Aus dem Institut für Physiologie
der Universitätsmedizin der Johannes Gutenberg-Universität Mainz

# A task to induce, quantify and operationalize subjectively perceived boredom
oder
# Ein Verhaltenstest zur Induktion, Messung und Operationalisierung subjektiv erlebter Langeweile

Inauguraldissertation
zur Erlangung des Doktorgrades der Medizin
der Universitätsmedizin
der Johannes Gutenberg-Universität Mainz

Vorgelegt von

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Mainz, 2020

Tag der Promotion: 07.12.2021

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The study was approved by the local ethics committee and was conducted in accordance with the Declaration of Helsinki.

J. Seiler

Johannes Seiler

# ACKNOWLEDGEMENTS

I sincerely thank my supervisor for his support and all the helpful assistance, which made this work even possible. In our fruitful discussions, I always appreciated the combination of scientific tidiness and accuracy with playful and curious perspectives on the brain and its functions.

Furthermore, warm thanks to all colleagues and collaborators who contributed to the ideas and theoretical issues of this work in many extensive discussions.

Lastly, I heartily thank my family, especially my wife, for all the emotional support, the constructive criticism from an outside person and the steady encouragement throughout the last years.

# FOREWORD

*“How lethargic the bees are, lolling on their flowers, how sluggish the sunlight sprawled across the ground. A terrible idleness […]. The things people do out of sheer boredom! They study out of boredom; they pray out of boredom; they fall in love, get married and reproduce out of boredom; in the end they die out of boredom […].”*

Georg Büchner, “Leonce and Lena”, Act I (trans. John Reddick)

All humans know about the experience, which Georg Büchner describes in this short excerpt: boredom. Although popular literature and various philosophers for many years have debated about the character and role of tedium for flexible behavior, it has been widely neglected from natural scientific perspectives (Martin et al., 2006). But, if boredom arises in the ubiquity that Büchner charmingly exaggerates, by linking it to various human actions, what exactly is its role and benefit for individuals? The ever-changing environment of our planet makes it necessary for individuals to adapt their behavior flexibly in order to compete with others for the limited resources, which this surrounding provides. In this context, mechanisms to seek and integrate novel information about an individual’s environment are thought to be essential to accelerate the process of behavioral adaptation and maximize the individually obtained reward (Zuckerman, 1990). However, besides increasing the set of learned skills that may serve as a survival advantage, information-seeking mechanisms also have to prevent individuals from becoming stuck in *unlearnable* situations, which do not provide any beneficial information (Gottlieb et al., 2013). In this situation, boredom is discussed to be a central neural feature, carrying this filtering challenge into execution, by driving individuals away from monotonous and trivial situations (Bench and Lench, 2013; Elpidorou, 2018) towards novel experience.

This dissertation aims at contributing to boredom research by presenting a novel psychophysical approach to assess it, combined with a computational framework to interpret the measured behavior. My hope is, that the work at hand, through its methodological gain, sets a cornerstone for future systematic investigations of the behavioral, clinical and neurophysiological correlates of boredom.

Additionally, if in the end Büchner’s assumptions should turn out to be true, besides all insights and findings, this paper itself can be regarded as a case study of a young scientist’s boredom experience and a behavioral strategy to mitigate it.

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# 1) INTRODUCTION

## 1.1) Finding a definition for boredom

Boredom[1] is an ubiquitous human experience, apparent in many situations of daily life, ranging from school (Yazzie-Mintz, 2010) up to later workplaces (Cummings et al., 2016; Kompanje, 2018). Despite this omnipresence throughout life and cultural backgrounds (Sundberg et al., 1991), it has been poorly investigated in the past and only since the last few decades, there is a growing body of researchers systematically exploring it (Smith, 1981; Koerth-Baker, 2016; Raffaelli et al., 2017). The true characterization of boredom thus remains an open debate, but nevertheless some key features have been consistently reported across different studies, which build the core of its current definition. Eastwood and colleagues (2012) reviewed these features and developed a definition of boredom, which until today has found wide acceptance in the field, specifying boredom to be "an aversive mental state of wanting, but being unable, to engage in satisfying activity" (p. 483) that most often arises in a monotonous and dull environment. Accordingly, boredom is particularly composed of negative affect (see Martin et al., 2006), making individuals avoid it, whereas other dimensions of experience comprise the perception of non-optimal arousal (see Danckert, 2018), attentional deficits (see Hunter and Eastwood, 2016) and the perception of a slow passage of time (see Fahlman et al., 2013; Raffaelli et al., 2017). This broad perspective on the various outcome levels of boredom allows to characterize it as a multidimensional syndrome of experiences, acting on perceptual, cognitive and physiological levels simultaneously, in order to drive individuals away from the respective cause of boredom (Bench and Lench, 2013; Elpidorou, 2018; Figure 1).

Although such a broad definition has proven useful, by condensing many dimensions of human boredom experience into one construct, scientific experiments describing these single dimensions have partly revealed conflicting results, raising the question whether to regard boredom as one unitary construct or as a variety of different experiential subtypes (Elpidorou, 2020).

A first aspect to consider in this respect is the temporal framework in which boredom is experienced. Here, boredom has been specified in two temporally distinct shapes, namely as

[1] The terms boredom, tedium and ennui are used synonymously in this work.

a state or trait (Vodanovich and Watt, 2016; Koerth-Baker, 2016). *State boredom* describes a transient experience in response to a discrete and limited situation, whereas *trait boredom* enfolds the general, temporally wide tendency to become bored in a broad range of environments. Both constructs, although being positively correlated to each other (Fahlman et al., 2013; Krotava and Todman, 2014), have been treated separately, since they relate to different behavioral outcomes and have different causes. High boredom proneness on the one hand has been linked to a variety of psychopathologies and personality traits (Lee and Zelman, 2019; Vodanovich and Watt, 2016), whereas state boredom on the other hand seems to manifest a more physiological kind of boredom, which any healthy individual may experience, promoting the pursue of alternative and novel goals (Elpidorou, 2018).

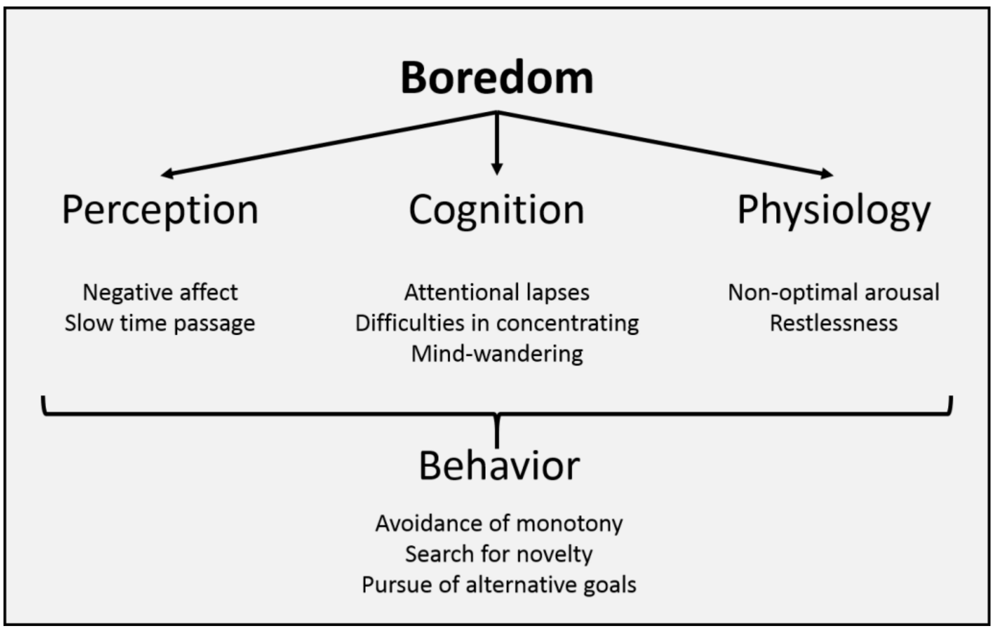


**Figure 1 – Conceptual overview of boredom:** Different experiential components of boredom and its behavioral consequences (contains modified elements from Eastwood et al., 2012 and Bench and Lench, 2013).

Additionally, boredom has been found to be linked to different perceptions of arousal. On one hand, a multitude of studies reported it to be a state of low arousal (Mikulas and Vodanovich, 1993; Danckert et al., 2018), but contrariwise it has also been described as a high arousal state (Merrifield and Danckert, 2014) or a mixture of both (Eastwood et al., 2012; Fahlman et al., 2013). This inconsistency however goes along with very different ways of operationalizing boredom and divergent measurements of arousal (Elpidorou, 2018; Raffaelli et al., 2017), besides having only a minor functional importance, since all potential types of boredom serve a unitary purpose (Elpidorou, 2020). Hence, although boredom can be specified in regard to the palette of temporal occurrence, level of arousal and concrete peculiarity of its perceptional features, the objective to treat and investigate it as an experimental subject requires to bundle it on key features, which necessarily demands a more narrow definition of boredom to operationalize it.

At the current status, for all characterizations the most consistent property of boredom is its negative affection (Eastwood et al., 2012; Smith, 1981; Elpidorou, 2018). The extent of this aversion during monotony becomes beautifully illustrated by a study, conducted by Havermans (2014) and colleagues. Here, participants were exposed to a repetitive movie scene, in order to induce boredom, or a less boring control environment, while being presented with a mechanism to administer electric shocks to themselves. It was found that individuals in the boring condition frequently chose to self-dispense the unpleasant electrocutaneous stimulation (for a replication of results see Nederkoorn et al., 2016). This throws light on the fact, that the character of the stimulation, that individuals seek to reduce boredom, is not necessarily appetitive. It rather can be any kind of incitement provided by the environment, which outstrips the painful monotony of the present situation that in consequence the individuals follow to escape boredom, even if it is nothing more than an unpleasant electric shock. In addition, the state of tedium has also under other experimental settings been described as frustrating, stressful and meaningless (see Martin et al., 2006; Fahlman et al., 2013), confirming the central attribute of boredom being displeasure and avoidance.

Based on this simplified characterization, the following chapter will present a theoretical understanding of the conditions, which evoke this state and the behavioral effects used to alleviate it.

