over, the smooth and well-balanced alternation of perceptual and active inference that is found in non-dyslexic individuals will never be reached. One reason for this could possibly be that the alternative cortical areas that are recruited as a result of cLDP do not have the same functional biases in terms of their intrinsic and connective processing properties as those cortical areas that are 'normally' recruited for neuronal processes associated with reading. This *dyslexic cLDP hypothesis* might deserve to be tested by future empirical research.

To the best of my knowledge, the description of developmental dyslexia in terms of dysculturation is the first philosophical attempt to account for a vast set of empirical data spanning neuroscientific, eye-tracking, and behavioural studies as well as theoretical accounts of the likely causes and characteristics of this rather frequent disorder. Furthermore, this treatment of dyslexia allows for the additional consideration of instructive and remediating strategies by describing them in terms of scaffolded learning. Thus, the EPP account of dyslexia unifies several lines of investigation and offers new hypotheses to be tested by future research. Finally, the notion of *dysculturation* highlights the crucial observation that developmental dyslexia is a phenomenon characterized by the dysfunction of a cognitive process rendered possible by the socio-culturally structured environment. However, this notion is also thought to refer to the idea that dyslexia is a disorder that is treatable and does not preclude completely the possibility for affected individuals to participate in cultural processes involving written language.

9.6. CONCLUDING REMARKS

In this chapter, I have considered cases of developmental dyslexia. It has turned out that it is possible to account for a vast set of empirical findings and theoretical considerations by contextualizing and interpreting them from the perspective of EPP. In particular, I have tried to show that the two most prominent deficits associated with this developmental disorder, a phonological deficit and an ‘orthographic coding deficit’, can be investigated by assuming that they represent complementary and mutually reinforcing impairments of the hierarchical generative model implemented in the human cortex. In turn, these impairments affect the efficiency of eye movements in terms of active inference. Furthermore, the considerations of developmental dyslexia have highlighted that cognitive transformations can only be successful if both the neuronal and bodily constitutive components are capable of undergoing changes in correspondence with scaffolded, path-dependent learning. Finally, cases of developmental dyslexia illustrate the importance of cognitive norms. This is because they show that a cognitive practice such as reading can only be learned successfully if this goes along with the acquisition of the relevant cognitive norms (i.e., norms having to do with the alphabetic principle and grapheme-phoneme correspondences).

To conclude, cases of developmental dyslexia are important for at least two reasons. First, they help refine approaches to reading acquisition in ‘normally’ developing individuals, because they emphasize what needs to be acquired and which cortical and bodily changes must occur to render expertise in reading possible. Second, developmental dyslexia is theoretically interesting in its own right, for research on this disorder allows a thorough and fine-grained investigation of the complex interaction of many sub-components of reading and reading failure. In addition, research on dyslexia hopefully helps develop new remediation and intervention strategies to assist dyslexic individuals in getting along in their socio-culturally structured environment, in which the importance of literacy can hardly be underestimated.

10. HIGH-FUNCTIONING AUTISM

10.1. INTRODUCTION

In chapter 6, I have argued that the processing of syntactically cohesive und coherent linguistic structures can be adequately described in terms of EPP. The claim was that knowledge of the statistical probabilities of syntactic structures informs the prior predictions entertained by a system in the face of visually presented linguistic input. In this chapter, I will follow up on this approach to sentence processing by considering cases of high-functioning autism and of autism spectrum disorders (ASD) more generally.[151]

Autism is a developmental neuropsychological disorder that is characterized by a variability of both cognitive deficits and strengths and by highly specific behavioural profiles. In a nutshell, "[a]utism is diagnosed when a child or adult has abnormalities in a triad of behavioral domains: social development, communication, and repetitive behaviors and obsessive interests" (Baron-Cohen & Belmonte 2005, 110). One of the most influential theoretical attempts to understand autistic cognition is Uta Frith's (2003) *weak central coherence* account. The basic idea is that many autistic individuals show certain strengths in processing isolated units of stimuli while being impaired in integrating and contextualizing information:

> In the normal cognitive system there is a built-in propensity to form coherence over as wide a range of stimuli as possible, and to generalize over as wide a range of contexts as possible. It is this drive that results in grand systems of thought, and it is this capacity for coherence that is diminished in children with autism. As a result, their information-processing systems, like their very beings, are characterized by detachment. (Frith 2003, 159f)

This assumption does not imply that weak central coherence is an all-or-nothing phenomenon without any intra- or inter-individual variability. Rather, weak central coherence is considered to be "a processing bias for featural and local information" or a pervasive "cognitive style" characterizing many empirically observed patterns of autistic cognition on a wide range of tasks (Happé & Frith 2006, 6). For present purposes, I will restrict my considerations to findings indicating that the processing

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[151] The latter notion additionally includes Asperger's syndrome and pervasive developmental disorders not otherwise specified (PDD-NOS). Unless otherwise indicated, I will restrict my considerations to high-functioning autistic individuals, since this is the subgroup on the autism spectrum that is best studied with regard to the processing of syntactically structured written language.

of written language in autistic individuals is best captured by referring to weak central coherence. First, I will summarize results from behavioural studies targeted at the investigation of autistic reading performance. Second, I will describe neuroscientific results attempting to identify the neuronal specifics of autistic cognition that may account for the aberrant reading behaviour seen in autistic individuals. Third, I will consider recent attempts to elucidate eye movement patterns specific for autistic individuals in sentence processing. Finally, since an overarching theoretical framework integrating these data sets has been lacking, I will try to develop a parsimonious approach that accounts for the strengths and weaknesses of reading in high-functioning autism from the EPP perspective.

10.2. READING PERFORMANCE IN HIGH-FUNCTIONING AUTISM ON A PERSONAL LEVEL OF DESCRIPTION

There is converging evidence that the processing of linguistic representations in high-functioning autism shows a discrepancy between superior skills in the visual recognition of single, isolated words and comparatively poor performances in tasks being dedicated to the processing of cohesive and coherent syntactic structures (cf. Huemer & Mann 2010, 485f; Jones et al. 2009, 722; Nation et al. 2006, 912; Newman et al. 2007, 773; O'Connor & Klein 2004, 115f). In particular, many participants in behavioural studies show patterns of visual word recognition that are above average in terms of reading times and accuracy. These patterns are often associated with *hyperlexia*, which can be defined as a "precocious ability to read single words" (Newman et al. 2007, 773). Furthermore, this "phenomenon refers to an excess of ability to deal with the 'mechanical' (i.e., stripped of grammar, syntax, and meaning) aspects of words" (Grigorenko et al. 2003, 1080).[152] The most illustrative examples for this kind of reading behaviour come from studies comparing single-word reading to reading sentences that contain homographs. The pioneering

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[152] To date, it is debatable whether hyperlexia is necessarily co-occuring with high-functioning autism or whether hyperlexia might be dissociable from autism diagnoses (for discussions, see Grigorenko et al. 2003; Nation et al. 2006; Newman et al. 2007). However, based on the results from an MEG/EEG study on single word reading in autistic adults, Moseley et al. (2013, 10ff) have argued that the phenomenon of hyperlexia could be associated with an increased employment of a dorsal processing stream associated with the processing of grapheme-to-phoneme correspondences in contrast to decreased activities in the ventral stream assumed to be associated with the processing of the meaning of an entire word according to dual route models of visual word recognition (e.g., Coltheart et al. 2001). That is, the authors conclude that the consistent finding of superior visual word recognition in high-functioning autistic individuals might be due to an overreliance on the mapping of graphemes to phonemes in comparison to 'neurotypical' control participants.

study conducted by Frith and Snowling (1983) investigates the reading behaviour of autistic, dyslexic, and 'normal' control children and adolescents. It is based on the prediction that autistic children and adolescents (i.e., 9- to 17-years-old individuals) "[…] show reading failure only when it is necessary to take meaningful context into account, that is when sentences have to be read for meaning, but not when reading single words" (Frith & Snowling 1983, 330).[153] The researchers find that autistic children are able to read aloud regular, irregular, and pseudowords and that they are sensitive to the Stroop effect. These results are interpreted to "attest to the normality of autistic children's strategies in single-word reading" (ibid., 334). In the homograph reading task, however, the autistic participants show severe difficulties in reading aloud ambiguous words, whose correct pronunciation and accurate meaning depends on the context of an entire sentence: "The pattern of errors indicates a failure of the autistic children to use semantic/syntactic context in pronouncing the homographs. [...] Thus, if one considered accuracy in terms of single-word reading they were correct. In terms of connected prose, however, accuracy was poor" (ibid., 336). In follow-up studies involving the homograph reading task paradigm, these findings are replicated for both autistic children (Happé 1997; López & Leekam 2003) and autistic adolescents and adults (Happé 1997; Jolliffe and Baron-Cohen 1999). The authors take their results as evidence for the validity of the weak central coherence account. That is, they hold that autistic individuals appear to have difficulties in disambiguating constituents of sentences, because they fail to acknowledge that syntactically organized linguistic information are coherent and meaningful structures.

However, recently some criticism has been raised against the explanatory power of the above-mentioned studies. For instance, Brock and Caruana (2014, 128) acknowledge "that there is clear and fairly consistent evidence" in support of the initial study conducted by Frith and Snowling (1983). They go on to argue that "[w]hat standardized tests fail to address, however, is the underlying mechanism".[154] This criticism is well-taken and points to specific shortcomings of most research on language processing in high-functioning autism. While the empirical evidence is highly consistent in observing certain behavioural performances in tasks such as

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[153] For a concise summary of this study and comparisons to more recent studies proving the validity of initial results, see Brock and Caruana (2014).

[154] This evaluation of the state of research, which also applies to other target phenomena being associated with particular deficits and assets seen in ASD more generally, is also admitted by Happé and Frith (2006, 19): "A major limitation of the coherence account to date is the lack of specification of the mechanism, at both the cognitive and neural levels, that underlies detail-focused processing bias among people with ASD."

reading homographs, an overarching framework accounting for the underlying cognitive mechanisms remains to be developed.

In summary, there is converging evidence from a rich number of behavioural studies indicating that high-functioning autistic individuals as well as children, adolescents, and adults on the autism spectrum show a consistent pattern of reading behaviour: While their performance in tasks requiring single-word reading is on average or even superior, their sentence processing capacities tend to be impaired. This phenomenon is consistently referred to as *weak central coherence*.[155] However, there are a number of open questions that need to be addressed by future research: First, it is not clear how this phenomenon of weak central coherence in the processing of syntactically structured written language can be explained on a functional level of description. Second, to date it remains unclear what causes the aforementioned deficits in sentence processing. As pointed out by Huemer and Mann (2010, 485), potential explanations might refer to “difficulties integrating information in context”, “deficits in verbal skills and oral language ability”, or “impairments in communication […] and/or general language impairment”. Further behavioural studies targeted at investigating the interaction of these factors with specific reading performances are clearly needed. Finally, it remains to be specified to what extent syntactic processing in high-functioning autism is subject to inter-individual differences and to intra-individual trajectories throughout the lifespan.

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[155] Interestingly, Leo Kanner (1943), who is considered to be a pioneer of autism research, described cases of autistic cognition that are majorly confirmed by more contemporary research. In particular, he interprets the behaviour of autistic children in a way that is highly consistent with the findings reported here. To appreciate this, it is worth quoting a paragraph from his paper *Autistic Disturbances of Affective Contact* (1943, 246) in full length: “A situation, a performance, a sentence is not regarded as complete if it is not made up of exactly the same elements that were present at the time the child was first confronted with it. If the slightest ingredient is altered or removed, the total situation is no longer the same and therefore not accepted as such, or it is resented with impatience or even with a reaction of profound frustration. The inability to experience wholes without full attention to the constituent parts is somewhat reminiscent of the plight of children with specific reading disability who do not respond to the modern system of configurational reading instruction but must be taught to build up words from their alphabetic elements. This is perhaps one of the reasons why those children of our group who were old enough to be instructed in reading immediately became excessively preoccupied with the ‘spelling’ of words, or why Donald, for example, was so disturbed over the fact that ‘light’ and ‘bite’, having the same phonetic quality, should be spelled differently.”