## 1.2) Boredom drives behavior – The causes and consequences of boredom

As widely experienced, boredom arises in situations where an individual is not able to engage successfully with its current environment (Eastwood et al., 2012), by way of example sitting in a waiting room, or listening to the same radio song over and over again. These exemplary situations open two main starting points to understand the emergence of boredom: Either the current environment per se does not fulfill the criterion of satisfying an individual's needs, which mainly means that an environment lacks variability and meaning of stimulation (Mikulas and Vodanovich, 1993; Smith, 1981; Berlyne, 1960), or an individual is not able to draw the desired stimulation from its environment, due to intrinsic, for instance attentional, deficits (Gerritsen et al., 2014; Eastwood et al., 2012; Westgate, 2019). Hence, the appearance of boredom signals a mismatch between an individual's need for information and the amount and quality of information, provided by the present environment. Information in this sense describes the amount of variety in the stimulation of a given situation, and the meaning it has for an individual. To illustrate this, imagine the following thought experiment: Two persons are visiting a museum for modern arts. One of them never really cared about artworks at all, whereas the other one is a real connoisseur and familiar with many epochs and artists. In this imagined situation, both individuals are experiencing the same environment with the same set of stimuli, however the art-naïve person would be much more likely to value the whole trip as boring, due to a shorter mental framework to embed the experienced stimulation and to give it meaning. Boredom hence always constitutes a subjective experience, depending on the external degree of monotony on the one side and an individual's traits, personality properties and prior experience on the other.

After entering percipience, boredom then unfolds its value for adaptive behavior by prompting individuals to tackle its sources, which may affect either of the criteria mentioned above. Firstly, in order to mitigate the external monotony, an individual may simply turn its attention towards an alternative and more promising environment (Smith, 1981; Martin et al., 2006; Bench and Lench, 2013). Concretely, in the example mentioned above, this could mean to step out of the museum into the next café. But also simply taking out a smartphone to review the latest news and press would represent a shift towards a more variable environment. On the opposition, boredom relieve may also be accomplished internally, by starting to mind-wander and daydream (Danckert, 2017; Eastwood et al., 2012; Miyauchi and Kawasaki, 2018). These two coping strategies – one intrinsic and one extrinsic path to monotony relief – are crucial for the understanding of boredom and its behavioral consequences (Figure 2).

Especially, attentional properties have been spotlighted for mediating between these coping strategies (Eastwood et al., 2012; Westgate, 2019). Highly boredom susceptible individuals are found to perform poorly in tasks requiring sustained attentional focus (Malkovsky et al., 2012) and additionally, monotonous tasks often lead to attentional lapses and task-unrelated thoughts (see Raffaelli et al., 2017). In contrast, situations which an individual can easily keep its attention directed on, are often positively evaluated and can lead to a feeling of flow, which typically is conceptualized as the opposite of boredom (Raffaelli et al., 2017), with entire congruence between external demands and the own mental resources (Csikszentmihalyi, 2000; Ulrich et al., 2014). The role of attention in the framework of boredom thus is a functional one, where attention is not the full explanation of tedium, but a consequential prerequisite to successfully shift the focus of action to alternative goals.

So all in all, boredom experience has an inseparable connection to the behavioral response it drives to mitigate itself, implying that there is a direct behavioral readout of an individual's current boredom state. The function and dysfunction of this motivational drive will be discussed in the following subchapter.

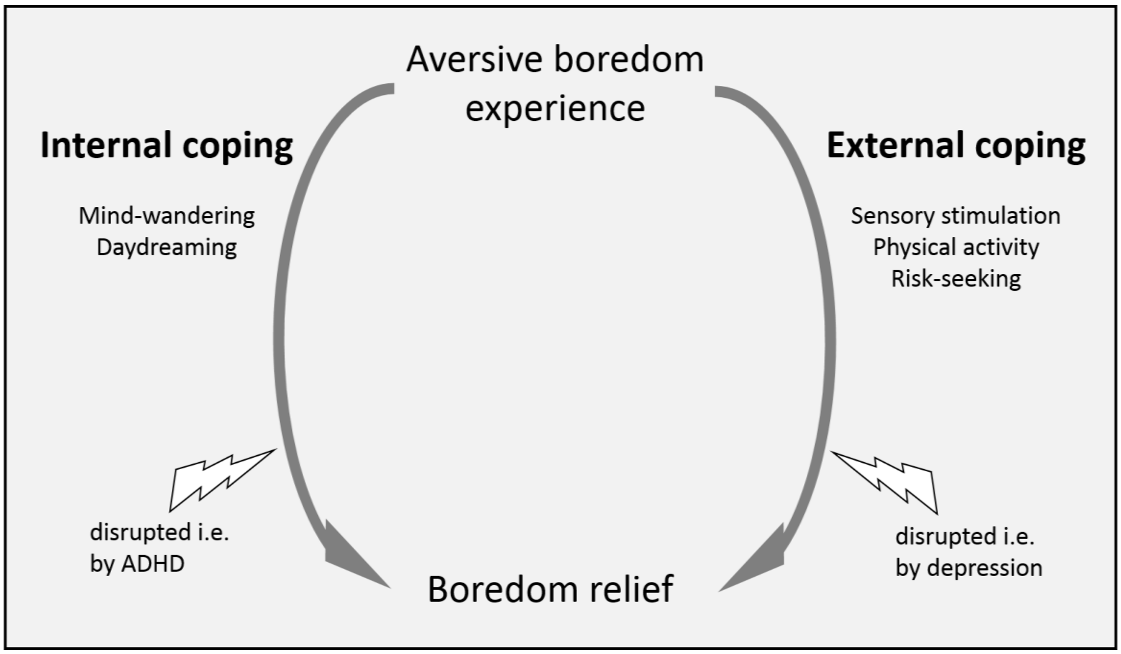


**Figure 2 – Different strategies of boredom coping:** Central strategies of boredom coping and their disruptions in exemplary psychopathologies.

## 1.3) The functions and dysfunctions of boredom

The characterization of boredom as an aversive mental state, accruing during disengagement with one's surrounding, already implicates the concomitant motivation to reduce the cause of negative experience by pursuing alternative, more promising goals (Eastwood et al., 2012; Bench and Lench, 2013). This perspective identifies boredom as a mechanism that promotes novelty-seeking and the exploration of potentially unknown surroundings, which offer higher amounts of sensory stimulation (Zuckerman, 1990). The following subchapter will in more detail present these processes driven by boredom and discuss, in how far it differs from other phenomena that also enhance exploration, like for instance curiosity.

One exemplary situation, illustrating how boredom can facilitate the pursue of novelty, is the emergence of new fashion trends, which has been investigated by Kwon and colleagues (2020), where they found experimental subjects reporting to cycle their clothing due to ennui with old trends. Furthermore, it has been theorized that boredom is a key ingredient for ensuring efficient model learning (Yu et al., 2019) and for optimizing exploration and exploitation tendencies in the framework of predictive coding (Gomez-Ramirez and Costa, 2017). These investigations all display conditions under which boredom prevents individuals from becoming stuck in monotonous dead ends, by prompting alternative behavior and the search of novel information. In this sense, tedium serves the general aim of adaptive functioning in a flexible environment, which enables the maximization of environmental rewards by exploring one's surroundings. Hereby, rewards do not simply comprise consumptionable goods, but especially refer to information and knowledge which might be beneficial for future situations (Gottlieb et al., 2013).

In the interplay with boredom, also curiosity is known to contribute to novelty-seeking (Yu et al., 2019). Various studies emphasize an important role of curiosity in facilitating learning (Jepma et al., 2012) and describe it as an essential feature that makes individuals appreciate novel information (Kidd and Hayden, 2015). Thus, nosiness acts on behavior on a similar way as boredom, by also enhancing the pursuit of novelty, but despite this similar consequence, both constructs are separated by a clear edge, which is defined by different valence. Boredom, as aforementioned, is perceived aversively, whereas curiosity on the other side states a positively affected experience that has been shown to involve neural activation of dopaminergic reward circuits (Kang et al., 2009). Hence, both constructs can be brought together into one framework by considering novelty-seeking behavior to rest upon two main pillars: curiosity on the one hand acts as a *pull factor* that makes novelty more attractive, whereas boredom on the other hand represents a *push factor*, which through negative affection drives individuals away from monotony. Further distinction between constructs is carried out by the internal concept that individuals have of the novel information. According to a famous theory from Loewenstein (1994) curiosity implies a gap between an individual's desired knowledge and the actual knowledge it has, which is subsequently filled by curiosity-driven learning. As the discrepancy of information is reduced, also curiosity becomes weaker. This perspective on curiosity presumes, that an individual has a relatively concrete concept of what the desired information is, defining the size of the informational gap and hence also the extent of nosiness. Such a concept of information deviates from boredom experience, where individuals solely report the desire to escape the current situation, without concretely knowing what they would like to do (Eastwood et al., 2012). Experienced ennui thus drives behavior away from monotony, but in a less target-oriented manner compared to curiosity.

Altogether, these different characteristics point out the discreteness of boredom and curiosity as independent states and features, which although acting together by turning towards novel and more variable information, are based on different cognitive mechanisms.

Besides all these constructive and functional aspects of boredom experience, where it is limited to a certain situational condition, there are also psychopathologies, which make humans suffer from chronical and excessive boredom. This amplification often includes both, the timeframe and magnitude of experience, making individuals more susceptible to boredom as a trait, and also intensifying the coping actions in response to state boredom.

Early phenotypes that have been correlated to ennui included various impulse control deficits. Those behaviors are often summarized as a personality shape under the broader concept of sensation-seeking (Zuckerman, 1990; Moller et al., 1998). These boredom-linked constructs span risk-related behaviors like pathological gambling (Blaszczynski et al., 1990; Bonnaire and Barrault, 2018), drug and alcohol abuse (Windle and Windle, 2018; Biolcati et al., 2018; Phillips et al., 2017) and risky motoring (Horrey et al., 2017). But also increased food consumption (Mathur and Stevenson, 2015) under conditions of emotional eating (Kauffman et al., 2018; Ferrell et al., 2019) and obesity (Abramson and Stinson, 1977), up to binge eating (Lee et al., 2019) have been linked to higher boredom proneness. All these behavior patterns have in common that they involve the search for external stimulation, although being fraught with economic or health-related risk. Such extreme pursuit of external boredom coping suggests an impaired internal coping capacity, by way of example deficient mind-wandering, leading to an overcompensation of boredom with experience-seeking behavior. A great clinical model to illustrate this perturbation is the attentional deficit hyperactivity disorder (ADHD), that is linked to the triad of impaired attentional focus, decreased impulse control and hyperactivity (Ougrin et al., 2010). Patients suffering from this disorder report higher boredom proneness compared to a healthy collective and have troubles focusing their attention, which leads to a continual urge of external self-stimulation (Kass et al., 2003; Pironti et al., 2016; Golubchik et al., 2020).

On the other side, contrarious disorders may have a deficient mechanism of external boredom coping, leading to an overexprimation of internal retreat and constantly wandering thoughts. One example of this sort of impairment is constituted by major depression, which makes participants being trapped in rumination and looped thoughts (Beck et al., 1996). This disorder has also been shown to correlate positively to boredom experience, where affected individuals report being trapped in a situation, which they feel is irrelevant for them, but which they are not able to escape (Spaeth et al., 2015; Lee and Zelman, 2019; van Hooft and van Hooff, 2018).

Hence, these models of psychopathology exemplify again the two main strategies to alleviate boredom either internally or externally, and furthermore depict how a deficit in one path leads to behaviors that deviate from physiology by favoring the opposite strategy. In addition, this brings up the hypothesis, that a deeper investigation of the neural correlates of ADHD- and depression-related boredom, their overlap and discrepancies, could reveal distinct functional regions or networks that realize boredom and its coping mechanisms in the brain.