10.3. NEURONAL IMPAIRMENTS IN SENTENCE PROCESSING

Recently, research in cognitive neuroscience has begun to investigate sentence processing in individuals with high-functioning autism on a neuronal level of description. Just et al. (2004) report an fMRI experiment seeking to identify aberrant neuronal activation patterns in brain areas that have been associated with sentence processing in 'neurotypical' individuals. Furthermore, the researchers are interested in measuring the functional connectivity of these regions of interest. The task to be performed by both adult high-functioning autistic and control participants was to read isolated sentences being either active or passive and responding to probe questions (cf. Just et al. 2004, 1813). Two significant findings are derived from the patterns of neuronal activation elicited by this imaging paradigm. First, in comparison to the control group, the data derived from the autistic participants indicate for the two tasks that they show a higher level of activation in the left posterior superior temporal gyrus (LpSTG) and middle temporal gyrus (LMTG) and less activation in the left inferior frontal gyrus (LIFG; cf. ibid., 1816). This finding is interpreted as follows:

> […] compared with controls, the autistic participants engage in more extensive processing of the meanings of individual words that comprise a sentence, manifested as more LSTG (Wernicke's area) activation, which is consistent with their hyperlexicality or unusual strength in processing single words […]. At the same time, the autistic participants showed less activation in LIFG than the control group. […] The reduced activation in this region is consistent with the finding that high-functioning autistic participants are impaired in their ability to process the meaning of complex sentences […]. (ibid.)

This interpretation is in line with converging evidence from studies indicating that significant activities in the left IFG are associated with sentence processing in 'neurotypical' participants (Braze et al. 2011; Constable et al. 2004; Fedorenko et al. 2012; Just et al. 1996; Kaan & Swaab 2002; Michael et al. 2001; Shankweiler et al. 2008).[156] That is, while successful sentence processing routines are frequently associated with neuronal activation patterns in left IFG, the behaviourally manifested impairment of this particular processing stage seen in high-functioning autistic individuals is consistently associated with comparatively reduced neuronal activation in this cortical area. Furthermore, the increased neuronal activation of the LpSTG and the LMTG found by Just et al. (2004) can be related to findings on sentence processing in 'neurotypical' individuals. Specifically, as reviewed in chapter 6, increased activation in the LMTG has been associated with syntactic priming effects

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[156] For details, see chapter 6.

(cf. Noppeney & Price 2004, 705), and syntactic ambiguity resolution (cf. Snijders et al. 2009, 1500). Furthermore, increased activation in the LMTG, together with neuronal activation in the LpSTG, has been associated with tasks involving the processing of grammatically complex syntactic structures (cf. Constable et al. 2004, 18f; see also Keller et al. 2001; Michael et al. 2001). This suggests that high-functioning autistic individuals display more cognitive effort in processing syntactic structures. This is associated with alleviated neuronal activation patterns in associated cortical areas.

The second significant finding reported by Just et al. (2004, 1817) is "[…] that the functional connectivity was lower throughout the cortical language system among the autistic participants than in the control participants, suggesting that the coordination and communication between cortical areas is lower in the autistic group." This is interpreted as evidence for the *underconnectivity theory*, which basically assumes "[…] that autism is a cognitive and neurobiological disorder marked and caused by underfunctioning integrative circuitry that results in a deficit in integration of information at the neural and cognitive levels" (ibid.).[157] As the authors acknowledge, this theoretical approach, which is majorly concerned with the neuronal mechanism underlying autistic language processing, is consistent with weak central coherence (cf. ibid., 1819). That is, the patterns of autistic behaviour captured by Frith's (2003) account might be at least partly explained in terms of functionally under-connected higher-level brain regions that are usually associated with specific cognitive activities such as sentence processing.

Additionally, Kana et al. (2006) provide further evidence for functional underconnectivity in sentence processing performed by adult autistic individuals. They report a task-related fMRI paradigm in order to investigate the functional connectivity of brain areas that are associated with both sentence processing and visual imagery. The main finding is that high-functioning autistic adults show increased patterns of neuronal activation in parietal and occipital regions associated with visuo-spatial processing. Kana et al. (2006) conclude that this finding can be explained in terms of a compensation for the functional hypo-connectivity of cortical areas that are usually associated with sentence processing in non-impaired individuals. Consequently, autistic individuals are described as "[…] making greater

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[157] For an elaboration on this assumption, see Just et al. (2012) and Schipul et al. (2011). Generally, these authors hold that "lower frontal-posterior connectivity" might be responsible for the behavioural patterns seen in (adult) autistic individuals performing cognitive tasks (Schipul et al. 2011, 3). For reviews of recent approaches to functional and structural connectivity in autism and ASD more generally, see Lenroot and Yeung (2013) and Vissers et al. (2012).

use of parietal and occipital areas and relying less on frontal regions for linguistic processing, possibly because the connections between the frontal and parietal regions are compromised” (Kana et al. 2006, 2492). This suggests that sentence processing in high-functioning autistic individuals is characterized by a tendency to rely more on lower-level sensory information than on higher-level cognitive processing routines associated with sentence processing in ‘neurotypical’ individuals.

Further evidence for this general tendency comes from Keown’s et al. (2013) RSFC study performed with adolescent individuals diagnosed with ASD. While long-distance functional connections appear to be underdeveloped in autistic participants, local-distance functional connections at lower cortical levels, especially in temporal and occipital regions, are significantly increased in comparison to control participants (cf. Keown et al. 2013, 567f). This provides support for the idea that adolescent autistic individuals tend to prefer low-level localized over more integrative cognitive processing styles which is associated with local lower-level functional overconnectivity and global, long-distance functional underconnectivity.

More recently, some researchers have raised doubts against the proposal that functional underconnectivity might exhaustively explain the observed patterns of aberrant cognitive functioning in high-functioning autism (Müller et al., 2011; Supekar et al. 2013; Uddin et al. 2013). They point to rather disparate findings across fMRI studies investigating task-related functional connectivity in autism. In particular, they report emerging empirical evidence for whole-brain functional *over*connectivity in autistic children in contrast to task-dependent functional *under*connectivity in autistic adults (cf. Supekar et al. 2013, 738f; Uddin et al. 2013, 2). Consequently, Uddin et al. (2013, 2) argue “that discrepancies between findings of autism-related hypo-connectivity and hyper-connectivity might be reconciled by taking developmental stage into account”. It is important to bear in mind that the “developmental trajectory” of aberrant cortical functioning in autism is not yet well understood and that more elaborate accounts and further empirical investigations are clearly required (cf. Supekar et al. 2013, 743). The mixed results obtained by Keown et al. (2013) might point into the right direction by suggesting that autistic individuals between childhood and adulthood show significant differences between low-level local and higher-level global functional connectivity, which might ultimately lead to the task-related pattern of neuronal activation seen in Just’s et al. (2004) study. Thus, Uddin’s et al. (2013) and Supekar’s et al. (2013) concerns do not necessarily affect Just’s et al. (2004) findings on functional underconnectivity being associated with sentence processing. Rather, a proviso is at order: it is important to acknowledge that Just’s et al. (2004) findings are likely to apply to *adult* high-functioning autistic individuals only. This allows for the possibility that the underlying neuronal mechanisms might be different for high-functioning autistic children and adults. This hypothesis needs to be empirically tested by future research seeking to investigate the neuronal processes associated with sentence processing in high-functioning autistic children, adolescents, and adults. One way this could be done is by conducting well-controlled longitudinal studies that thoroughly investigate the development of autistic cognition from early childhood to adolescence and adulthood (cf. Uddin et al. 2014, 8).

In summary, the study by Just et al. (2004) is a first important step towards identifying the neuronal mechanisms underlying the reading patterns of (adult) high-functioning autistics identified by behavioural studies in terms of weak central coherence. Clearly, follow-up studies employing a wide variety of paradigms and testing further subgroups of individuals with autism and ASD are needed in order to gain further insights into the neural underpinnings of aberrant sentence processing throughout the lifespan of autistic individuals.
However, it is reasonable to propose a theoretical approach to syntactic processing in high-functioning autistic individuals that accounts for the current state of research. This will be done in the course of this chapter.

10.4. OCULO-MOTOR ABERRATIONS IN SENTENCE PROCESSING

Sansosti et al. (2013) report an eye-tracking experiment with adolescent autistic as well as ‘neurotypical’ control participants. The task is to read pairs of sentences requiring a bridging inference. The results indicate that the autistic participants “made more fixations”, that their “mean fixation duration […] was longer than control participants’ mean fixation duration” and that they “made significantly more regressions per stimulus than the control participants” (Sansosti et al. 2013, 1539). This suggests that autistic individuals tend to rely on thorough and time-consuming fixation and re-fixation strategies that significantly exceed the eye movement patterns observed in control participants. To the best of my knowledge, this is the only eye-tracking study reported so far that is interested in eye movement patterns associated with sentence processing in high-functioning autistic individuals.

However, Brock and Bzishvili (2013) report an eye-tracking experiment with non-autistic individuals that perform the seminal homograph reading task first employed by Frith and Snowling (1983). They conclude that their results

> […] demonstrate that performance on the homograph reading task cannot simply be assumed to measure context processing or central coherence. Homograph reading accuracy is also influenced by interference from previous trials, the length of the participant's eye-to-voice span and, it would appear, their ability to detect errors and strategically alter eye-to-voice span to minimize future errors.” (Brock & Bzishvili 2013, 1771f)

This suggests that more research is needed to disentangle the complex neuronal and oculo-motor sub-processes associated with the performance of the homograph reading task in both non-impaired and high-functioning individuals. The acquired data remain to be compared with eye-tracking data from autistic participants in order to achieve any significant results that more directly contribute to research on reading in autism and ASD.

10.5. High-Functioning Autism and Dysculturated Predictive Processing

Psychological research suggests that there is a discrepancy between comparatively good visual word recognition (*strong local coherence*) and poor sentence processing (*weak central coherence*) in high-functioning autistic individuals. In ‘neurotypical’ readers, the stages of visual word recognition and sentence processing are highly interactive. However, the integration of locally processed single words into a broader, syntactically organized context appears to go astray in cases of high-functioning autism. This leads to the assumption that the transition from visual word recognition to sentence processing is impaired. Put differently, visual word recognition and sentence processing skills appear to become dissociated. I shall argue that this dissociation is best captured by describing them from the perspective of EPP. Furthermore, I will argue that the reading performance of high-functioning autistic individuals is yet another important example of dysculturation. This is because the process of enculturated reading acquisition goes astray and leads to reading performance that significantly differs from the application of cognitive norms observed in ‘normal’ individuals. The remainder of this section will serve to carefully develop a new account of reading performance in high-functioning autistic individuals in terms of dysculturated PP.

Consider hierarchical generative modelling associated with sentence processing in ‘normal’ individuals. Here, high-level top-down predictions are associated with prior knowledge of the statistical probabilities of specific syntactic structures and sequentially ordered combinations of words. The prediction error is the discrepancy between top-down prior predictions and bottom-up neuronal information at each level of the hierarchically organized generative model. Applied to sentence processing in high-functioning (adult) autistic individuals, it seems reasonable to suppose that the system holds insufficient prior predictions associated with syntactic structures conveyed by the visual input. In addition, these impoverished high-level prior predictions should have limited causal influence on lower-level processing levels.

This idea is in line with recent approaches in autism research considering Bayesian modelling as a mechanism that might explain the characteristics of autistic perception. Pellicano and Burr (2012a) suggest that autistic perception can be described within a Bayesian framework. The proposal here is “that altered autistic perception results from atypicalities at the level of the prior – either in its construction or in combining appropriately with sensory information – yielding unusually attenuated priors or ‘hypopriors’” (Pellicano & Burr 2012a, 506f). The attenuation of high-level priors would help explain the superior performance of autistics in tasks requiring the processing of local, isolated information. This is because imprecise top-down predictions lead to a greater influence of bottom-up information on the overall processing hierarchy. Following up on this proposal, Friston et al. (2013) argue that it is reasonable to embed this Bayesian approach in the PP framework and relate it to *weak central coherence* (Frith 2003; Happé & Frith 2006). On their construal,

> […] the lack of central coherence seen in autism can […] be attributed to attenuated estimates of precision (or hyperpriors) at higher (central) levels of hierarchical models in the brain. Crucially, this means that the abnormality – from a psychological perspective – is not a failure *per se*, but a failure to instantiate top-down predictions during perceptual synthesis because their precision is too low.[158] (Friston et al. 2013, 1; italics in original)

This implies that the weak performance of high-functioning autistic individuals in tasks requiring information integration can be described in terms of an imbalance in the precision estimation of high-level top-down predictions and low-level bottom-up

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[158] A related idea is mentioned by Happé and Frith (2006, 21), who propose “[…] that a lack of top-down modulation, due to failure of early neural pruning of feedback connections, could be a cause of abnormal connectivity.”

prediction error signals.[159] This is also implied in Jakob Hohwy's (2013, 163) PP account of autism:

> The simple idea is then that in autism there is a bias towards particularist perceptual inference as a result of failed optimization of expected precisions. That is, in autism much of the world is represented correctly but is harnessed by hypotheses that are causally shallow, that miss out on longer-term regularities and that cannot well predict deeply hidden causes.

Lawson et al. (2014, 2) capture this line of reasoning in their *aberrant precision hypothesis*: "[…] high sensory precision in autism, relative to prior precision, may be caused by a failure of sensory attenuation. In other words, an inability to contextualize sensory information renders sensory prediction errors too precise and context insensitive."[160] However, they go on to argue that it is hard to decide whether aberrant precision estimations in autistic individuals are primarily caused by attenuated precision estimations of higher-level top-down predictions, by amplified precision estimations of lower-level prediction error, or by a combination of both: "Although mechanistically distinct, both overly precise estimates of sensory precision and under-precise estimates of prior precision would produce the same functional consequences; i.e., perception/interaction that lies closer to the sensory input and is insensitive to context" (ibid., 6). On theoretical grounds, it seems more likely that the processing bias observed in high-functioning individuals on the autism spectrum are associated with an increased reliance on lower-level bottom-up prediction errors that are estimated as yielding very precise information. In developmental terms, this amounts to the idea that a continuous overreliance on precise lower-level bottom-up prediction error leads to ever-new fine-grained

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[159] Quattrocki and Friston (2014) speculate that the aberrations in second-order statistics associated with autistic processing routines might be causally linked to aberrant neuro-modulatory effects of oxytocin on interoception and exteroception. According to their proposal, in 'neurotypical' individuals "[...] oxytocin is necessary for contextualizing top-down prediction and the subsequent learning of multimodal generative models during development" (Quattrocki & Friston 2014, 414). If oxytocin fails to modulate neuronal processing associated with interoception and exteroception, the imbalance of the optimization of precision estimations associated with autistic cognition is assumed to ensue: "As a result of this oxytocin dependent failure to prescribe appropriate salience to exteroceptive cues and to facilitate interoceptive attenuation, an onslaught of unfiltered sensory information overwhelms the child […]" (ibid., 424). In order to support this assumption, more empirical evidence for the neuro-modulatory role of the oxytocin system in both 'neurotypical' and autistic individuals is needed. However, given the current state of research, which assumes that neurotransmitter systems (which are in turn influenced by hormones such as oxytocin) are associated with the estimation of precision, it is intelligible to assume that failures in the optimization of precision estimations are causally influenced by imbalances in neurotransmitter and neuro-modulation systems.

[160] Relatedly, Hohwy (2015b, 308) argues that "[e]xpecting too much precision in the prediction error is a kind of attention grabbing: the gain on lower-level error units is set too high, and there is a preoccupation with sensory input, as is often seen in ASD."

prediction updating at lower levels of the hierarchy over time. Consequently, high-level predictions fail to represent more general and abstract properties of sensory information, because they do not receive the kind of bottom-up information that is required for their development. This is associated with comparatively imprecise high-level top-down predictions. In this vein, van de Cruys et al. (2014) argue that an exaggerated estimation of the precision of low-level bottom-up prediction error is at the core of aberrant perceptual and cognitive processing in high-functioning individuals on the autism spectrum.[161] Their HIPPEA (i.e., high, inflexible precision of prediction errors in autism) account of ASD rests on the following assumptions:

> The starting point is a high and inflexible estimation of precision in prediction errors in ASD. […] Indiscriminately high precision will mean that unrepeated, accidental variations in the input receive disproportionate weight. This in turn, prevents abstract representations from being formed, because matching will continue on a more specific level, closer to the input. Indiscriminately high precision also induces superfluous learning, leading to narrowly defined, lower-level predictions, and incomplete hierarchical models. (van de Cruys et al. in 2014, 653)

If this line of reasoning is on the right track, a deficit in the optimization of precision estimations throughout the cortical hierarchy leads to impaired perceptual and active inference. This is because the system overly relies on the precision of bottom-up prediction error at lower levels at the expense of precise high-level top-down predictions. This gives rise to the psychological effects described as weak central coherence.[162]

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[161] In contrast, van Boxtel and Lu (2013) argue that imprecise high-level top-down predictions are primary to the second-order statistics deficit ascribed to individuals on the autism spectrum: “With decreased high-level processing in ASD [...], predictions are presumably less precise (or less strong, i.e., hypo-priors [...]), and thus prediction errors (‘surprises’) will increase. As a result, the sensory systems of people with ASD will be constantly bombarded by new ‘surprises’, and hence overloaded with sensory stimulation” (van Boxtel & Lu 2013, 2).

[162] In a series of experiments, Paton et al. (2012), Palmer et al. (2013), and Palmer et al. (2015) provide evidence for this approach. By exposing individuals on the autism spectrum and ‘normal’ individuals scoring high on a measurement scale of ASD to the rubber hand illusion, they find that the intensity of autistic traits is correlated with an increase of precision expectations given certain sensory inputs (see Hohwy & Palmer 2014). This is suggested by the main trend seen in all three studies: while autistic individuals and individuals with a significant number of autistic traits seem to experience the rubber hand illusion in ways comparable to control participants, they are less affected by the illusion in a reaching task performed after the illusion has been experienced (cf. Palmer et al. 2015, 6). This trend is taken “[…] as reflecting a greater weighting of sensory feedback in determining arm position during movement, such that prior representations of the environment are relatively circumscribed in their influence” (ibid.). The results derived from all three studies are interesting, because they allow for a specification of the influence of the imbalanced optimization of precision expectations at multiple scales on the close coordination of perceptual and active inference.

These considerations can be readily applied to the reading behaviour observed in high-functioning (adult) autistic individuals. The results of behavioural studies employing the homograph reading task suggest that the lower-level predictions required for visual word recognition are sufficiently precise and therefore appropriately fulfil their proper function in the PP hierarchy. However, sentence processing is more complex than the recognition of isolated, visually presented words. This is because more general and abstract cognitive operations are needed in order to account for syntactic complexity and the probability distributions of syntactically connected, meaningful linguistic structures. Therefore, it seems reasonable to assume that sentence processing allocates additional neuronal resources at higher levels of the processing hierarchy. If the aberrant precision hypothesis advocated above proved correct, high-level top-down predictions associated with probabilistically assessed syntactic structures should be estimated as being imprecise, such that they do not exert the causal influence that usually is to be expected. This leads to the manifestation of dysculturated cognitive processing in the sense that the imprecision of high-level predictions and exaggerated precision estimations of lower-level prediction error are associated with a dysfunction in the performance of the cognitive practice under scrutiny here. Call this the *dysculturated precision estimation failure* (DPEF) hypothesis.

The DPEF hypothesis is able to account for the behavioural pattern observed in adolescent and adult high-functioning autistic individuals, which suggests that visual word recognition skills have been successfully acquired while higher-level sentence processing routines remain impaired. This hypothesis further suggests that the specific features that characterize reading in high-functioning autistic individuals at least partly result from sub-personally recruited compensatory strategies in terms of cLDP and cLDOA. This is because the neuronal and oculo-motor patterns observed in autistic individuals imply that the comparatively fragmentary processing style is also a specific way to cope with sensory information. By employing such compensatory strategies, the autistic organism tries to compensate for the inability to track long-term regularities and to predict abstract linguistic properties (e.g., compositionality). This is associated with an emphasis on neuronal low-level processing and small-scale eye movements.

In addition, the DPEF hypothesis is able to interpret the finding reported by Just et al. (2004) that the level of neuronal activation in the LIFG is decreased in high-functioning autistic adults in comparison to control participants. In terms of the DPEF hypothesis, this suggests that prediction error minimization at higher cortical levels is significantly affected, because top-down predictions are inefficient. The reason for this is that they have been assigned poor precision and thus impoverished causal efficacy. The increased activation observed by Just et al. (2004) in the LpSTG and LMTG can be interpreted as a relative increase of causal influence that lower-level bottom-up prediction errors exert on the overall prediction error minimization process, because they are estimated as yielding high precision. In this case, the interpretation would be that an increase of prediction error is a result of imprecise top-down predictions. That is, the generative model as a whole needs to rely more heavily on bottom-up processing signals because the predictions are rendered imprecise.

Furthermore, the DPEF hypothesis would be in line with the aforementioned assumption that functional underconnectivity at higher cortical levels is a pervasive phenomenon associated with the neural mechanisms underlying sentence processing in high-functioning autism, at least in cases of high-functioning autistic adults (Just et al. 2004; Just et al. 2012; Keown et al. 2013; Schipul et al. 2011). The causal inefficiency of imprecise predictions is associated with a decrease of neuronally realized top-down processing. This is intelligible, given that the optimization of precision estimations is an important causal factor in the establishment of functional connections across cortical areas over time. If an impairment in second-order statistics leads to an impoverished development of functional connections responsible for perceptual and active inference, this will have long-lasting effects on the overall efficiency of high-level cognitive processing routines. This view can be complemented by the empirical finding reviewed earlier that high-functioning adolescent autistic individuals display both significantly decreased long-distance functional connections and increased local functional connections, especially in occipito-temporal regions as obtained from RSFC analyses (Keown et al. 2013). From the perspective of the DPEF hypothesis, this suggests that while lower-level cortical interactions may be unaffected (such as occipito-temporal regions which are associated with visual word recognition), the consequence of impaired second-order statistics is a comparatively poor functional interaction between higher-level cortical areas. The finding that functional connections between lower-level cortical areas are increased can be captured in terms of cLDP. Given that the neuronally realized part of the prediction error minimizing system is impaired in providing precise high-level top-down predictions, the system needs to rely more heavily on lower-level processing routines in order to compensate for its failure to engage in more abstract prediction error minimizing instances. This would be associated with a relative increase of neuronal activation patterns in relevant lower-level cortical areas and an increase of functional connectivity among these areas. This is exactly what has been observed by Just et al. (2004) and Keown et al. (2013).

So far, the discussion has only been concerned with the consequences of a failure in precision estimation for perceptual inference. It is reasonable to suppose that an imbalance in second-order statistics also has a causal influence on active inference. Previously, I have mentioned Sansosti's et al. (2013) eye-tracking study indicating that high-functioning autistic individuals appear to execute more and longer fixations as well as more regressions in comparison to 'neurotypical' individuals. This suggests that predictions leading to the initiation of eye movements in terms of active inference are associated with lower-level features of the visually manipulable stimulus array. In particular, the assumption is that the difference between high-functioning autistic and 'neurotypical' individuals is that the former group performs active inferences as if the available sensory data did not represent linguistic information that encodes cohesive and coherent syntactic units, but isolated words that can be meaningfully processed independently from each other. This shows how impaired second-order statistics has significant consequences not only for perceptual inference, but also for active inference. Put differently, the specific eye movement patterns that are characterized by a slow and exhaustive sub-personally initiated fixation strategy figures as the system's attempt to compensate for the absence or unreliability of high-level predictions. Thus construed, the eye movements exhibited by high-functioning autistic individuals are in instance of cLDOA. However, more empirical evidence is needed in order to conclusively evaluate the plausibility of the DPEF hypothesis and its take on aberrant active inference observed in high-functioning autistic individuals. As already mentioned, it would be desirable to conduct an eye-tracking study which investigates the eye movement patterns of (adult) autistic participants while they perform the homograph reading task.

Generally, more empirical research on written language processing in high-functioning autistic individuals is clearly needed. This primarily concerns neuroimaging and eye-tracking studies that have the explanatory power to decide whether the view developed here is feasible and empirically plausible. I suggest that there are at least two research strategies that might be helpful for directly testing the DPEF hypothesis.

First, it is conceivable to conduct EEG studies which are able to investigate the differences between visual word recognition and sentence processing in high-functioning autistic individuals and carefully matched control participants by measuring ERPs in at least two conditions. One condition could involve the visual recognition of a group of unrelated single words, while another condition could be targeted at the processing of syntactically structured sequences of words (which might contain homographs). Prior research has identified several ERPs that are reliably associated with visual word recognition and sentence processing in non-impaired individuals. In particular, the N1 ERP has been associated with visual word recognition (cf. Brem et al. 2010; Eberhard-Moscicka et al. 2015; Maurer et al. 2006) and increased neuronal activation patterns in the left vOT area. The P600 effect has been repeatedly associated with syntactic processing (cf. Friederici 2011). In addition, the N400 effect has been associated with semantic processes both at the word and sentence level (cf. Friederici 2011). My prediction based on the DPEF hypothesis is that the P600 effect should either be absent or significantly reduced in high-functioning autistic individuals in comparison to the electrophysiological data obtained from the control group. For autistic individuals, but not for the control group, the N400 effect should not significantly differ across conditions, which would indicate that the autistic processing style does not distinguish between visual word recognition proper and sentence processing. The N1 effect should be present in both groups across conditions, which suggests that both groups in all contexts are able to process visually presented words. Because of the hyperlexic reading behaviour observed in high-functioning autistic individuals, it is also possible that the N1 effect might turn out to be more significant in this group in comparison to controls.