A key finding emphasizing the neurostructural basis of boredom is illustrated by patients with traumatic brain injury, who tend to be more tedium susceptible, where the severity of brain injury is a good predictor for the extent of boredom proneness (Isacescu and Danckert, 2016) and its association to depressive symptoms (Goldberg and Danckert, 2013).

After understanding the functional value of boredom under physiological conditions, this link between boredom, brain structure and psychopathology leads to the question for the concrete neural engine involved in this experience, which will be discussed in the following.

## 1.4) Boredom in the mammalian brain and the problem of measuring it

As aforementioned, the link of strengthened boredom experience under certain neuro- and psychopathological conditions underpins the importance of regarding boredom as a feature with a neurostructural basis. Such a mechanistic perspective has received comparatively little attention in the research and definitions of the field, but will be of outstanding interest in order to develop tools to modulate and mitigate it under clinical conditions.

A key brain region which has shown to exhibit altered neural activity during boredom induction is the anterior insula (Danckert and Merrifield, 2016; Dal Mas and Wittmann, 2017), while the so called default mode network (DMN) – a set of brain areas thought to be important for introspection during states of passivity (Andrews-Hanna, 2012) – showed robust activation (Ulrich et al., 2014). This pattern has been interpreted as a disability of executive brain regions to engage with a boring environment, in order to reduce monotony in the situation at hand. Although these findings were obtained using functional magnetic resonance imaging (fMRI), there are multiple more electroencephalographic changes which seem to accompany this boredom related activity pattern ranging from less synchronized activity in frontal areas, reflecting decreases in cognitive control (Katahira et al., 2018), over changes in baseline frontal EEG asymmetry (Perone et al., 2019), up to tonically modulated theta activity, representative for the involvement of task-unrelated thoughts (Miyauchi and Kawasaki, 2018; Atchley et al., 2017).

These mechanistic insights suffer from different operationalization of boredom, complicating their comparison and therefore doubtlessly only built the peak of tedium's neural underpinnings. To make these more accessible for experimental investigation, it needs a robust definition and well-operationalized method to quantify boredom, which ideally would be simple enough to translate boredom research also to non-human model organisms, where experimental manipulations are better accessible.

Boredom in animal research has mainly been described according to the search of novel stimulation (Olsen and Winder, 2009) or behavioral stereotypes, which resemble human coping strategies for boredom, by way of example increased food consumption (Meagher and Mason, 2012). In line with the broader branch of human sciences, the field likewise lacks a clear conceptualization and tool to induce boredom experimentally and thus, the narrow toolkit to quantify boredom is a central problem that limits current research about it (Burn, 2017).

Most of the human assessment instruments so far focus on self-report scales, where the single items of these questionnaires refer to different experiential dimensions of boredom (Vodanovich, 2003; Vodanovich and Watt, 2016). In this manner, a variety of questionnaires has been developed to quantify state (Fahlman et al., 2013; Donati et al., 2019) and trait aspects of boredom (Farmer and Sundberg, 1986; Struk et al., 2017), where each method incorporates different perceptual aspects of boredom and is based on a slightly different definition. Especially assessment tools for state boredom are still poorly represented among these measures (Eastwood et al., 2012), although this is thought to be the most fundamental kind of boredom experience, since one cannot be said to possess the trait of boredom without experiencing state boredom (Elpidorou, 2018). Thus, the self-report methodology, although it has proved useful to investigate the relation of ennui to other human psycho- and sociological features, suffers strongly from heterogeneity and inconsistency in conceptualization of boredom (Mercer-Lynn et al., 2013; Vodanovich and Watt, 2016), besides general qualitative deficits of self-report measures, comprising dishonesty and social desirability biases (McDonald, 2008) and the limitation to study boredom in individuals with adequate linguistic understanding. In addition, also the induction methods for boredom strongly vary across studies, ranging from a dull video sequence showing people hang laundry (Merrifield and Danckert, 2014) up to repetitive, simple tasks (Markey et al., 2014).

All these points lead to the central problem of lacking standardized methods for inducing and objectively measuring boredom (Eastwood et al., 2012; Raffaelli et al., 2017). This current limitation is the starting point for the present study, where this work presents a novel psychophysical approach to quantify state boredom behaviorally. Furthermore, this task is applied in multiple cohorts of healthy human participants to validate the link between task performance and boredom experience, and a theoretical framework is developed to capture the dynamics that drive boredom-related decision-making.

Overall, the task paradigm is designed in an unsophisticated way, so that its principles are readily implicable in future animal studies as well. To allow this translational approach, the methodology uses a simplified definition of boredom that covers its most prominent and species-overlapping features. The following chapter will elaborate the task paradigm and its operationalization of boredom, besides presenting the concrete experimental steps, which are taken in this study.

# 2.) MATERIALS AND METHODS

Central aim of this study is to establish a behavioral task that quantifies boredom in humans, which could also be used in future translational animal studies. The following chapter will present this task in its principles and conceptualization of boredom. Based on this paradigm, four experiments were conducted in independent samples of healthy humans, to stepwise explore behavior during the testing, its relation to boredom experience and the factors driving and modulating it.

## 2.1) A task to quantify boredom

To quantify boredom, this work characterizes ennui in line with the abovementioned core of its definition as aversion towards monotony (Burn, 2017; Eastwood et al., 2012), where sensory stimulation of different variety is used to induce particular levels of monotony. In concrete, we established a modified two-alternative forced choice task, which is referred to as *Boredom Choice Task* (BCT), to measure boredom avoidance behavior in a trialwise fashion. Each trial includes a decision for one of the two alternatives and the following presentation of a sensory stimulus. Both alternatives have a symmetric design and only differ in their position, located either right or left, and the extent of monotony in the stimulation they provide.

For the human study at hand, these alternatives consisted of two buttons, which were displayed on opposite corners of a computer screen, realized by a custom php software, accessible through a standard internet browser. For the behavioral test participants were placed in front of the screen and received an instruction, informing them that they had to complete a certain amount of choices by clicking on one of the buttons with the computer mouse, which triggered the presentation of a sensory stimulus. After completing the task, participants received a pre-determined monetary reward that was independent from task performance. One complete task cycle consisted of an afore-defined amount of trials, where each trial of the task started with both buttons being visible at opposite corners of the screen. Then, after clicking on either of them, both buttons disappeared and a sensory stimulus was presented. The stimulus set of one cycle comprised either images of everyday objects, displayed for one second in the middle of the screen (*visual modality*), or sounds that were played via a headphone, which participants had to wear for the duration of the experiment (*auditory modality*) (Figure 3).

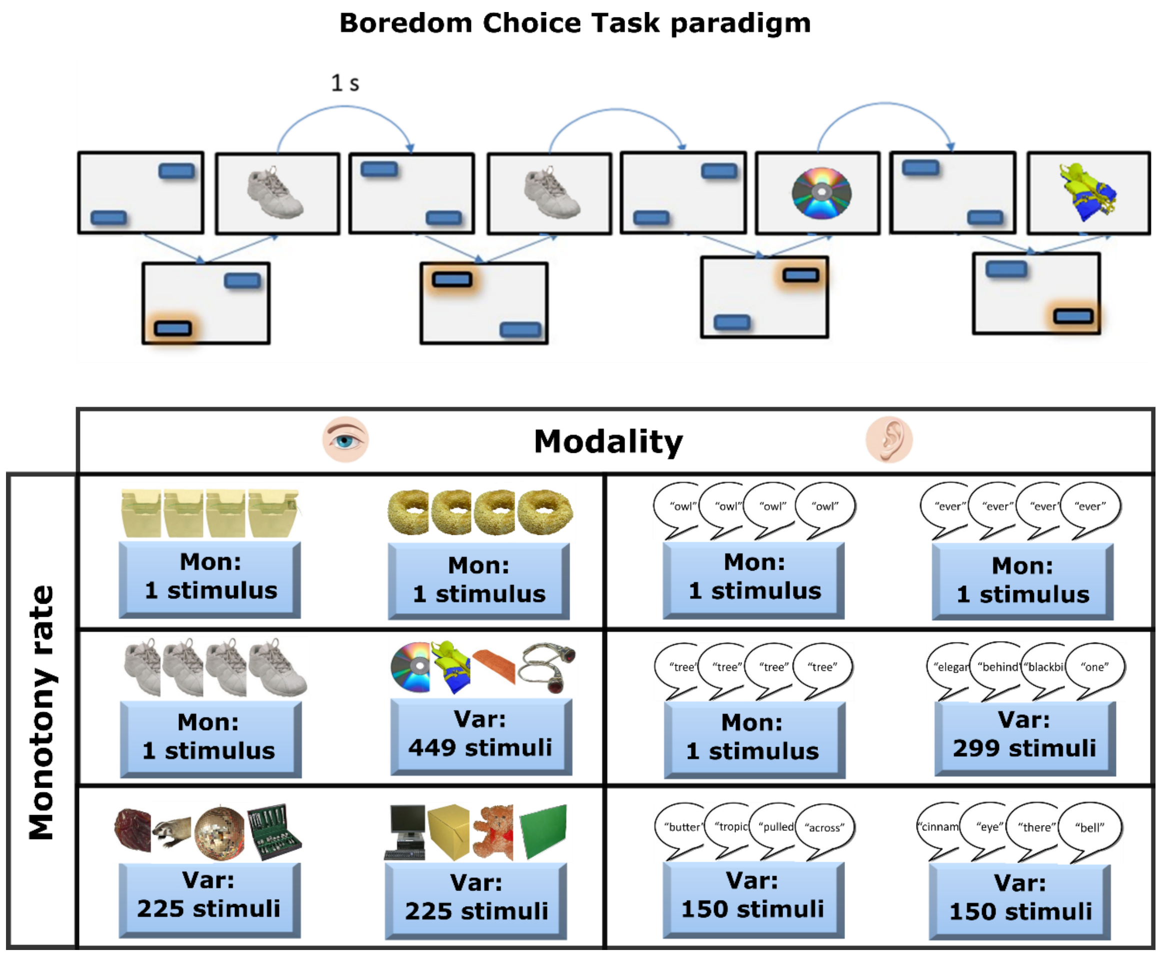


**Figure 3 – Concept of the *Boredom Choice Task*:** The upper panel shows a sequence of choices and stimulus presentations in the monotonous vs. variable condition, where the variable alternative in this example is located right. The shaded buttons represent the currently chosen options. The lower panel depicts the six basic task conditions (monotonous vs. variable, monotonous vs. monotonous and variable vs. variable) with different stimulus library pairings in visual and auditory modality.