Second, it might be promising to employ a similar paradigm in future fMRI studies in order to be able to follow up on Just’s et al. (2004) and Keown’s et al. (2013) studies. In particular, based on the DPEF hypothesis it is to be expected that there should be significant differences of neuronal activation patterns in crucial brain regions associated with higher-level language processing such as the left IFG (e.g., Friederici 2012; Zempleni et al. (2007); left superior STG (e.g., Price & Mecchelli 2005), and left MTG (e.g., Braze et al. 2011; Noppeney & Price 2004) across conditions in control participants, but not in high-functioning autistic individuals. A further prediction is that the activation in the left vOT area is not markedly different in autistic and non-autistic individuals across conditions. This is because this area is thought to be associated with the visual recognition of words, almost independent of whether they are presented in a syntactic context or in isolation.

It would be ideal to have new sets of data from both EEG and fMRI experiments, because both neuroimaging technologies differ with regard to their local and temporal accuracy. Combining both approaches would increase the explanatory scope of both experimental strategies. In addition to neuroimaging attempts to elucidate the neuronal sub-processes of reading in high-functioning autistic individuals, it would possibly be rewarding to conduct new eye-tracking studies using the same kinds of tasks as those proposed above. These eye-tracking studies could either be self-sufficient or they could be combined with EEG or fMRI measurements. My prediction is that in comparison to control participants, the eye movement patterns of high-functioning autistic individuals should not be significantly different across conditions. This is likely to be the case, because the kind of top-down predictions that causes the initiation of saccades should majorly be concerned with probability distributions at lower processing stages (i.e., at the word level) only. If this prediction turned out to be verified, this would also be in line with the general trend of eye movement patterns reported by Sansosti et al. (2013). The combination of eye-tracking methodologies with EEG and fMRI is desirable because it could provide further information about the close coordination of neuronal processing and oculo-motor actions (i.e., perceptual and active inference) across time. Furthermore, it would allow for a more fine-grained analysis of data obtained from EEG and fMRI, because the location and duration of fixations can provide useful information for the association of neuronal events with psychological categories. This is perhaps more important for fMRI experiments, because fMRI data acquisition has it that the temporal resolution is worse than in EEG experiments.

However, it needs to be kept in mind that the current stage of research and the available technologies hardly allow to decide between two possible causes of the specific reading pattern associated with high-functioning autism in adults. Recall that the deficits seen in this group could be caused primarily by decreased precision estimations of higher-level top-down predictions or by increased precision estimations of lower-level prediction error in comparison to ‘normal’ individuals, or by a combination of both. Both scenarios would lead to the same results derived from EEG, fMRI, and eye-tracking experiments. In addition, both scenarios are compatible with the DPEF hypothesis. This is because both decreased precision estimations of predictions at higher levels and increased precision estimations of lower-level prediction error signals would lead to an overreliance on low-level processing stages in perceptual and active inference. However, an indirect way to disentangle both possibilities could be obtained from longitudinal studies investigating the cognitive development of high-functioning autistic children and adolescents with regard to their reading capacities. For example, consider that we gather data from an EEG experiment with autistic individuals when they are in second grade (t_1) and fourth grade (t_2), inspired by the Maurer et al. (2006) study reviewed earlier in chapter 8. Further assume that this experiment uses tasks similar to those advised above. Recall that in typically developing children, the N1 ERP associated with neuronal activation in the left vOT area peaks in beginning readers and decreases the more proficient children become in visually recognizing words. If the cause for inefficient prediction error minimization in high-functioning autistic individuals is an exaggerated estimation of the precision of bottom-up prediction errors, we should expect to find the N1 more pronounced in autistic individuals than in the control group. This prediction should hold for both data sets acquired at t_1 and t_2. In ‘normally’ developing individuals, the level of activation of the N1 decreases over time, because the top-down predictions become more precise as the individuals become more advanced in applying the alphabetic principle. The same should not hold for autistic individuals, because the higher-level top-down predictions are still imprecise, so that the system needs to rely more heavily on lower-level prediction error minimization closer to the sensory cortex. If it were shown that the N1 were more pronounced in autistic individuals than in control individuals at t_1 – when the participants are supposed to be at the very beginning of their reading development – we could be led to assume that this is indirect evidence for the hypothesis that the cause for the imbalanced prediction error minimizing routines is an exaggerated estimation of precision assigned to lower-level prediction error. This imbalance would then ultimately lead to the problems with sentence processing observed in high-functioning (adult) autistic individuals. This would also be in line with the HIPPEA hypothesis by van den Cruys et al. (in press). In a nutshell, the idea here is that further empirical insights into the developmental trajectory possibly leads to a better understanding of the ultimate cause(s) of the reading deficits observed in high-functioning autistic individuals.

I have argued above that reading difficulties in high-functioning individuals on the autism spectrum can serve as a paradigm case of dysculturation. Recall from the last chapter that dysculturation is defined as an incomplete process of cognitive transformation. This is supposed to lead to deficient performances of a certain cognitive practice such as reading. I have further argued that cases of dysculturation are characterized by aberrant LDP and LDBA throughout cognitive development. This is exactly what we have observed in the reading development of high-functioning autistic individuals. However, scaffolded, path-dependent learning is an important factor in processes of both enculturation and dysculturation. In the last chapter, we have seen that dyslexic individuals are able to develop specific processing strategies that help compensate for their cognitive impairment. Scaffolded learning is a crucial contributing factor to the development of compensation strategies. If we consider that many individuals on the autism spectrum additionally show deficits in social interaction, it is reasonable to suppose that these social deficits might also affect scaffolded learning routines. These routines usually require a close and coordinated interaction between learners and teachers (and other care givers). This is because the acquisition of expertise over a certain cognitive practice is itself a structured socio-cultural process. The suggestion here is that high-functioning autistic individuals do not have a learning deficit *per se*, but that they might find it more difficult to engage in scaffolded learning routines. It would be desirable to obtain empirical data concerning the reading acquisition trajectories of autistic individuals and the efficiency of specific remediation strategies. This is another modest proposal for future empirical research on autistic cognition.

A related idea would be that high-functioning autistic individuals employ a different set of cognitive norms in comparison to ‘normal’ readers. This is because they reliably manipulate and interpret linguistic cognitive resources in ways departing from the literate ‘neurotypical’ population. Their engagements with tokens of an alphabetic writing system are characterized by the application of normatively constrained grapheme-phoneme correspondences and other norms required for visual word recognition. However, the psychological research on reading in high-functioning autistic individuals suggests that high-functioning autistic individuals fail to acquire important manipulative and interpretative norms that govern the processing of larger, syntactically connected units of written language. This view is able to extend the DPEF hypothesis, because it provides the conceptual resources to describe the consequences of neuronal and oculo-motor deviations on a personal level of description.

10.6. CONCLUDING REMARKS

In this chapter I have argued that reading performance of high-functioning autistic individuals is an important example of dysculturation, in addition to cases of developmental dyslexia considered in the last chapter. If have started with a review of the current state of research with an emphasis on the explanatory and descriptive scope of the weak central coherence account. Based on the state of research, I have tried to develop a novel and original approach to reading performance in high-functioning autistic individuals from the EPP perspective. I have argued that reading performance in high-functioning autistic individuals is exhaustively described in terms of the DPEF hypothesis. In a nutshell, this hypothesis assumes that failures in the optimization of precision estimations at multiple scales lead to an exaggerated emphasis on low-level processes which is associated with specific neuronal and oculo-motor signatures. On a personal level of description, this suggests that visual word recognition is more pronounced at the expense of sentence processing competence. This is important, because it shows that visual word recognition and sentence processing can be dissociated. Furthermore, scaffolded learning routines and the acquisition of the relevant manipulative and interpretative cognitive norms are affected by the cognitive deficit associated with reading in high-functioning autism. I have proposed several strategies for future research on reading in high-functioning autism. These strategies would help enrich, refine, or falsify the DPEF hypothesis. In addition, I take it that these proposals for future research could possibly make an important contribution to current discussions on the deficits and assets observed in individuals on the autism spectrum and their underlying causes more generally.

However, it is important to acknowledge that high-functioning autism is not an all-or-nothing phenomenon. I have tried to sketch the most extreme version of impaired sentence processing in this condition, as it applies to a certain sub-group of high-functioning autistic adults. It is conceivable that there are many different degrees of impairments characterizing the reading performance of high-functioning autistic individuals. This kind of variability certainly applies to both inter-individual differences and intra-individual developmental changes. The DPEF hypothesis is a first attempt to develop a conceptual framework that could serve to account for these variabilities.

11. PURE ALEXIA

11.1. INTRODUCTION

In chapter 9, I have considered cases of dyslexia, which is a developmental disorder impairing reading acquisition. Developmental dyslexics suffer from life-long difficulties in visual word recognition. I have shown in that chapter that cases of developmental dyslexia are characterized by impairments in cognitive transformation and the acquisition of the relevant cognitive norms necessary for the fluent and automatic manipulation of tokens of an alphabetic writing system. Furthermore, I have argued that developmental dyslexia is a paradigm case of dysculturation. In these specific cases of dysculturation, scaffolded, path-dependent learning fails to the extent that the generative model necessary for efficient prediction error minimization in visual word recognition is not sufficiently established. However, there are not only cases of developmental impairments in visual word recognition, but also acquired impairments that prevent individuals from efficient interactions with tokens of an alphabetic writing system, although they have previously reached a stage of expertise in reading as a result of enculturation. This phenomenon is referred to as *pure alexia*. The purpose of this chapter is to consider this phenomenon and to interpret the available empirical findings from the perspective of EPP.

Pure alexia affects the recognition and identification of visually presented words. In pure alexia, the processing and production of oral language as well as writing abilities are usually left intact (cf. Cohen et al. 2003, 1313; Cohen & Dehaene 2004, 471).[163] In at least some cases, however, patients suffering from pure alexia might also show impaired or impeded processes associated with object and picture naming (cf. Price & Devlin 2011, 249).

Pure alexia can be caused by a stroke affecting the posterior cerebral artery territory (cf. Cohen 2003, 1326; Johnson & Rayner 2007, 2248; Marsh & Hillis 2005, 549;

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[163] See also Dehaene (2010, 58); Johnson and Rayner (2007, 2246); McCandliss et al. (2003, 295); Pflugshaupt et al. (2009, 1907); Price and Devlin (2011, 249). For historical case studies of pure alexia that have been proven to be fairly accurate in light of contemporary neuropsychological evidence, see Déjerine (1892) and Freund (1889). For a contextualizing account of Déjerine's approach to *pure verbal blindness* (*cécité verbale pure*) see Cohen et al. (2003); Coslett (2000); Dehaene (2010); Epelbaum et al. (2008); Leff et al. (2006). For a contemporary redescription of Freund's (1889) account of cases of *optic aphasia* (*optische Aphasie*), see Marsh and Hillis (2005).

Pflugshaupt et al. 2011, 1295; Rayner & Johnson 2005, 531), by a surgical removal of brain tissue after a diagnosis of left occipito-temporal lobe epilepsy (Epelbaum et al. 2008, 963; Gaillard et al. 2006, 192), or by venous thrombosis (Seghier et al. 2012, 3622). The lesions usually comprise (parts of) the left vOT area, specifically inhibiting neuronal activation in the occipito-temporal sulcus (cf. Cohen et al. 2003, 1328; Price & Devlin 2011, 249).[164] Additionally, the splenium of the corpus callosum might also be affected. It is normally associated with the transmission of visual information processed in the right hemisphere to contralateral areas being associated with visual word recognition (cf. Behrmann et al. 2001, 984; Pflugshaupt et al. 2009, 1908).[165]

In the next section, I will be concerned with personal-level descriptions of cases of pure alexia and the often observed compensation strategy of letter-by-letter reading. After that, the next two sections will be dedicated to the neuronal and bodily impairments observed in cases of pure alexia. I will then interpret the available empirical evidence from the integrative perspective of EPP.

11.2. PERSONAL-LEVEL DESCRIPTIONS OF PURE ALEXIA

The most pervasive symptom is *letter-by-letter reading* (LBL). That is, instead of recognizing words as a whole, pure alexics decipher each letter constituting a word one after another (cf. Dehaene 2010, 58; Price & Mechelli 2005, 235; Vogel et al. 2014, 6).[166] Accordingly, LBL reading has to be considered as a compensation for the lost capacity to effortlessly recognize visually presented words as a whole: “Although these [pure alexic] patients do not appear to be able to read in the sense of fast, automatic word recognition, many are able to use a compensatory strategy that involves naming the letters of the word in serial fashion; they read, in effect, 'letter-by-letter'” (Coslett 2000, 420f). As an illustrative example, consider this brief description by a pure alexic making use of this strategy: “Words of different lengths, like *cat*, *table* and *hippotamus*, are processed in my head at a different rate. Each

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[164] See also Cohen and Dehaene (2004, 472); Epelbaum et al., (2008, 963); Gaillard et al. (2006, 201); Habekost et al. (2014, 1); Johnson and Rayner (2007, 2247); Leff et al. (2006, 1005); McCandliss et al. (2003, 295); Montant and Behrmann (2000, 265); Pflugshaupt et al. (2009, 1908); Pflugshaupt et al. (2011, 1294); Seghier et al. (2012, 3621); Starrfelt et al. (2009, 2887); Starrfelt et al. (2013, 167); and Welcome et al. (2014, 113).