For the new trial, the buttons reappeared in contrary corners, so that subjects at each trial had to move the computer mouse to decide for one button anew. To implement boredom in this paradigm, both alternatives were associated with different degrees of sensory monotony, realized by stimulus libraries of different sizes. The smaller the stimulus library, associated with one button, the higher the probability was to experience a repetition when choosing this alternative, corresponding to a relatively higher level of monotony. Accordingly, a large stimulus library corresponded to a small extent of monotony. In the condition with maximally different degrees of repetitiveness, one alternative was associated exclusively with a singular stimulus (*monotonous alternative*), whereas the other one was linked to variable stimuli, that were randomly drawn from a large stimulus library (*variable alternative*). Throughout a cycle the assignment of monotonous or variable sensory stimulation to the right or left position on the screen was constant. For the visual task a stimulus library was used, containing 450 images of everyday objects from the Bank of Standardized Stimuli (Brodeur et al., 2010; Brodeur et al., 2014), whereas the auditory stimulus library consisted of 300 neutral spoken German words downloaded via the website https://soundoftext.com (for representative examples of the stimuli see Figure 3).

One task cycle, comparing two alternatives of particular degrees of monotony, built the core of each of the experiments, conducted in this study. Thereby, the Boredom Choice Task design derived from the hypothesis that the avoidance of the more monotonous alternative, respectively the preference for the more variable alternative, reflects state boredom.

## 2.2) Other psychometric assessment tools

To validate the behavioral readout of the BCT as a measure of ennui and to investigate the link to psychopathology, a variety of well-established self-report scales and other tests were included in the experiments, typically used to assess boredom-related features (Chapter 8.2 and 8.3) as well as personality traits and psychiatric symptoms. Since no validated German translation of the boredom questionnaires was available at the beginning of this study, all items were translated from the original works by a professional agency. These German version of the questions were thereupon back-translated and verified by three independent persons to show full congruence in meaning with the originals. The following catalogue lists all psychometric tools that were used in this study:

***Patient history and sociodemographic information (PH)***

Participants were asked about their date of birth, height and body weight as well as ethnical background, previously known diseases, regular drug intake, substance abuse, psychiatric disorders in their families, occupation and subject of studies.

***Boredom Proneness Scale (BPS)***

The BPS is a self-report scale to quantify individual trait boredom (Farmer and Sundberg, 1986). It includes 28 items that are rated on a 7-point Likert scale and includes the dimensions External Stimulation, Internal Stimulation, Affective Responding, Waiting Behavior and Time Perception.

***Multidimensional State Boredom Scale (MSBS)***

The MSBS is a 29 item questionnaire to measure state boredom (Fahlman et al., 2013). It incorporates subscales quantifying Disengagement, High Arousal, Low Arousal, Inattention and Time Perception. In this study an annotation was added, stating that all questions referred to the feeling while working on the BCT.

***General Health Questionnaire (GHQ-28)***

The GHQ-28 is a questionnaire to screen for minor psychiatric disorders in the general population (Goldberg and Hillier, 1979). This 28 item version includes four subscales: Somatic Symptoms, Anxiety and Insomnia, Social Dysfunction and Depression.

***Conner's Adult ADHD Rating Scale (CAARS-S:L)***

The CAARS-S:L is the long self-report version of a questionnaire to assess symptoms of Adult Attentional Deficit Hyperactivity Disorder (Conners et al., 1999). It consists of 66 items and includes the subscales Inattention/Memory Problems, Hyperactivity/Restlessness, Impulsivity/Emotional Lability and Problems with Self-Concept.

***Beck's Depression Inventory (BDI-II)***

The BDI-II is a self-report inventory including 21 items used to measure the prevalence and severity of depressive symptoms (Beck et al., 1996). It has been established for individuals aged over 13 years, matching the current study's sample of participants.

***Big Five Inventory (BFI-10)***

The BFI-10 is a short 10 item questionnaire, measuring the Big Five personality traits Extraversion, Agreeableness, Conscientiousness, Emotional Stability and Openness (Rammstedt and John, 2007).

***Impulsivity Questionnaire (I-8)***

The I-8 is a short 8 item self-report inventory, assessing the susceptibility to impulsive behavior on the four dimensions Urgency, Willingness to Take Risks, Endurance and Purpose (Keye et al., 2009; Kovaleva et al., 2012).

***State Trait Anxiety Inventory (STAI-Y)***

The STAI-Y is a diagnostic tool for measuring individual state and trait anxiety consisting of 20 items (Spielberger et al., 1999).

***Brief Resilience Scale (BRS)***

The BRS is a 6 item self-report scale to assess resilience to stress and burdens in life (Smith et al., 2008; Chmitorz et al., 2018).

***Visual analogue scale for state boredom (VAS-B)***

Additional to the multidimensional scales, participants rated their state boredom on a visual analogue scale. They were presented with the request "Please rate on the slider below how bored you feel right in this moment" and a digital slider they could move on a line, ranging from "not bored at all" to "completely bored" in a grading of one hundred steps (Chapter 8.3).

***Visual analogue scales for affect and arousal (VAS-AA)***

To quantify the perceived valence and arousal during the Boredom Choice Task and compare it with imagined mental states, visual analogue scales for both of these parameters were included. In particular, subjects were presented a textbox with the request "Imagine you are in a situation where you are bored by / curious about something. Please rate on the sliders below, how happy and aroused you feel in this situation". Below this textbox subjects then rated their affect and arousal for the imagined experience on a visual analogue slider (Betella and Verschure, 2016) with a grading of one hundred steps. Lastly, an equivalent rating was conducted for the BCT with the instruction "Please rate on the sliders below how happy and aroused you feel while playing the computer games" (Chapter 8.3).

***Working memory task (digit span backwards task)***

The digit span backwards task is a measure for working memory capacity (Ramsay and Reynolds, 1995). Participants were exposed to verbally read out number series (ranging from 0-9) which they had to memorize and write down in reverse order after the last number was presented. The first series had a length of two numbers, which was then increased from round to round up to seven digits, where each level of difficulty was presented twice (Chapter 8.4). The task was ended if a subject answered the two series of one difficulty incorrectly, or after correctly completing both series of seven digits. The sum score of the task was then computed as the amount of correctly noted digit series, corresponding to a maximum of twelve points with ideal performance.

## 2.3) Experimental procedures

### 2.3.1) Experiment I: Explorative description of behavior during the task

In the first step, 49 healthy human participants underwent the Boredom Choice Task and answered the aforementioned psychometric questionnaires under controlled conditions of a behavioral laboratory. Subjects were recruited via the online recruiting system ORSEE

(Greiner, 2015), mainly involving undergraduate students from the Johannes-Gutenberg University Mainz, which received an expense allowance of 25 € for participation. Exclusion criteria were: active psychiatric disorders, hearing loss, strongly impaired vision and insufficient language knowledge. All subjects fulfilled these requirements. The investigation was conducted in the Mainz Behavioral and Experimental Laboratory. Subjects were welcomed and instructed to the experiment, noting that the study simply meant to examine behavior during sensory stimulation. The fact, that boredom was the key issue of the study, was not provided. Hereupon, all participants filled out a battery of self-report scales before executing a total of six BCT cycles (Figure 4 A). The first two conditions included monotonous vs. variable BCT cycles, randomized in visual and auditory modality. This was followed by four control cycles with the BCT presenting monotonous vs. monotonous and variable vs. variable stimuli, again in random order. After completing all six cycles, participants filled out the MSBS, referring to their feeling during the task. The whole experiment took about 2.5 h and all participants provided written informed consent prior to participation.

### 2.3.2) Experiment II: Replication and validation

The second experiment of this study aimed at replicating the previous results in an independent sample of participants. Therefore, 53 task-naïve subjects were recruited to the Mainz Behavioral and Experimental Laboratory via the online recruiting system ORSEE (Greiner, 2015), again mostly comprising undergraduate students. Exclusion criteria and experimental procedure were equivalent to the previous study, except an addition of the visual analogue ratings of state boredom (VAS-B), affect and arousal (VAS-AA), where the imagined boredom and curiosity condition were rated prior to the behavioral test. On the other hand, affect and arousal of the task and a second rating of state boredom were conducted after completing the task (Figure 4 B). The experiment again took approximately 2.5 h and subjects received an expense allowance of 25 € for their participation.

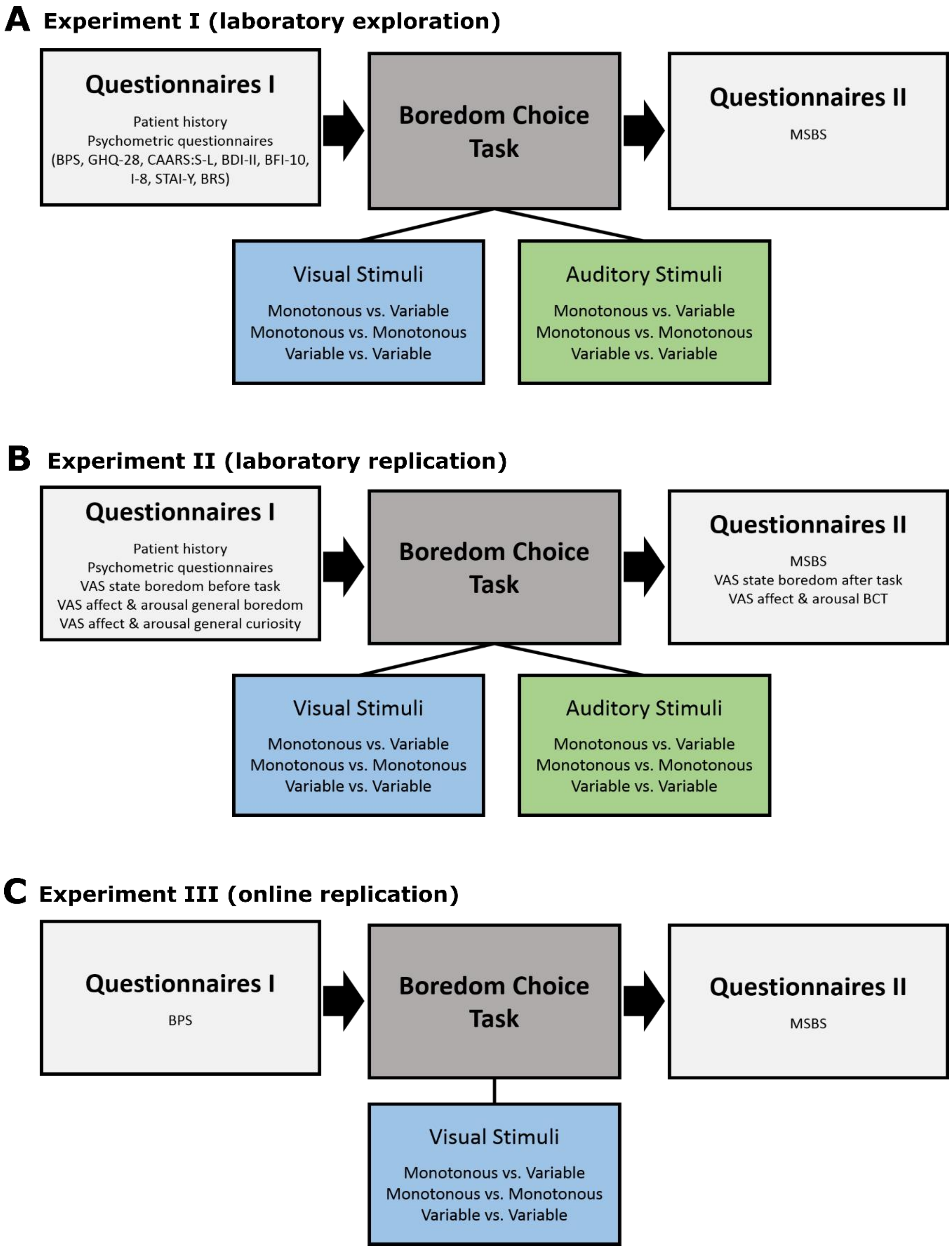


**Figure 4 – Procedures of Experiment I, II and III:** The task was in all test series at the core of the experiment, framed by self-report assessments. (**A**) Experiment I. (**B**) Experiment II. (**C**) Experiment III.

### 2.3.3) Experiment III: Replication in an online experiment

As a third step, this experiment aimed at replicating the results from the previous two test series in a less controlled, but experimentally readily accessible online environment. Therefore, 40 participants were recruited via the online platform Amazon Mechanical Turk (https://mturk.com), which is globally available. This website offers to distribute experiments, tasks or simple jobs to a wide collective of registered volunteers, who may execute these jobs from any computer with internet access and in the end receive an expense allowance for participation. In order to reduce the length of the experiment, online subjects were only presented the three visual cycles of the BCT and boredom questionnaires (BPS, MSBS), which took about one hour of lead time (Figure 4 C). The task settings corresponded to Experiment I and II. After completion of the experiment, participants received a monetary amount of 5 $ (USD).

### 2.3.4) Experiment IV: Altering the degree of monotony in the task

Finally, an adjacent experiment was conducted to investigate boredom-linked choice behavior and its underlying dynamics under different conditions of monotony. Therefore, 148 human participants were recruited equivalently to the criteria and methods of Experiment I and II. The experiment again took place in the Mainz Behavioral and Experimental Laboratory and was compensated with 25 €. Subjects were presented with the aforementioned questionnaires and visual analogue scales. A subset of participants (n = 73) further underwent a working memory test prior to the BCT. The behavioral probe that all subjects completed, incorporated 13 BCT cycles, each consisting of 100 trials, where all cycles only included visual stimuli and in each condition both alternatives were associated with stimulus libraries of particular sizes, in order to realize different degrees of monotony. The library sizes were chosen in the pairings ($size_{alternative1}$ : $size_{alternative2}$) 1:1, 2:1, 4:1, 8:1, 16:1, 32:1, 64:1, 64:2, 64:4, 64:8, 64:16, 64:32, 64:64 (Figure 5). The setting 1:1 was equivalent to the previous monotonous vs. monotonous condition, the 64:64 condition was equivalent to variable vs. variable and 64:1 was widely corresponding to variable vs. monotonous, offering the highest difference between alternatives. In line with the previous experiments the order of presenting all these conditions was random to compensate for time dependent drifts of behavior. The experimental procedure took approximately 2.5 h in total.

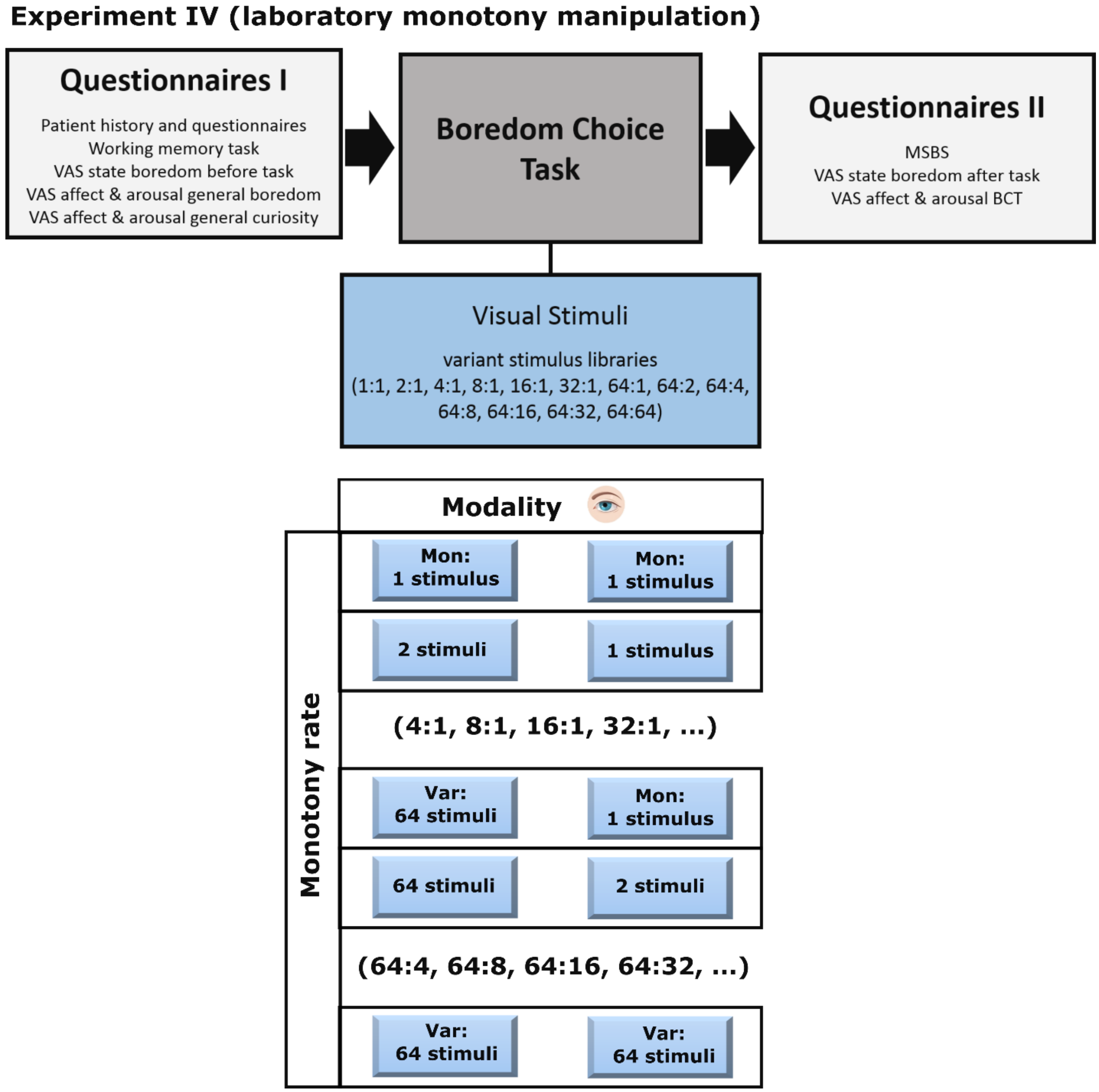


**Figure 5 – Procedure of Experiment IV:** The 13 task cycles were associated with different degrees of monotony, realized in form of varied stimulus library pairings.

## 2.4) Data analysis

All analyses were conducted using the MATLAB® statistics and machine learning toolbox (The Mathworks Inc., Natick, Massachusetts, USA, version R2016b).

The questionnaire data was analyzed by computing the sum score for each questionnaire. Subjects that missed to fill out items of a questionnaire were excluded from the respective analysis.

### 2.4.1) Preference analysis

As a simple readout for preference in the choice task, the amount of choices for the variable button relative to all trials of one game was computed (raw preference $\pi$). For the control conditions the same procedure was conducted, only referring to choices of the right alternative.

$$raw\ preference = \pi = \frac{n_{choices\ variable/right}}{n_{all\ choices}}$$

To analyze the evolution of preference over the duration of one task cycle, raw preference was analogously calculated in a bin of 15 trials, which was gradually shifted trial by trial until the end of the respective task cycle. Concretely, in a set of 300 trials in total, the first time bin ranged from trial 1-15 and was then shifted 285 times up to the last time bin from trial 286-300. This iterative analysis allows a description of choice behavior over different temporal cutouts of the task.

### 2.4.2) Relating raw preference scores to inherent side preference

In order to adjust the raw preference $\pi$ from the monotonous vs. variable condition to individual asymmetric side preferences, it was standardized according to the average choice bias in the control conditions. Therefore, in a first step the average preference $\overline{\pi_{MonVar}}$ was computed over all monotonous vs. variable BCT cycles (e.g. visual and auditory) for each participant:

$$\overline{\pi_{MonVar}} = \frac{1}{n_{MonVar}} * \sum_{i=1}^{n_{MonVar}} \pi_i$$

In addition, the mean preference for the right alternative $\overline{\pi_{Control}}$ was calculated over all control cycles of the BCT (monotonous vs. monotonous and variable vs. variable):

$$\overline{\pi_{Control}} = \frac{1}{n_{Control}} * \sum_{i=1}^{n_{Control}} \pi_i$$

Both preference scores were referred to each other by subtracting the inherent bias $\overline{\pi_{Control}}$, stemming from conditions of equivalent alternatives, from the choice bias $\overline{\pi_{MonVar}}$ of highly unequal alternatives:

$$\rho = \overline{\pi_{MonVar}} - \overline{\pi_{Control}}$$

This operation yielded an adapted preference parameter with values ranging from -1 (completely choosing the monotonous/left option) over 0 (no preference for either side) to 1 (completely choosing the variable/right option). This parameter is entitled as *adjusted preference index* $\rho$.

By way of example, if a subject experienced the variable button being positioned on the left side of the screen in both monotonous vs. variable BCT cycles and exhibited an average raw preference of $\overline{\pi_{MonVar}} = 0.9$, but in the control cycles showed a mean preference for the left side of $\overline{\pi_{Control}} = 0.6$, this corresponds to an adjusted preference index of $\rho = 0.9 - 0.6 = 0.3$.

## 2.4.3) Computation of empirical entropy

As a measure for experienced variability the empirical entropy was computed stepwise for each trial $t$ of each task cycle that a participant completed. Here, the following variables indicate:

- $n_{j,t}$ represents the amount of different unique stimuli, receipt from alternative $j$ up to trial $t$.
- $f_{i,j,t}$ is the relative frequency of presenting the stimulus with the index $i$ at alternative $j$ on trial $t$.