[165] See also Coslett (2000, 421); Hillis et al. (2005, 557); Marsh and Hillis (2005, 332f).

[166] See also Behrmann et al. (2001, 983); Cohen et al. (2003, 1329); Cohen and Dehaene (2004, 471); Coslett (2000, 420f); Habekost et al. (2014, 1); Johnson and Rayner (2007, 2246f); McCandliss et al. (2003, 295); Pflugshaupt et al. (2009, 1908); Plugshaupt et al. (2011, 2194); Rayner and Johnson (2005, 530); Starrfelt et al. (2013, 167).

added letter adds more weight to the load that I am trying to lift" (Engel 2008, 75; italics in original). As implied by Engel, a phenomenon accompanying LBL reading is the *word-length effect* (cf. Habekost et al. 2014, 1; Johnson & Rayner 2007, 2246; Pflugshaupt et al. 2011, 1294; Starrfelt et al. 2013, 167).[167] Since each letter is initially processed in isolation, there is a "positive linear relationship between length and speed" (Behrmann et al. 2001, 984). For instance, in a study comparing the reading time of pure alexics with a 'normal' control group, it is found that pure alexics read on average 24 words per minute in a text processing task, in contrast to the mean value of 237 words per minute achieved by the control group (cf. Pflugshaupt et al. 2009, 1913). To illustrate the tight relationship between LBL reading and the word length effect, consider again a brief report by the pure alexic Howard Engel (2008, 74):

> As a 'letter-by-letter' reader I might get through one or two lines in the same time as it took others to read a whole page. In spite of my snail's pace, my reading was one hundred percent accurate. But I was not able to scan a page, and the whole process was exhausting beyond belief.

Another phenomenon that accompanies LBL-reading in many cases of pure alexia is the absence of the word superiority effect (WSE). The WSE refers to the pervasive observation that "normal readers are better at identifying letters embedded in words than in letter strings, or even single letters" (Habekost et al. 2014, 2). Habekost et al. (2014) report two studies with four alexic individuals in total and a control group. Their main finding is that across different conditions, "[…] none of the patients showed a word superiority effect in naming or in visual perception" (ibid., 17). The absence of the WSE effect in pure alexic individuals is to be expected, given that words cannot be recognized anymore without laboriously deciphering each single letter one after another. Since pure alexics are no longer able to process words as a whole, it does not make a difference anymore whether they have to process single letters, letter strings, or words, as long as the WLE is controlled for under experimental conditions.

11.3. NEURONAL IMPAIRMENTS IN PURE ALEXIA

On a neuronal level of description, it seems reasonable to assume that the neuronal activation in the left vOT area usually associated with the propagation of prediction

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[167] See also Behrmann et al. (2001, 983); Coslett (2000, 421); Montant and Behrmann (2000, 265); Pflugshaupt et al. (2009, 1908); Rayner and Johnson (2005, 530); Starrfelt et al. (2009, 2880); Starrfelt et al. (2010, 242).

errors in visual word recognition is severely affected in cases of pure alexia. Operating on the assumption that the correlation of prediction errors with activation in the left vOT area is correct, the disconnection of this area from lower- and higher-level cortical areas should result in a disruption of the hierarchical generative model necessary for the success of visual word recognition. This is in line with Price and Devlin's (2011, 249) following assumption: "According to the Interactive Account, damage to vOT will disconnect forward and backward connections at all levels of the hierarchy […], leading to imprecise perceptual inference." In pure alexia, the higher-level cortical areas associated with phonological and semantic processing in visual word recognition, such as the left IFG and areas within the left temporal cortex, are usually still intact. However, the predictions generated on these levels are rendered inefficient to the extent that the left vOT area can neither receive top-down predictions nor feed forward prediction error to higher-level cortical areas. As a result, automatic and fluent visual word recognition is no longer possible in these cases.

However, a recent case study reported by Welcome et al. (2014, 122) suggests that pure alexia could also result from the disconnectivity of the left vOT area and higher-level middle temporal regions while the integrity of the left vOT area is preserved: "The present data suggest that a functional disconnection between the output of occipito-temporal cortex and regions supporting higher-up processes is also sufficient to disrupt typical reading." In the case of their alexic participant, the novelist Howard Engel who I have already mentioned above, it is not the function of the left vOT area *per se* that is severely compromised. Rather, the connections to and from higher-level middle temporal regions are affected. This suggests that prediction error associated with neuronal activation in the left vOT area cannot be fed forward to higher levels. At the same time, top-down predictions associated with neuronal activation in left middle temporal regions cannot be fed backwards to the left vOT area. Consequently, the manifestation of pure alexia seems to be correlated with different types of disconnectivity resulting from lesions that affect fibre tracts and functional connections being crucial for visual word recognition.

An interesting question arises from the behavioural profile of pure alexia: How is LBL reading still possible when at least one crucial brain area associated with visual word recognition is severely impaired and/or functionally disconnected? Tentative answers to this question are provided by Cohen et al. (2003) and Seghier et al. (2012). According to the explanatory strategy chosen by Seghier et al. (2012), there exist two cortical pathways being associated with visual word recognition. The assumption is that damage to the left ventral occipito-temporal (LvOT) pathway leads to increased activations in an alternative pathway, under the proviso that the brain areas comprising this latter pathway are preserved. Here, the hypothesis is "[…] that such a reading-without-LvOT pathway might involve functional connectivity between the left inferior occipital cortex and the left superior temporal sulcus" (Seghier et al. 2012, 3622). The patient investigated in this study shows a reading behaviour consistent with a diagnosis of pure alexia. However, she is still "able to read short familiar words successfully under speeded conditions". At the same time, "her reading performance was strongly influenced by word length and familiarity" (ibid., 3621). A functional connectivity analysis of data gathered from an fMRI experiment conducted with this particular pure alexic and a control group confirms the hypothesis. This analysis reveals that reading aloud single words is associated with a significant pattern of neuronal activation in a pathway comprising the left superior temporal sulcus (cf. ibid., 3630).

In contrast, Cohen et al. (2003) assume that LBL reading might be enabled by neuronal activation in the right hemispheric homotopic region of the left vOT area (VWFA) or the 'right visual word form area' (R-VWFA).[168] In comparing the neuronal activation patterns attributed to a patient suffering from pure alexia in two conditions, identifying single letters and looking at checkerboards, it is found that "callosal connections appeared to be intact, allowing for interhemispheric transfer of letter identities" and that "the right-hemispheric R-VWFA activations showed a strong preference for alphabetic stimuli over checkerboards, a pattern normally specific to the VWFA" (Cohen et al. 2003, 1327). Taken together, these findings lead the authors to the following consideration:

> If we assume that residual reading abilities, including letter-by-letter reading and implicit lexical access [...] result from right-hemispheric word processing, the intervention of the corpus callosum is required whenever the output of this right-hemispheric computations must be made available to the left-hemispheric verbal system. (ibid., 1329)

Both proposals share the commitment that an alternative pathway is likely to be involved in compensating for the deficiency of the left vOT area and its functional connections to other relevant cortical areas. This would explain LBL reading and the associated word length effect. Still, it is an open empirical question whether this

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[168] See also Price and Mechelli (2005, 235). This suggestion is interesting, for it resembles empirical evidence for a similar, right-lateralized 'compensation' in cases of developmental dyslexia (see chapter 9).

alternative pathway comprises the right homologue of the LvOT mediated by the splenium of the corpus callosum, the left temporal sulcus, or both in the majority of cases. Another question concerns the consideration whether this alternative pathway is already in place in non-pathological cases, as Seghier et al. (2012, 3631) suggest, or whether the development of an alternative neuronal processing route can be explained exclusively in terms of compensatory "lesion-induced plasticity" (cLIP; Menary 2013b, 356).

Independent of the outcomes to be expected from future empirical research, these first attempts to account for the residual abilities of LBL reading are worth to be interpreted in terms of EPP. Here, the initial idea would be that in cases of preserved LBL reading capacities, the hierarchical generative model is comprised of certain levels being relevant for the bottom-up processing of prediction error that should not be correlated with errors being causally relevant for visual word recognition *per se*, but for lower-level letter recognition. That is, instead of predictions having top-down influence on levels that are crucial for the recognition of entire words, they would now be employed in predicting upcoming letters or graphemes. In functionalistic terms, the proposal here is that in the case of functional disconnectivity of certain levels of the processing hierarchy being associated with visual word recognition, the hierarchy is 'reconnected' by now comprising new levels doing the causal work necessary for feeding forward prediction error to higher levels of the hierarchy. This *alexic cLIP hypothesis* clearly needs empirical support and the development of new research paradigms combining behavioural and brain imaging methodologies. However, it is a promising hypothesis from the perspective of EPP.

An issue that clearly requires consideration concerns the specificity and selectivity of the left vOT area in cases of pure alexia. In chapter 5, we have seen that there is a lively debate about the extent to which this area is selectively dedicated to visual word recognition or whether it also causally contributes to cognitive functions other than reading. This question is also relevant for cases of pure alexia. This is because lesion studies have traditionally taken to provide support for at least a soft version of massive modularity. On the one hand, if it were the case that lesions within specific parts of the left vOT area would selectively impair visual word recognition, this would provide strong support for both regional selectivity and functional specialization of this area. On the other hand, if it were the case that other cognitive functions were similarly affected by brain lesions located in the left vOT area (as suggested by, e.g., Behrmann & Plaut 2013; Price & Devlin 2003; Vogel et al. 2012), it seems more likely that both regional selectivity and functional specialization for a specific stage of visual word recognition are fairly weak. To date, however, most patients suffering from pure alexia who participated in neuropsychological studies have been tested on rather restricted tasks having to do with the production and processing of letters, single words, or sentences based on either oral or written language (Cohen et al. 2003; Epelbaum et al. 2008; Johnson & Rayner 2007; Leff et al. 2006; Pflugshaupt et al. 2009, 2011; Rayner & Johnson 2005). However, a subset of studies have paid attention to picture or object naming tasks (Gaillard et al. 2006; Hillis et al. 2005; Marsh & Hillis 2005 Seghier et al. 2012; Starrfelt et al. 2009). Except for Gaillard et al. 2006, all studies report that their alexic participants showed a significant degree of impairment (most pervasively documented in increased response times) in performing these tasks. In addition, Hillis et al. (2005) and Marsh and Hillis (2005) report that their alexic participants also face difficulties in a task that requires to name tactically presented stimuli. Finally, Starrfelt et al. (2009) and Starrfelt et al. (2010) report significant difficulties of pure alexics to recognize visually presented digits. Contrary to these empirical indications, Cohen et al. (2003, 1314) assume that the left vOT area (VWFA) is more or less exclusively dedicated to visual word recognition. On their construal, “[…] the VWFA is activated by alphabetic strings relative to fixation but also relative to complex non-alphabetic stimuli such as false fonts, faces or geometrical patterns [...]” (Cohen et al. 2003, 1314). In contrast, Seghier et al. (2012, 3621) are committed to the view that cases of pure alexia not only demonstrate that visual word recognition is impaired, but that in addition “difficulties with visual recognition of objects and colour naming are typically revealed”. In addition to this assumption, Roberts et al. (2015) report a study with a large group of individuals who have been diagnosed with pure alexia. All participants show a lesion in the left posterior fusiform gyrus (pFG), which is part of the left vOT area (cf. Roberts et al. 2015, 80). The goal of the study is to test to what extent this lesion causes difficulties in the visual processing of both familiar and novel faces in addition to the difficulties associated with pure alexia. The main result is that there are “[…] striking deficits in processing both familiar and novel faces in [a] large sample of patients with damage to the pFG, an area traditionally associated with written word recognition” (Roberts et al. 2015, 91). This lends direct support to the idea that pure alexia is not a highly selective disorder. Rather, this study suggests that other visual processing routines are significantly impaired as a result of a damaged and/or disconnected left vOT area. This clearly speaks against the view that this cortical area becomes functionally specialized in the course of reading acquisition.

At its least, this accumulated evidence leaves open the possibility that the left vOT area is not functionally selective and exclusively associated with visual word recognition. More empirical studies are certainly needed to settle this issue. It would be desirable to have more results derived from functional connectivity analyses performed on data received from neuroscientific studies with participants suffering from pure alexia. However, even if it turned out that a lesion in the left vOT area selectively impairs the neuronal process associated with visual word recognition, this would still be compatible with the idea of neural reuse. In particular, Anderson (2015, 37) argues that

> […] it is possible for focal lesions to cause specific functional deficits and double dissociations in provably nonmodular systems […]. In any event such deficits are the exception rather than the rule in human brain injuries. Even some of the patients most celebrated for having specific behavioral deficits often have multiple problems, even when one problem is the most obvious or debilitating […].

This position emphasizes the need for more empirical data and more fine-grained investigations of pure alexia. Also, it needs to be taken into account that the severity and scope of impairments is dependent on the specific location of the critical lesion and the success rates of compensation strategies. Thus, it should be expected that we will find considerate variation in the behavioural and neuro-functional profiles of pure alexia.

11.4. Oculo-Motor Impairments in Pure Alexia

Assuming that efficient visual word recognition is constituted by neuronal and bodily components, it is worth considering the relationship between LBL reading, the word length effect, and eye movements. As already discussed in chapter 6, eye movements show specific patterns of fixations, saccades, and regressions. In pure alexics, eye movements are altered in comparison to ‘typical’ readers not suffering from relevant neuropsychological deficits (Behrmann et al. 2001, 997; Pflugshaupt et al. 2009, 1913; Rayner & Johnson 2005, 530; Starrfelt et al. 2010, 254). This concerns the frequency and duration of fixations, their location and the saccadic amplitude as a function of word length. For instance, in an experiment designed to investigate the relationship between eye movements and crucial features of pure alexia, Behrmann et al. (2001, 997) arrive at the conclusion that "[…] the patients made more fixations and fixations of longer duration per word as well as more regressive saccades per word. Furthermore, the number of fixations increased disproportionally as the word length increased […]." Similarly, Pflugshaupt et al. (2009, 1913) report that "[r]elative to healthy participants, patients with pure alexia displayed a higher fixation-to-character ratio, longer fixation durations, shorter amplitudes of rightward saccades and an enhanced percentage of regressions."[169] In addition, Johnson and Rayner (2007) investigate to what extent word frequency and word predictability influence the overall reading performance of a pure alexic individual in addition to word length as dependent variable. They find that "[t]he total fixation time spent on high frequency words was significantly shorter than that on low frequency target words" and that "the total number of fixations on high frequency target words was significantly fewer than that on low frequency target words" (Johnson & Rayner 2007, 2251). Furthermore, their results show that "[t]he total fixation time was significantly shorter for highly predictable words than unpredictable words" and that "the total number of fixations was significantly fewer on highly predictable words than unpredictable words" (ibid., 2252).[170]

Taken together, these considerations are highly informative for the EPP approach to eye movements in reading. On the one hand, inefficient eye movements seem to amplify the neuronally caused deficit associated with pure alexia. On the other hand, however, the eye movements observed in pure alexics help compensate for the impaired neuronal processing routines. In addition, the consideration of the word frequency and predictability effects demonstrated by Johnson and Rayner (2007) provides further support for the plausibility of the EPP approach to visual word recognition in both 'normal' and pathological cases: The laboriously, letter-wise processed visual input in pure alexia still gives rise to prediction error resolving

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[169] A crucial point that needs to be mentioned is that pure alexia is accompanied by homonymous hemianopia in some cases. Homonymous hemianopia is defined as a "contralateral visual field cut" (Johnson & Rayner 2007, 2246; see also Behrmann et al. 2001, 983; Leff et al. 2006, 1004); it is associated with a milder word length effect in comparison to pure alexia (cf. Starrfelt et al. 2009, 2886). However, homonymous hemianopia is not sufficient for pure alexia to occur, since the deficits stemming from this visual field defect can be compensated by specific eye movements, for instance by "extra rightward saccades" (ibid.). This strategy is also employed in pure alexia, but in this case it is not able to resolve the impairment of visual word recognition as such.

[170] However, these results should be treated carefully, since the task requiring reading entire sentences was not controlled for comprehension. That is, even if the eye movements show a sufficient degree of consistency, this does not necessarily lead to the conclusion that the participants have successfully processed the presented sentences.

discrepancies between the actually given visual input and prior predictions. But these prediction errors are not to be associated with visual word recognition *per se* as it were, but rather with letter strings having a certain statistical probability that can still be estimated by functionally intact higher-order levels of the hierarchy. This reasoning is consistent with Rayner and Johnson's (2005, 533) interpretation of reading in pure alexia by referring to an interactive account of reading, which in turn provides the crucial background assumption of Price and Devlin's (2011) approach to visual word recognition in terms of PP: "While bottom-up orthographic input from each letter (although weak, degraded, and encoded serially) propagates upward through the system, top-down influences (such as word frequency) feed back down to facilitate further bottom-up processing." These hierarchical interactions are crucially facilitated by the almost inflationary performance of eye movements in terms of active inference. Hence, both the putatively employed alternative neural pathway and the increase of fixations per word constitute the success of LBL reading although the usually employed mechanism is significantly impaired.[171] Additionally, the word frequency and word predictability effects demonstrate that this replacement of the original visual word recognition mechanism is highly dependent upon high-level predictions. That is, the better the predictions are as function of exposure to similar linguistic structures prior to the onset of pure alexia, the better is

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[171] A further compensatory strategy sometimes accompanying LBL still warrants further empirical investigation, but it is theoretically interesting because it tabs on issues having to do with active inferences in terms of bodily manipulation in a fairly straightforward way. Déjerine (1892, 66) describes the reading behaviour of his patient *C* diagnosed with *pure verbal blindness* (*cécité verbale pure*) as follows: "[…] même les lettres isolées sont mortes pour lui; il ne peut pas les reconaître qu'après un bon moment d'hésitation et toujours *en s'aidant du geste qui dessine les contours de la lettre*. C'est donc le sens musculaire qui reveille le nom de la lettre; et la preuve, c'est qu'on peut lui faire dire un mot les yeux fermés en conduisant sa main dans l'air pour lui exécuter les contours des lettres." ("[…] even the isolated letters are dead to him; he recognizes them only after great hesitation and always with the help of employing gestures that trace the contours of the letter. The letter's name is thus revealed by the muscle sense. The proof is that one can make him say a word with his eyes closed by guiding his hand through the air in order to let him draw the letters's countours." (My translation, R.E.F.; italics in original.) For a brief account and an alternative translation of this description, see Dehaene (2010, 57). It seems that even LBL reading is severely impaired in Déjerine's patient, but that this impairment can be overcome by bodily enacting the letters' shape, thereby being able to process entire words by *manually spelling* them. The idea that impaired neural processing mechanisms can be compensated by heavily relying on gestures that help access higher-order word processing stages is intriguing, because it might further emphasize the crucial role of embodied active inferences in constituting PP mechanisms associated with reading. Empirical questions that should be resolved in order to verify this reasoning would then concern the frequency, reliability, and the scope of this compensatory strategy as well as the interaction of bodily and neural sub-processes constituting *manual spelling*.

the capacity to process the visually presented input and the employment of active inferences.

11.5. PURE ALEXIA AND DECULTURATED PREDICTIVE PROCESSING

Cases of pure alexia are interesting, because they highlight that a cognitive practice such as reading, once successfully acquired, can also be lost due to an acquired, neurological impairment. That is, in contrast to developmental dyslexia, individuals suffering from pure alexia had been successfully enculturated prior to the onset of pure alexia. However, due to a neurological impairment, pure alexics are no longer able to visually recognize words automatically and fluently. Pure alexia is a good example of what I would like to call *deculturation*. This notion refers to cases in which the performance of a cognitive practice is significantly impaired after the human organism has already acquired that performance as a result of enculturation. The impairment might be caused by a neurological or a bodily injury or disease, or it might be caused by a combination of both. In cases of pure alexia, an impairment of the neuronal component leads to impairment-induced alterations of the bodily component, which manifests itself in specific eye movement patterns. This is because the neuronal and bodily components constituting the cognitive practice of reading are highly interactive and mutually influence each other. In some cases, specific sub-personally realized strategies might be employed in order to compensate for the acquired deficit. These strategies can be accounted for by referring to cLIP and what I would like to call *compensatory lesion-induced oculo-motor adaptability* (cLIOA). On a personal level of description, these compensatory strategies suggest that individuals suffering from pure alexia are able to apply a new set of manipulative norms which are applied in LBL reading. That is, the manipulative, normative strategies targeted at tokens of an alphabetic writing system change in the course of the adjustment to the limited possibilities given to individuals who have acquired pure alexia.

11.6. CONCLUDING REMARKS

In summary, cases of pure alexia are philosophically relevant for the EPP approach for at least two reasons. First, the neuronal processes being impaired in pure alexia and the cognitive deficits stemming from this impairment highlight the importance of the functional role fulfilled by the left vOT area and its functional connectivity to higher-level (especially temporal) cortical areas. If the neuronal activation of the left vOT area and its functional connectivity with higher-level areas are no longer given – as it is the case in pure alexia – automatic, fluent and efficient visual word recognition is no longer possible. Second, neuronal impairments attributed to individuals suffering from pure alexia are complemented by aberrant eye movement patterns which are characterized by a significant increase of saccades and regressions in comparison to non-impaired individuals. This emphasizes the close coordination of neuronal and bodily components, even in cases of an acquired disorder such as pure alexia. We have seen in this chapter that the EPP framework can provide a unifying account of a large set of empirical data on pure alexia by describing this disorder in terms of deculturation, impaired prediction error minimization routines, and neuronal and bodily compensation strategies.

12. CONCLUSION

Reading matters. It can be understood as the dynamic prediction error minimizing interaction of an enculturated human organism with linguistic structures in its cognitive niche. This is the key claim of the EPP framework. This framework offers an original and innovative theoretical perspective and a set of new conceptual tools for the analysis and description of reading and associated neuropsychological disorders. The strategy employed in this dissertation has been threefold: First, I have attempted to show that EPP is a convincing and tenable philosophical position on theoretical grounds (Part I). Second, I have argued that EPP is supported by many results from empirical research on the sub-processes of reading. Vice versa, it has turned out that EPP has great predictive power, because it has the conceptual resources to formulate new hypotheses that can be tested by future empirical research (Part II). Finally, EPP assembles the right kind of conceptual tools to approach reading disorders and to develop new theoretical accounts of their characteristics on personal and sub-personal levels of description (Part III).

If we consider reading to be a cognitive practice that is a pervasive phenomenon in literate societies, we can come to acknowledge the delicate balance between neuronal and bodily sub-processes – described in terms of prediction error minimization and the optimization of precision estimations – and the benefits and challenges of enculturation in the cognitive niche. The complexity of reading has become evident when we considered ‘normal’ cases of written language processing and reading acquisition. It has become even more obvious when we investigated cases of dysculturation (i.e., developmental dyslexia and high-functioning autism) and deculturation (i.e., pure alexia). It is only from the perspective of EPP, I submit, that we are able to uncover and appreciate the fine-tuned and dynamical interaction of neuronal and bodily components that are associated with an organism’s normatively constrained engagement with culturally shaped cognitive resources. From this perspective, I could not agree more with Menary’s (under review, 12) suggestion that “[…] the division of labour between PP and evolutionary accounts of the origin of NPP and ICS [i.e., the integrated cognitive system] must be in place. The role of scaffolded learning and neural redeployment should not be replaced by error minimization processes.” It is in virtue of EPP that we have the conceptual tools and the theoretical insights to account for the entire range of factors that significantly contribute to ('normal' and 'pathological') cases of reading on multiple levels of description.

In order to be able to describe the neuronal and bodily changes that are associated with reading in both 'normal' and 'pathological' cases, I have developed a new set of conceptual tools that help unveil the functional contributions of these changes (see table 1). In particular, I have suggested that reading acquisition is not only rendered possible by learning driven neural plasticity (LDP), but also by what I have called learning driven bodily adaptability (LDBA) and, more specifically, learning driven oculo-motor adaptability (LDOA) in the case of reading. Furthermore, I have argued that cases of developmental dyslexia and high-functioning autism require us to think not only about the deficits associated with these developmental disorders, but also about the sub-personally realized neuronal and bodily (oculo-motor) strategies that partly compensate for the attested impairments. In this context, I have introduced the concepts of compensatory learning driven plasticity (cLDP) and compensatory learning driven oculo-motor adaptability (cLDOA). Similarly, is has turned out that it is reasonable to complement the notion of compensatory "lesion-induced plasticity" (cLIP; Menary 2013b) with the concept of compensatory lesion-induced oculo-motor adaptability (cLIOA) in cases of pure alexia.