Then, the absolute entropy for one option was computed for each trial as

$$Entropy_{j,t} = H_{j,t} = -\sum_{i=1}^{n_{j,t}} f_{i,j,t} * \log(f_{i,j,t})$$

where $i$ refers to the stimulus or the stimuli which were experienced at alternative $j$ up to trial $t$. Analogically, such an entropy value was computed for the second alternative at each trial. This computation method quantifies entropy for one alternative at a given trial as a fraction of the total entropy of both alternatives. Overall, the obtained numerical value reflects the current state of variety within the distribution of experienced stimuli at a specific alternative and trial, where the algorithm leads to the following dynamics: If one alternative is never chosen, its entropy is set to zero ($f_{j,t} = 0 \rightarrow H_{j,t} = -0 * log(0) \rightarrow H_{j,t} = 0$). On the other hand, the entropy of an alternative also would be zero, if this option is exclusively chosen and only presenting one single stimulus. In this case, the equation follows: $f_{j,t} = 1 \rightarrow H_{j,t} = -1 * log(1) = 0$. In addition, if both options present only a singular stimulus, the entropy of an alternative becomes lower, as it is chosen more frequently, and on the other side, if both alternatives present non-repetitive stimuli, the entropy value of an alternative increases, as it is chosen more frequently (for an example that illustrates the computation of entropy see Chapter 8.5)

### 2.4.4) Linear regression model for choice behavior during the task

To describe the individual choice probability at each trial the following logistic regression model was considered:

$$P_t(right) = \frac{1}{1 + e^{-\theta}}$$

where

- $P_t(right)$ is the probability of choosing the alternative, positioned on the right side of the screen, based on the experience up to trial $t$.
- $\theta = \beta_0 + \beta_1 * M_t + \beta_2 * \Delta H_t$

In this model

- $\beta_i, i \in \{0..2\}$ are the fitted parameter weights for each single participant,
- $right = \begin{cases} 1 & if\ right \\ 0 & if\ left \end{cases}$ is the binary indicator of whether current choice is in favor of the right positioned alternative. Together with the parameter weight $\beta_0$ it reflects *inherent side preference*,
- $M_t = \begin{cases} 1 & a_t = a_{t-1} \\ -1 & otherwise \end{cases}$ is the binary indicator of whether the current choice $a_t$ is identical to the previous one $a_{t-1}$, referred to as *momentum*,
- $\Delta H_t$ is the difference in entropy between the two alternatives at the current trial, where the entropy from the left alternative is subtracted from the right alternative's entropy. This parameter is termed *sensitivity to entropy*.

The model was applied to each participant's dataset of Experiment IV, including 1,287 decisions per subject, as well as their preceding entropy difference values and choices. Then a maximum likelihood estimation was conducted to find the best fitting parameter weights $\beta_0$, $\beta_1$, $\beta_2$ for each participant.

***Relative contribution of momentum and sensitivity to entropy***

The absolute contribution of the model parameters *entropy sensitivity*, *momentum* and *inherent side preference* to each decision was computed as the product of the best fitted parameter weight and the parameter value from the respective trial. In the case of entropy sensitivity and momentum, this yields a vector for each individual, whereas the absolute contribution of inherent side preference is reflected by a scalar that is equal to its parameter weight:

$$absolute\ contribution_{\text{entropy sensitivity}} = |\beta_2 * \Delta H_t|$$
$$absolute\ contribution_{\text{momentum}} = |\beta_1 * M_t|$$
$$absolute\ contribution_{\text{inherent bias}} = |\beta_0|$$

Next, the absolute contribution of entropy sensitivity was set in relation to the sum of the contributions of momentum and entropy sensitivity. Thus, for each trial $t$ the proportion of contribution for sensitivity to entropy was calculated as:

$$c_{\Delta\text{H,t}} = \frac{|\beta_2 * \Delta H_t|}{|\beta_2 * \Delta H_t| + |\beta_1 * M_t|}$$

This relative contribution of each participant was then averaged over all trials:

$$\overline{c_{\Delta\text{H}}} = \frac{\sum_{i=1}^{n_{trials}} c_{\Delta\text{H,t}}}{n_{trials}}$$

A value of this mean relative contribution larger than 0.5 reflects, that an individual in its choice is more strongly driven by entropy sensitivity. Vice versa, an average contribution smaller than 0.5 indicates stronger impact of the momentum parameter.

## 2.4.5) Statistical tests

For the data analysis, this study followed an exploratory approach with further confirmatory hypothesis testing based on these findings. Here, the concrete hypotheses derive from the respective step of the study and are, together with the corresponding statistical methods, more specifically described in Chapter 3. All tests were conducted with the aforementioned MATLAB® software.

***Correlation analysis***

In most of the correlation analyses Spearman's correlation coefficient was applied as a rank-based measure that is well applicable to the non-normally distributed variables of the study.

In addition, Pearson's correlation coefficient was used to specifically test correlations that presented a linear interaction. In the validation of the Boredom Choice Task a correlational screen was conducted with various psychometric variables, without correcting the p-values for multiple testing. In the next step, only one particularly strong correlation was selected and tested for confirmation in an independent dataset. Then, both datasets were pooled and the correlative interaction was reported after Bonferroni-correcting the p-value for multiple testing (all correlation coefficients and p-values can be found in Chapter 3).

***Hypothesis tests***

Differences between dependently sampled variables were investigated with Wilcoxon signed rank tests, whereas discrepancies between dependently sampled variables were tested with a Wilcoxon ranked sum approach. In addition, Wilcoxon ranked sum tests were also used to investigate differences between a distribution of certain sets of observations and random permutation of these sets. This approach allows to test, if the property that underlies a specific arrangement of the data into sets has an impact on the observed variable, or if it does not deviate from random grouping. A further bootstrap sampling of permutations was conducted and the impact of the respective arrangement parameter was referred to this distribution of resampled data, in order to corroborate a significant difference in the Wilcoxon ranked sum test.

Furthermore, one-sample t-tests were used to investigate whether a certain distribution differed from a normal distribution with a particular arithmetic mean.

# 3) RESULTS

## 3.1) Descriptive statistics and general findings

### 3.1.1) Sociodemographic characteristics of participants

To investigate the characteristics of the recruited sample, the sociodemographic background of participants from laboratory Experiments I, II, and IV was analyzed (Table 1).

| | **Experiment I** (n = 49) | **Experiment II** (n = 53) | **Experiment IV** (n = 148) |
|---|---|---|---|
| **Gender** | | | |
| Female | 34 (69.4%) | 32 (60.4%) | 114 (78.0%) |
| Male | 15 (30.6%) | 21 (39.6%) | 34 (23.0%) |
| **Age** (years) | | | |
| Mean | 24.6 | 21.6 | 22.1 |
| Standard deviation | 4.7 | 2.8 | 3.0 |
| **Body weight** (kg) | | | |
| Mean | 68.1 | 67.5 | 68.3 |
| Standard deviation | 11.4 | 11.5 | 12.6 |
| **Height** (cm) | | | |
| Mean | 172.4 | 173.5 | 172.1 |
| Standard deviation | 9.3 | 9.1 | 9.5 |
| **BMI** ($kg/m^2$) | | | |
| Mean | 22.8 | 22.4 | 23.0 |
| Standard deviation | 2.6 | 2.8 | 3.5 |
| **Ethnical background** | | | |
| Kaukasian | 44 (89.8%) | 51 (96.2%) | 141 (95.3%) |
| African | 1 (2.0%) | 1 (1.9%) | 3 (2.0%) |
| Asian | 5 (10.2%) | 4 (7.5%) | 4 (2.7%) |
| Other | 1 (2.0%) | 1 (1.9%) | 2 (1.4%) |
| **Size of hometown** (inhabitants) | | | |
| < 10 000 | 16 (32.7%) | 22 (41.5%) | 71 (48.0%) |
| 10 000 – 100 000 | 21 (42.9%) | 18 (34.0%) | 48 (32.4%) |
| > 100 000 | 12 (24.5%) | 13 (24.5%) | 29 (19.6%) |
| **Subject of studies** | | | |
| Economics | 13 (26.5%) | 13 (24.5%) | 33 (22.3 %) |
| Business administration | 2 (4.1%) | 1 (1.9%) | 1 (0.7%) |
| Law | 7 (14.3%) | 6 (11.3%) | 9 (6.1%) |
| Teaching post | 4 (8.2%) | 5 (9.4%) | 18 (12.2%) |
| Sociology | 2 (4.1%) | 1 (1.9%) | 7 (4.7%) |
| Biology | 4 (8.2%) | 4 (7.5%) | 6 (4.1%) |
| Medicine | 1 (2.0%) | 3 (3.8%) | 8 (5.4%) |
| Journalism | 1 (2.0%) | 4 (7.5%) | 5 (3.4%) |
| Politics | 1 (2.0%) | 2 (3.8%) | 7 (4.7%) |
| Other | 14 (28.6%) | 15 (28.3%) | 54 (36.5%) |
| **Psychiatric disease in family** | | | |
| Yes | 13 (26.5%) | 13 (24.5%) | 49 (33.1%) |

**Table 1 – Sociodemographic characteristics of participants from Experiments I, II and IV.**

Subjects showed an average age of 23 years and a mean BMI of 22.7 kg/m², corresponding to normal weight on average. The majority of sampled individuals was female (72.0%), had a Kaukasian background (94.8%) and stemmed from a small hometown with less than 10,000 inhabitants (43.6%). All of them were enrolled students from the Johannes-Gutenberg University Mainz, where the most frequent fields of study were economics (23.6%), teaching post (10.8%) and law (8.8%). None of them suffered from active psychiatric disorders, however a significant fraction reported diagnosed psychiatric disorders in the close family (30.0%). All in all, these results indicate a homogenous sample of young and healthy adults with a higher-than-average education.

## 3.1.2) Self-reported boredom correlates to risk- and pathology-related phenotypes

In a first step, this study aimed at replicating the link of boredom and self-reported psychopathological symptoms. Therefore, Spearman's correlation coefficient was computed over the self-report psychometric data from Experiment I to exploratively screen for interrelations to the boredom questionnaires (Figure 6).

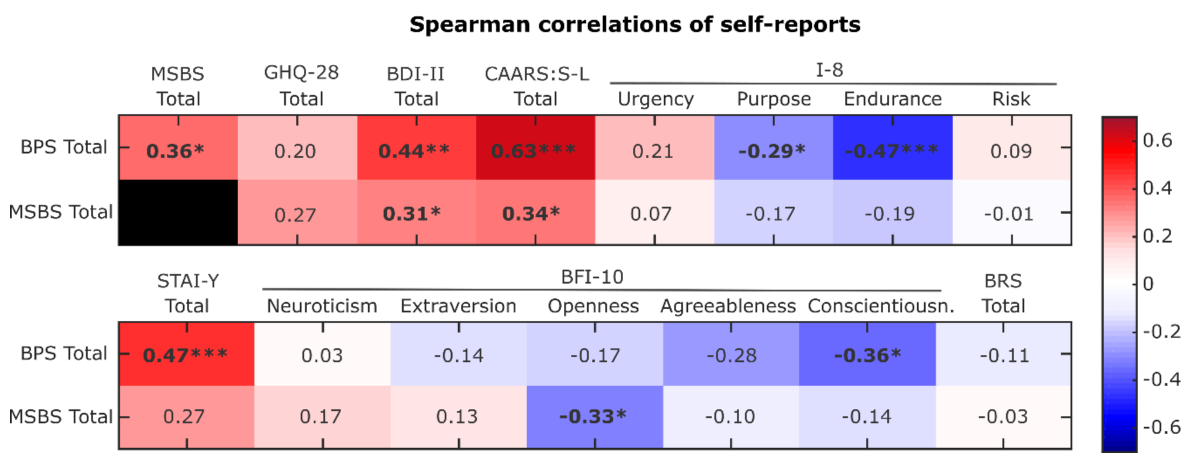


**Figure 6 – Correlations of boredom questionnaires and psychometric assessments:** The color of each cell represents the Spearman correlation coefficient's magnitude. Each correlation contains data from n = 49 participants. *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$. All correlations with $p < 0.05$ are presented in bold digits.

This analysis revealed a positive correlation between trait and state boredom (R = 0.29, p = 0.04), indicative of the close connection of both constructs. Furthermore, boredom ratings showed a link to inattentional, impulsive and depressive symptoms, as well as to anxiety.

Importantly, these connections predominantly were stronger for trait boredom scores compared to state boredom. In addition, a negative link between trait boredom and the personality dimension of conscientiousness was observed, whereas state boredom correlated negatively to openness.

All in all, these findings replicate the previously described connection between boredom and psychopathology (see Kass et al., 2003; Pironti et al., 2016; Spaeth et al., 2015; Lee and Zelman, 2019), demonstrating the clinical relevance of it. Although state and trait boredom are positively inter-connected, both constructs, as operationalized by the questionnaires used here, show distinct correlation profiles to the single types of symptoms, which reflects their disparity.

### 3.1.3) The Boredom Choice Task robustly induces boredom

To verify that boredom is even prevalent and intensified during the behavioral task, the visual state boredom ratings from time points before and after the BCT cycles were compared (Figure 7). Here, all subjects without exception reported higher state boredom after completing the paradigm in comparison to the prior condition (Wilcoxon signed rank test: $p < 0.001$).

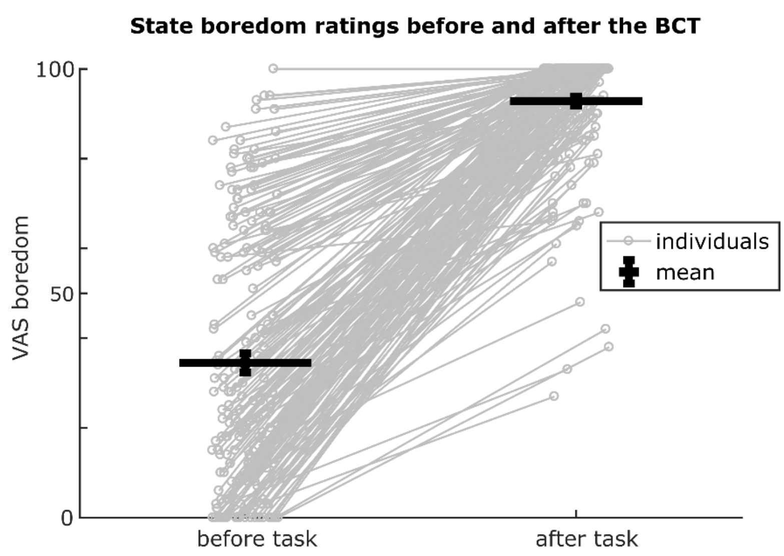


**Figure 7 – State boredom ratings before and after the Boredom Choice Task:** Grey circles reflect the visual analogue rating from each individual (n = 250 participants from Experiment I, II and IV). The horizontal bars reflect the average over all subjects and the vertical bars indicate the standard error of the mean. Boredom ratings after the task are significantly higher compared to the prior condition ($p < 0.001$ in a Wilcoxon signed rank test).

Importantly, most individuals rated low to medium boredom scores before the task, however some of them also rated very high levels, indicating individual differences in baseline boredom after answering the anteceding questionnaires. In the post-task condition, a large proportion of subjects chose the maximally possible visual analogue state boredom rating. On one side, this ceiling effect hinders gradual comparisons between individuals, but on the other side it illustrates the robust induction of tedium through performing the Boredom Choice Task, even in individuals with initial boredom report.

## 3.2) Experiment I, II and III

### 3.2.1) Monotonous sensory stimulation elicits an aversive choice bias

Initially, the behavioral data of Experiment I was analyzed, which comprised the BCT behavior under conditions of highly different or equivalent monotony rates (for an exemplary individual choice trace see Supplementary Figure 1). As a basic behavioral readout, raw preference was computed as proportion of choices for one reference alternative (Chapter 2.4.1) In the control conditions with equal monotony at each button, preference scores distributed symmetrically around chance level, indicating no significant trend of side preference on average over all participants (upper panel of Figure 8 A; Wilcoxon signed rank test: visual: monotonous vs. monotonous against variable vs. variable $p = 0.22$, auditory: monotonous vs. monotonous against variable vs. variable $p = 0.43$). However, in the divergent monotonous vs. variable conditions, this distribution of preference was found to be shifted towards the variable alternative, reflected by an average preference of $median_{Exp\ I} = 0.80$ (Wilcoxon signed rank test: visual: monotonous vs. monotonous against monotonous vs. variable $p < 0.001$, variable vs. variable against monotonous vs. variable $p < 0.001$; auditory: monotonous vs. monotonous against monotonous vs. variable $p < 0.001$, variable vs. variable against monotonous vs. variable $p < 0.001$). This pattern was consistent across both, visual and auditory modality, with a similar magnitude.

To support the reliability of this key finding, Experiment II was conducted as a replication study with an independent sample of participants. Here, subjects showed corresponding behavior, again with a robust avoidance of the monotonous alternative (middle panel of Figure 8 A; $median_{Exp\ II} = 0.83$; Wilcoxon signed rank test: visual: monotonous vs. monotonous against monotonous vs. variable $p < 0.001$, variable vs. variable against monotonous vs. variable $p < 0.001$; auditory: monotonous vs. monotonous against monotonous vs. variable p

< 0.001, variable vs. variable against monotonous vs. variable $p < 0.001$). The control conditions with equivalent stimulation, consistent with Experiment I, revealed average probabilities of choosing either alternative that did not significantly differ (Wilcoxon signed rank test: visual: monotonous vs. monotonous against variable vs. variable $p = 0.74$, auditory: monotonous vs. monotonous against variable vs. variable $p = 0.13$).

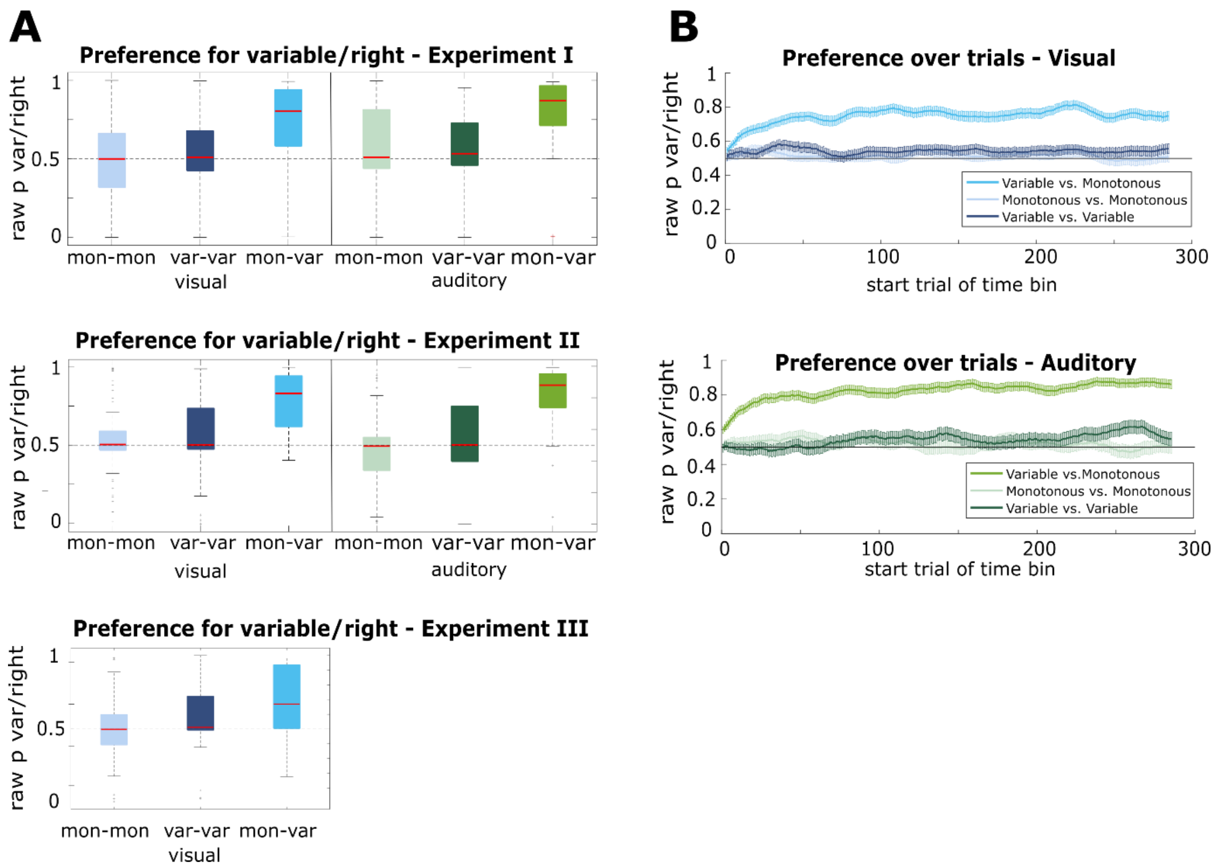


**Figure 8 – Analysis of raw choice preference:** (**A**) Boxplots with the distributions of raw preference for Experiment I (n = 49 participants), II (n = 53 participants) and III (n = 40 participants). The red line indicates the median, the box indicates the upper and lower 25% quantiles and the whiskers indicate the 50% quantiles around the median. Grey crosses represent outliers, defined as data points with a difference higher than +/- 2.7 standard deviations from the median. Blue colors reflect visual task cycles, whereas green colors represent auditory task cycles. In all experiments the differences between the monotonous vs. variable and both corresponding control conditions are significant ($p < 0.05$ in a Wilcoxon signed rank test). (**B**) Mean raw preference of all participants from Experiment I, II and III (n = 142) over the duration of each task cycle across all conditions. Raw preference was computed in a bin of 15 trials, which was then shifted stepwise. The bars indicate the standard error of the mean.