CONCEPTUAL TOOL	DEFINITION
Learning driven bodily adaptability (LDBA)	… denotes the bodily adaptation to acquired, culturally afforded processing needs. It is an important factor of enculturation.
Learning driven oculo-motor adaptability (LDOA)	… is a special case of learning driven bodily adaptability. It refers to the adaptation of eye movements to acquired, culturally afforded processing needs.
Dysculturation	… is an incomplete process of enculturation. Dysculturation results in deficient cognitive processing routines that involve the interaction with cognitive resources. It also refers to the possible development of sub-personal strategies that help compensate for congenital neuronal and/or bodily deficits.
Compensatory learning driven plasticity (cLDP)	… is the allocation of alternative structural and functional cortical resources (in comparison to 'normal' brain development) in cases of developmental cognitive disorders.

Compensatory learning driven oculo-motor adaptability (cLDOA)	… refers to aberrant patterns of active inference (bodily manipulation). These patterns have the function to compensate for cognitive impairments in cases of developmental disorders.
Deculturation	… refers to specific cases of acquired cognitive disorders. In these cases, competence in the performance of a cognitive practice is (partially) lost after the initially successful acquisition of this practice as a result of enculturation. The impairment might be caused by a neurological or a bodily injury or disease, or by a combination of both. In some cases, specific sub-personally realized strategies might be employed in order to compensate for the acquired deficit.
Compensatory lesion-induced plasticity (cLIP)	… is the allocation of alternative structural and functional cortical resources in cases of acquired cognitive disorders.
Compensatory lesion-induced oculo-motor adaptability (cLIOA)	… refers to aberrant patterns of active inference (bodily manipulation). These patterns have the function to compensate for cognitive impairments in cases of acquired disorders.

Table 1. New conceptual tools provided by EPP.

These new conceptual tools help investigate important sub-processes that uniquely contribute to the entire spectrum of types of reading performance, associated with both ‘normal’ and ‘pathological’ cases through ontogeny. This emphasizes the descriptive scope of EPP and its capacity to open up a whole new space of questions and desiderata for future empirical and conceptual research.

In the course of this dissertation, the EPP perspective has helped develop new hypotheses about many aspects that are relevant for research on reading and reading disorders. First, the assumption that reading is a hybrid cognitive process that is co-constituted by neuronal processes (perceptual inference) and eye movements (active inference) has led to the idea that empirically established effects have distinct neuronal and oculo-motor signatures that mutually influence each other over time. This has led to the frequency hypothesis and the ambiguity hypothesis. The *frequency hypothesis* says that the frequency of a to-be-processed word should not only be associated with specific eye movement patterns, but also with a significant pattern of neuronal activation in relevant cortical areas such as the left vOT area. The *ambiguity hypothesis* suggests that the resolution of syntactic ambiguities should similarly be associated with the close interaction of specific neuronal and oculo-motor processing strategies.

Second, the EPP framework has been able to shed new light on developmental reading disorders. The perspective of dysculturation has led to the formation of new hypotheses about the features of written language processing in developmental dyslexia. I have argued in chapter 9 that the neuronal processing routines in dyslexic individuals suggest the employment of a neuronally realized strategy to compensate for hypoactivated and functionally disconnected cortical areas that are usually recruited for visual word recognition. This is the *dyslexic cLDP hypothesis*. Furthermore, we have seen in chapters 8 and 9 that the properties of a specific orthographic system, i.e., the degree of consistency of grapheme-phoneme correspondences, has an influence on the neuronal and oculo-motor processes associated with visual word recognition. If this were the case, we should expect that the aberrant eye movement patterns observed in dyslexic individuals should vary as a function of the respective orthographic system. This is the *orthography-dependent dysculturated eye movements hypothesis*.

Third, the dysculturated PP perspective has provided the conceptual resources to develop a new and original approach to the reading performance of high-functioning autistic individuals. In particular, we have seen in chapter 10 that high-functioning autistic individuals show hyperlexic reading performance in the visual recognition of unconnected single words while their performance in sentence processing tasks is inferior in comparison to undiagnosed individuals. This has led to the *dysculturated precision estimation failure* (DPEF) *hypothesis*. In line with other accounts of autistic cognition, this hypothesis suggests that the specific processing profile of high-functioning autistic individuals can be elucidated by the idea that the estimation of precision is not optimized at all levels of the cortical hierarchy. More specifically, the DPEF hypothesis suggests that neuronal information at lower levels of the cortical hierarchy are always assigned a constantly high degree of precision. At the same time, higher cortical levels hardly have any significant causal influence on the entire prediction error minimization process. This hypothesis should be empirically tested and I have outlined some suggestions for future empirical research at the end of chapter 10.

Finally, the investigation of pure alexia – approached as a case of deculturated PP – has led to the idea that the specific patterns of neuronal activation associated with visual word recognition in pure alexic individuals are a non-trivial case of compensatory lesion-induced plasticity (cLIP). In particular, this *cLIP hypothesis* suggests that the disruption of the left vOT area caused by a lesion leads to the compensatory employment of other, preserved cortical areas. This in turn is associated with the pervasive phenomenon of LBL reading that characterizes the residual processing capacities of pure alexic individuals. In sum, the diversity of these hypotheses should suffice to establish the fecundity and predictive power of the EPP perspective.

The new perspective that has emerged in the course of this dissertation is supposed to be a timely contribution to the debate about the theoretical commitments of the prediction error minimization framework. Hohwy (2013, 2014) and Clark (2013a, 2015) seem to agree that socio-cultural cognitive resources play an important role in our cognitive lives. However, they disagree on the epistemic and methodological consequences that might follow from this important observation (see the discussion in chapter 4). While Hohwy argues that a ‘neurocentric’ and brain-bound view follows naturally from the PP framework (cf. Hohwy 2014, 25), Clark suggests that this framework is the perfect theoretical partner for approaches to cognition that are opposed to internalism (cf. Clark 2013a, 195).

EPP makes a unique contribution to this debate. This is because it adopts the PP framework and applies it to the analysis of a specific type of cognitive process that is the product of cognitive niche construction and embodied enculturation. EPP is committed to the view that reading is rendered possible by the ongoing interaction of human organisms with tokens of a writing system on various time scales.

First, there are time scales that need to be approached on a sub-personal level of description. On these time scales, we are concerned with the fine-tuned neuronal and bodily sub-processes that ultimately give rise to the cognitive practice of reading. It is here that we can describe reading in terms of perceptual inference, active inference, and the optimization of precision estimations.

Second, we are confronted with time scales that are important on a personal level of description. We focus on these time scales when we wish to understand the cognitive development of human organisms through ontogeny. On this level of description, the interaction of a human organism with tokens of a writing system is rendered possible by the process of enculturation, the cognitive resources in the socio-culturally structured cognitive niche, and by the set of cognitive norms that constrain instances of enculturated cognition.

Finally, we might also operate on a descriptive level that is concerned with supra-personal time scales (Metzinger, personal communication). Supra-personal time scales are of interest when we want to understand the cultural evolution of specific cognitive resources or inter-generational processes of downstream epistemic engineering.

This distinction of different levels of description that focus on different types of time scales is perfectly in line with Menary's (under review, 1) observation that "PP is all about predictions, happening in real time, however CI/ENC [i.e., enculturation] occurs at different levels and over much longer time scales." This is one the reasons why we need EPP for the description of the cognitive practice of reading: it gives us the conceptual resources to adequately describe this multi-level phenomenon. Furthermore, EPP puts us in the position to account for different temporal dimensions that are of vital importance if we ever wish to understand how complex enculturated cognition is rendered possible.

The wealth of new conceptual tools and the descriptive and predictive power provided by the EPP approach to reading and its disorders should have established that the theoretical integration of the PP and CI and the resulting theoretical insights are conceptually warranted and heuristically fecund. Just consider what we would lose if we dismissed the enculturated and embodied dimension of the EPP perspective. First, our approach to reading would be hopelessly incomplete, because we would not be inclined to think that eye movements play an indispensable functional role in 'normal' and 'pathological' cases of reading. Second, we would be stripped off many valuable theoretical insights that help account for the diversity and multiplicity of factors that non-trivially contribute to reading acquisition. Third, we would probably overlook that the interaction with written language is structured by a set of cognitive norms. Fourth, we would certainly not have arrived at the idea that reading acquisition is also rendered possible by the fluent application of instructive norms by teachers and other care-givers. Finally, it is hard to conceive that we would have been able to uncover the compensatory functional role of eye movements in cases of developmental and acquired neuronal impairments. These considerations should suffice to justify the unique contribution of the enculturated and embodied integrationist position to the investigation of reading. Thus construed, EPP can be understood as a concrete application of Clark's suggestion that the prediction error minimization framework is at least compatible with other, externalistically inspired philosophical views. Part II and III of this dissertation are a lengthy argument in favour of the conceptual coherence and empirical plausibility of the idea that PP and CI complement and enrich each other in many important and informative ways. Furthermore, we have seen in the last chapters how the integrative perspective of EPP leads to new theoretical insights and hypotheses.

This last point is important, because it also suggests that there are some interesting and non-trivial desiderata that result from the EPP approach to reading. For instance, I suggest that EPP might have laid the foundations for future research on the relationship between reading and other types of cognitive processing. In particular, it might shed some new light on what Clark (1998, 177) calls “second-order cognitive dynamics”, where this is understood as “[…] a cluster of powerful capacities involving self-evaluation, self-criticism and finely honed remedial responses.” These types of cognitive processing are assumed to be rendered possible by the capacity to interact with linguistic tokens: “For as soon as we formulate a thought in words (or on paper), it becomes an object for both ourselves and for others. As an object, it is the kind of thing we can have thoughts about” (Clark 2014, 175). In this vein, Dehaene et al. (2015, 241) argue that “[l]iteracy provides a unique means of acquiring and structuring new knowledge and is therefore likely to affect many aspects of higher-level cognition.”

We have seen that it is certainly not a trivial and easily-acquired capacity to process ‘objectified’, linguistically represented thoughts. But once this capacity is acquired (even with severe limitations), it opens up new spaces for thought and reason. Now that we have arrived at a coherent and plausible description of reading, we have new, empirically informed conceptual resources to investigate the synergetic effects of reading and enculturated kinds of ‘second-order cognitive dynamics’ that shape the ways in which we develop and re-create our cognitive capacities in the cognitive niche.

In the beginning of this dissertation, I have reported how surprised I was when I realized that reading has hardly ever received any undivided attention in philosophical discussions. The EPP framework, I submit, might give us the right kind of conceptual tools to investigate the influence of reading on other cognitive practices that shape the ways in which philosophy – as a mode of thinking *and* as an academic discipline – is practiced in modern, literate societies. The idea here is that the interaction with specific ensembles of tokens of a writing system facilitates and influences logical reasoning, the verification or falsification of arguments, or the evocation and refutation of certain intuitions. From this perspective, it might become obvious why many philosophers have seemed to be so reluctant to give much thought to reading as an interesting cognitive phenomenon in its own right. The reason might be that reading is such a familiar and inbuilt part of contemporary philosophical practice that its complexity and its multi-faced character are all too easily overlooked. Future research could pursue the goal to elucidate the suggested link between reading and other cognitive phenomena such as reasoning, arguing, and imagining.

The EPP perspective also invites us to think about the relationship between reading and the content of the *phenomenal self-model* (PSM) and the *phenomenal self-model of the intentionality relation* (PMIR) attributable to enculturated, literate human organisms (Metzinger 2003, 2010, 2013, 2014). Specifically, Metzinger (2003, 599) emphasizes "[…] how the human variety of conscious subjectivity is unique on this planet in being deeply culturally embedded […], namely, through language and social interactions." He goes on to suggest that "[i]t is therefore interesting to ask how the actual contents of experience *change* through this constant integration into other representational media […]" (ibid., italics in original). The EPP framework might help specify this question. This is because it provides the conceptual tools and empirical insights for a close scrutiny of the question how reading contributes to the manifestation of new or transformed modes of phenomenally accessible self-related thinking and phenomenal experience. There are at least two lines of future investigation that might be dedicated to this question.

First, we could specify the contents of the PSM and the PMIR and their realization, respectively, during the performance of the cognitive practice of reading. In particular, we could assume that there are specific classes of phenomenal experiences associated with cognitive and attentional agency (Metzinger 2013). In many cases, the actual processes of visual word recognition and sentence processing may be unconscious. However, the contents thus retrieved from a visually accessible linguistic cognitive resource are often accessible for conscious thinking, reasoning, and 'second-order cognitive dynamics' more generally. This would be an example of cognitive agency, which is defined as "the ability to control goal/task-related, deliberate thought" (Metzinger 2013, 2). Sometimes, readers phenomenally experience that they possess the ability to actively direct their attention, for instance to publicly accessible, structured tokens of a writing system. This would be an example of attentional agency, i.e., of "[…] the conscious experience of actually initiating a shift of attention, of controlling and fixing its focus on a certain aspect of reality" (ibid.). Thus construed, expertise in reading could under certain conditions increase the degree of mental autonomy, where this is understood "[…] as the ability to control the conscious contents of one's mind in a goal-directed way, by means of attentional or CA [i.e., cognitive agency]" (ibid., 4).

It might be valuable to investigate these relationships in the future, because they promise to provide important insights into the many ways that reading possibly enriches and alters our phenomenal repertoire and the ways we consciously conceive of ourselves as readers and enculturated agents who are capable of complex cognitive processes. In addition, it might also be of interest to consider how both cognitive and attentional agency might vary across conditions, populations, and the life-span of individuals. For instance, it could be explored to what extent, if any, the phenomenal experience of cognitive and attentional agency (and of mental autonomy more generally) in readers with developmental and acquired reading disorders might depart from the classes of phenomenal experience attributable to unimpaired readers. Furthermore, it could also be revealing to examine whether there are any interesting phenomenological differences between beginning, advanced, and expert readers.

The second line of investigation I would like to suggest for future research concerns the effects that reading might have on the phenomenal realm of contemporary enculturated human organisms. It stands to reason that the cognitive practice of reading makes accessible a vast number of ideas, concepts, stories, or arguments. They can then become available for 'second-order cognitive dynamics' that might have profound effects on the contents of the PSM and the PMIR. This is implied by Metzinger (2010, 210), who argues that contemporary human organisms "[…] are also capable of creating fantastically complex cultural environments, which in turn shape and constantly add new layers to our self-models." This could also imply that the cognitive practice of reading permits new forms of self-knowledge, which might influence the content of the self-model (Metzinger, personal communication). Written language is part of these "fantastically complex cultural environments", and EPP might help uncover how the interaction with this particular type of cognitive resource brings about new forms of phenomenality experienced by self-conscious, enculturated, and literate human organisms.

Ultimately, EPP might also provide tentative answers to traditional problems in philosophy of mind. This perspective can be understood as an epistemically motivated solution of Karl Popper's (1977) formulation of the mind-body problem (Metzinger, personal communication). According to Popper (1977, 37), the traditional mind-body problem amounts to "[t]he question whether both physical and mental states exist, and whether they interact or whether they are otherwise related […].” He acknowledges the importance of the interaction of human organisms with cultural artifacts, linguistic representations, and other kinds of cognitive resources. This leads him to develop a ternary schema that might help resolve the alleged mind-body problem:

> First, there is the physical world – the universe of physical entities – […] this I will call ‘World 1’. Second, there is the world of mental states, including states of consciousness and psychological dispositions and unconscious states; this I will call ‘World 2’. But there is also a *third* such a world, the world of the contents of thought, and, indeed, of the products of the human mind; this I will call ‘World 3’ […]. (ibid., 38; italics in original)

He elaborates on the idea of World 3 by indicating that this is “[…] the world of products of the human mind, such as stories, explanatory myths, tools, scientific theories (whether true or false), scientific problems, social institutions, and works of art” (ibid.). Importantly, objects attributed to World 3 can also belong to World 1, because “they are material artefacts” (ibid., 41). At the same time, they can also be attributed to World 2, because they are associated with the content of mental states (cf. ibid.). The crucial question is how World 3 interacts with World 1 and World 2 in such a way that it does justice to physicalism without denying the efficacy of artifacts and cognitive states.[172] World 1, World 2, and World 3 should be understood as metaphors for distinct ways to classify certain target phenomena for heuristic reasons. This opens the possibility to consider how the relationship between World 1, World 2, and World 3 ought to be spelled out. If we assume for the sake of the argument that Popper’s metaphorical distinction is justified as a preliminary means of classifying objects, states, and processes, we can see that EPP is able to provide a concrete proposal how the alleged problem of the interaction between World 1, 2, and 3 can be easily and parsimoniously solved. On the EPP construal, processes attributed to World 2 are realized by the ongoing, flexible, and dynamic interaction of neuronal and bodily sub-processes. These sub-processes belong to World 1, because they are physical processes. In terms of prediction error minimization, cognitive (i.e., World 2) processes are realized by the mutual influence of perceptual and active inference and the optimization of precision estimations (i.e., World 1 processes). Theoretically, the relation between World 2 and World 1 is correlational – all cognitive processes are strictly correlated with neuronal and bodily (i.e.,

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[172] I submit that cognitive states are a sub-type of mental states. Similarly, all cognitive processes are mental processes, but not all mental processes are cognitive processes.

physical) sub-processes on the EPP construal.[173] If all World 3 objects are also World 1 objects, because they have physical properties and if World 1 physical processes causally interact with other physical processes, then we can easily see how physical artifacts, cognitive processes, and physical processes relate to each other. Applied to the case of reading, materialized tokens of a writing system (World 3 and World 1) are neuronally and bodily processed (World 1) in such a way that the cognizing human organism as a whole can be said to have access to the meaning conveyed by this material symbol structure (World 2). This is possible because the organism has acquired the cognitive practice of reading and because it is able to interact with physical cognitive resources.

Reading is a powerful cognitive tool. It is a complex cognitive practice that co-ordinates neuronal and bodily sub-processes in compliance with a potent web of cognitive norms. Reading transforms and augments the cognitive capacities of enculturated human organisms. The EPP framework invites us to think about these dimensions in a new way.

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[173] In chapter 3, I have argued that the PP framework might offer an embodied version of eliminative materialism (Churchland 1994). We can now see that this important ramification helps elucidate Popper’s formulation of the alleged mind-body problem. This is because on the PP construal, the mentalistic description of cognitive processes (in terms of World 2) can ultimately be substituted by mechanistic neuro-functional descriptions (in terms of World 1) as epistemic progress will proceed.

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Summary

In the past few years there have been numerous attempts to account for the phylogenetic and ontogenetic trajectories of neuronal processing, embodied action, and socio-culturally shaped cognitive practices. These attempts have led to ongoing debates about the details of the neuronal realization of cognitive functions, the degree of embodiment that is required for certain cognitive abilities, and the influence of the socio-cultural environment on certain classes of cognitive processing routines. This PhD thesis makes decisive contributions to these current debates in philosophy of cognitive science.

The key idea is to deliver a new, integrative, and unifying framework for the conceptual and empirical investigation of cognitive processes that are characterized by the delicate interplay of neuronal, bodily, and socio-culturally shaped processes at multiple time scales. In particular, I argue on both conceptual and empirical grounds that the emerging *predictive processing* framework is complementary to *cognitive integration* and its approach to *enculturation*. The resulting integrative perspective – combined with in-depth considerations of cognitive niche construction models, neural reuse, and neural plasticity – provides the unique opportunity to investigate cognitive practices with new conceptual tools and empirically informed theoretical insights. I call this perspective *enculturated predictive processing* (EPP).

The emerging EPP framework is applied to reading, which I take to be a paradigm case of enculturated cognition. It is an ontogenetically acquired cognitive skill that significantly transforms the cognitive capacities of an individual. Reading is realized by the close dynamic interaction of neuronal and bodily (e.g., ocular-motor) sub-processes and constrained by a set of cognitive norms guiding the successful manipulation of tokens of an orthographic system. The investigation of this paradigm case yields two related advantages. On the one hand, the EPP perspective allows for a well-informed interpretation of empirical research on specific components of reading. On the other hand, the scrutiny of these components leads to a refinement, specification, and extension of the conceptual tools and hypotheses developed by EPP.

I also consider cases of reading disorders, namely developmental phonological dyslexia, high-functioning autism, and pure alexia. The reason is that reading disorders help specify the most important conditions of reading in both ‘normal’ and ‘pathological’ cases. Furthermore, reading disorders are interesting in their own right, because they unveil the fragility of socio-culturally shaped cognitive processes. They also contribute to the discovery of the plethora of sub-personally initiated neuronal and bodily strategies to compensate for certain cognitive deficits. This equally applies to developmental disorders (i.e., cases of *dysculturation*) and acquired disorders (i.e., cases of *deculturation* on the EPP construal).

In summary, the EPP framework with its synergy of conceptual analysis and the interpretation of a vast array of empirical results leads to the development of new theses and hypotheses that are relevant to both philosophy and cognitive science.

Zusammenfassung

In den letzten Jahren sind zahlreiche Versuche unternommen worden, die phylogenetischen und ontogenetischen Entwicklungsverläufe neuronaler Verarbeitung, verkörperlichter Handlung und sozio-kulturell beeinflusster kognitiver Praktiken zu erklären. Diese Versuche haben zu anhaltenden Debatten geführt. Sie betreffen die Details der neuronalen Realisierung kognitiver Funktionen, das Maß an Verkörperlichung, das für bestimmte kognitive Fähigkeiten erforderlich ist, sowie den Einfluss der sozio-kulturellen Umwelt auf bestimmte Klassen kognitiver Verarbeitungsroutinen. Diese Dissertation trägt auf entscheidende Weise zu diesen aktuellen Debatten in der Philosophie der Kognitionswissenschaft bei.

Die Grundidee besteht darin, ein neues, integratives und vereinheitlichendes Bezugssystem für die begriffliche und empirische Untersuchung derjenigen kognitiven Prozesse zur Verfügung zu stellen, die sich durch die feingliedrige Wechselwirkung von neuronalen,

körperlichen, und sozio-kulturell bestimmten Prozessen in unterschiedlichen Zeitrahmen charakterisieren lässt. Insbesondere argumentiere ich aus begrifflichen und empirischen Gründen dafür, dass sich das in der Entwicklung begriffene Bezugsystem der *prädiktiven Verarbeitung* zu der Theorie *kognitiver Integration* und ihrer Sichtweise auf *Enkulturation* komplementär verhält. Die daraus resultierende integrative Perspektive – in Kombination mit tiefgreifenden Überlegungen zu Modellen kognitiver Nischenkonstruktion, zur neuronalen Wiederwendung und zu neuronaler Plastizität – ermöglicht es auf einmalige Weise, kognitive Praktiken mit neuen begrifflichen Werkzeugen und empirisch informierten theoretischen Erkenntnissen zu untersuchen. Diese Perspektive nenne ich *enkulturierte prädiktive Verarbeitung*.

Das entstehende Bezugssystem enkulturierter prädiktiver Verarbeitung wird auf die Untersuchung des Lesens angewendet, wobei die Annahme lautet, dass Lesen ein paradigmatischer Fall enkulturierter Kognition ist. Es handelt sich hierbei um eine ontogenetisch erworbene Fähigkeit, die das kognitive Leistungsvermögen eines Individuums auf signifikante Weise transformiert. Lesen wird durch die engmaschige dynamische Interaktion neuronaler und körperlicher (z. B. okular-motorischer) Teilprozesse realisiert. Diese Teilprozesse sind durch eine Anzahl kognitiver Normen beschränkt, die die erfolgreiche Manipulation von Vorkommnissen eines orthographischen Systems anleiten. Die Untersuchung dieses paradigmenbildenden Beispiels hat zwei, miteinander verbundene Vorteile. Einerseits ermöglicht die Perspektive enkulturierter prädiktiver Verarbeitung eine wohlinformierte Interpretation der empirischen Forschung zu bestimmten Komponenten des Lesens. Andererseits führt die kritische Betrachtung der entsprechenden Komponenten zu einer Verfeinerung, Spezifizierung und Erweiterung der begrifflichen Werkzeuge und Hypothesen, die von der enkulturierten prädiktiven Verarbeitung entwickelt werden.

Ich berücksichtige zudem Lesestörungen, nämlich phonologische Legasthenie, hochfunktionalen Autismus und reine Alexie. Der Grund hierfür besteht darin, dass die Auseinandersetzung mit Lesestörungen dazu beiträgt, die wichtigsten Bedingungen des Lesens sowohl in ‚normalen' als auch in ‚pathologischen' Fällen zu spezifizieren. Darüber hinaus sind Lesestörungen an sich interessant, weil sie die Fragilität sozio-kulturell geformter kognitiver Prozesse freizulegen vermögen. Sie tragen auch zur Entdeckung der Vielfalt von subpersonal initiierten neuronalen und körperlichen Strategien bei, die gewisse kognitive Defizite kompensieren. Dies betrifft gleichermaßen Entwicklungsstörungen (d. h. Fälle von Dyskulturation) und erworbene Störungen (d. h. Fälle von Dekulturation).

Zusammenfassend lässt sich sagen, dass das Bezugsystem enkulturierter prädiktiver Verarbeitung, mit seiner Synergie aus begrifflicher Analyse und der Interpretation einer großen Anzahl empirischer Ergebnisse, dazu führt, neue Thesen und Hypothesen zu entwickeln, die sowohl für die Philosophie als auch für die Kognitionswissenschaft relevant sind.