In addition, yet another replication study was performed through Experiment III, where the behavioral pattern of monotony avoidance was reproduced under web-based conditions with less control about participants' background activities (bottom panel of Figure 8 A). Interestingly, the median preference bias in this online experiment turned out to be slightly smaller than under controlled conditions in the lab ($median_{Exp\ III}$ = 0.67; one-tailed Wilcoxon ranked sum test: p = 0.06), however, the basic pattern of monotony avoidance was analogue (Wilcoxon signed rank test: visual: monotonous vs. monotonous against monotonous vs. variable p = 0.04, variable vs. variable against monotonous vs. variable p = 0.002).

Next, the behavioral choice strategy throughout BCT cycles was analyzed. Therefore, all independent test series from Experiment I, II and III were pooled and average raw preference was computed in a bin of trials, which was shifted trial by trial until the end of the cycle (Figure 8 B; see Chapter 2.4.1). In the monotonous vs. variable condition subjects on average started with no initial side preference, but then successively adapted their behavior in the form of an increasing choice bias, until reaching a preference plateau with about 80% of the trials avoiding the monotonous option. In contrast, participants did not develop a preference trend in the control conditions, instead the choice probability fluctuated around chance level. These adaptation curves in their extent and shape are again very alike across visual and auditory modality, supporting the idea of boredom spanning multiple sensory modalities. To further underpin this assumption, the Spearman correlation between participants' visual and auditory choice behavior was computed for the second half of the BCT cycles, after reaching a stable bias level (Figure 9).

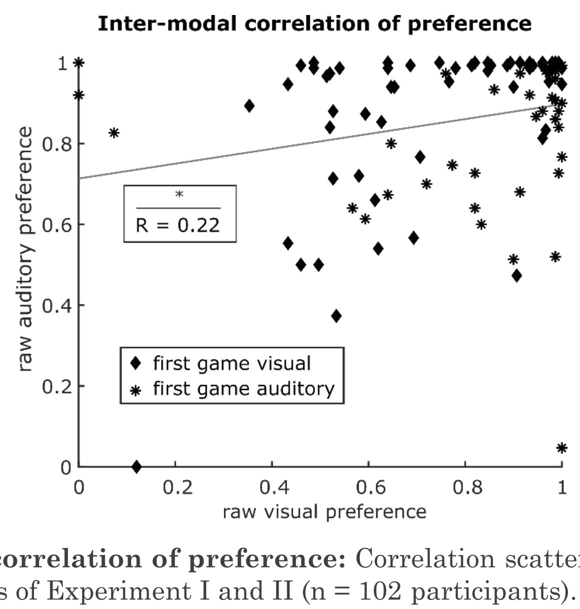


**Figure 9 – Inter-modal correlation of preference:** Correlation scatter plot of the raw preference in the two tested modalities of Experiment I and II (n = 102 participants). The different marker types indicate which of the modalities participants underwent first. Both preference scores show a significant Spearman correlation (R = 0.22, p = 0.03), despite higher initial preference in the second task cycle. The grey line indicates the best fitted linear regression.

Preference scores of both modalities were found to be significantly positively correlated with each other (Spearman's R = 0.22, p = 0.03). This correlation withstands the fact that subjects adapted their preference not only within, but also between task cycles, which is reflected by a higher average choice bias in the second BCT cycle of the experiment (see Supplementary Figure 2 A).

### 3.2.2) Finding a refined metric of monotony avoidance

Based on the raw preference described above, the next step of this study aimed at refining the behavioral readout obtained from the BCT for each individual. In concrete, a measure was applied that related the choice bias from the task condition of highly different alternatives to inherent side preference under conditions of equivalent alternatives, concentrating the behavioral data from all BCT cycles into one single score.

First, the hypothesis that subjects show an inherent side preference was tested. For this purpose, it was investigated whether the variance in raw preference scores from all control BCT cycles of one individual was smaller than variance, obtained by random sampling preference values across individuals. Standard deviation was computed as a measure for variance and a Wilcoxon ranked sum test was applied to test a difference between both distributions. This revealed lower variance for the individually assorted set of bias values ($p < 0.001$; Figure 10 A and B), underpinning the assumption that preference asymmetry in the control conditions of the BCT is an inherent, individual feature.

Based on this finding, each participant's raw preference score from the monotonous vs. variable conditions was adjusted by relating it to the mean side preference from this individual's control cycles (see Chapter 2.4.2). The distributions of these *adjusted preference indices* from each independent experiment again illustrate the aforementioned trend of monotony avoidance in the monotonous vs. variable task cycles, only with a different scaling (Figure 10 C and D). This pattern, in line with the previous finding, is prevalent for the pooled laboratory test series as well as in the online study. Adjusted preference distributions were tested for shifts with a t-test, revealing a significant effect of monotony avoidance (one-sample t-test with pooled data over all experiments: visual: $p < 0.001$; auditory: $p < 0.001$). On the other hand, the control task conditions did not lead to such a prominent shift and showed no statistically significant deviation from chance behavior (one-sample t-test with pooled data: monotonous vs. monotonous: visual: $p = 0.31$, auditory: $p = 0.76$; variable vs. variable: visual: $p = 0.28$; auditory: $p = 0.70$).

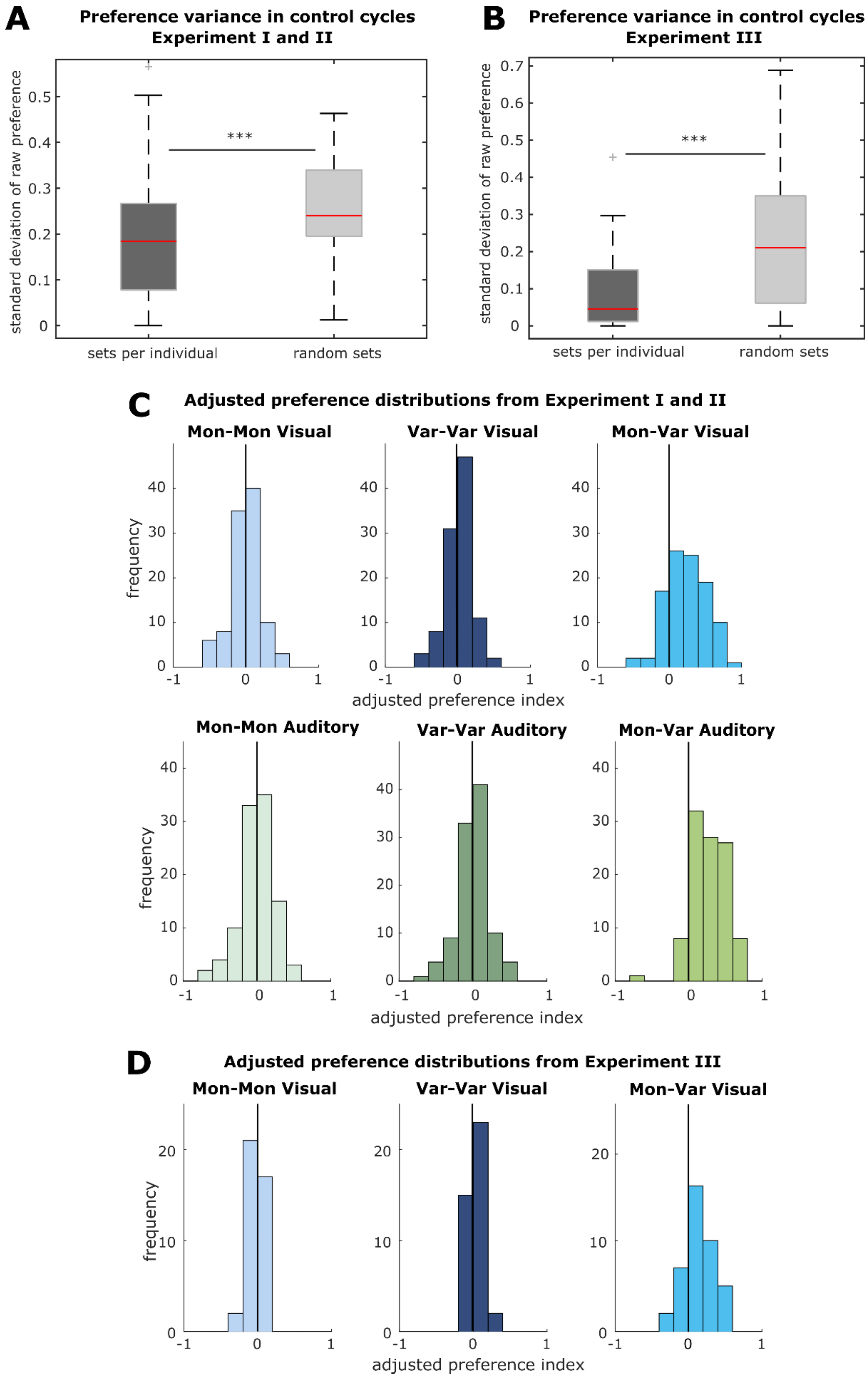


**Figure 10 – Adjusted preference indices:** (**C**) Distributions of adjusted preference indices from the laboratory sample (n = 102 participants) in visual (blue color) and auditory (green color) modality. (**D**) Same illustration of adjusted preference for the online dataset of Experiment III (n = 40

participants). The pooled scores from all monotonous vs. variable conditions differ significantly from a normal distribution with a mean of zero (one-sample t-test: $p < 0.001$).

### 3.2.3) Linking monotony avoidance to state boredom experience

With the previously presented findings of this study, the BCT has been described as a behavioral method to reliably induce boredom and quantify the avoidance of monotonous sensory stimulation in different modalities. Nevertheless, the question, if monotony avoidance indeed reflects boredom experience, is not answered yet. This point was tackled in a stepwise validation: firstly, an exploratory correlation analysis was conducted with the dataset from Experiment I without correction for multiple testing, investigating the relationship between participants' adjusted preference index and the various psychometric features, assessed with self-report questionnaires (Figure 11 A). This explorative analysis revealed relevant positive correlations to state boredom, measured by the MSBS total score (Spearman's R = 0.30, p = 0.04), to the MSBS subdimensions of inattention (Spearman's R = 0.33, p = 0.02) and low arousal (Spearman's R = 0.34, p = 0.02), as well as to the internal stimulation subscale of the BPS (Spearman's R = 0.28, p = 0.05). Importantly, monotony avoidance did not significantly correlate to self-reported symptoms of psychiatric disorders or other distress factors, portraying a measure that seems to be fairly specific for *unpathological* state boredom. This central positive association of participants' adjusted preference index with their state boredom ratings was secondly tested for confirmation in the independent test series of Experiment II (see Chapter 2.4.5). Here a significant positive correlation was found (Spearman's R = 0.32, p = 0.02), corroborating the exploratory results. Pooling both datasets hence demonstrated a robust interaction that withstands Bonferroni correction for multiple testing (Experiment I+II: Spearman's R = 0.30, p = 0.002 for an adjusted significance level $p^*$ = 0.002 after Bonferroni correction for the 26 correlation tests; Figure 11 B). Together, these observations underline that individuals reporting high state boredom also show a stronger avoidance of the monotonous alternative in the BCT.

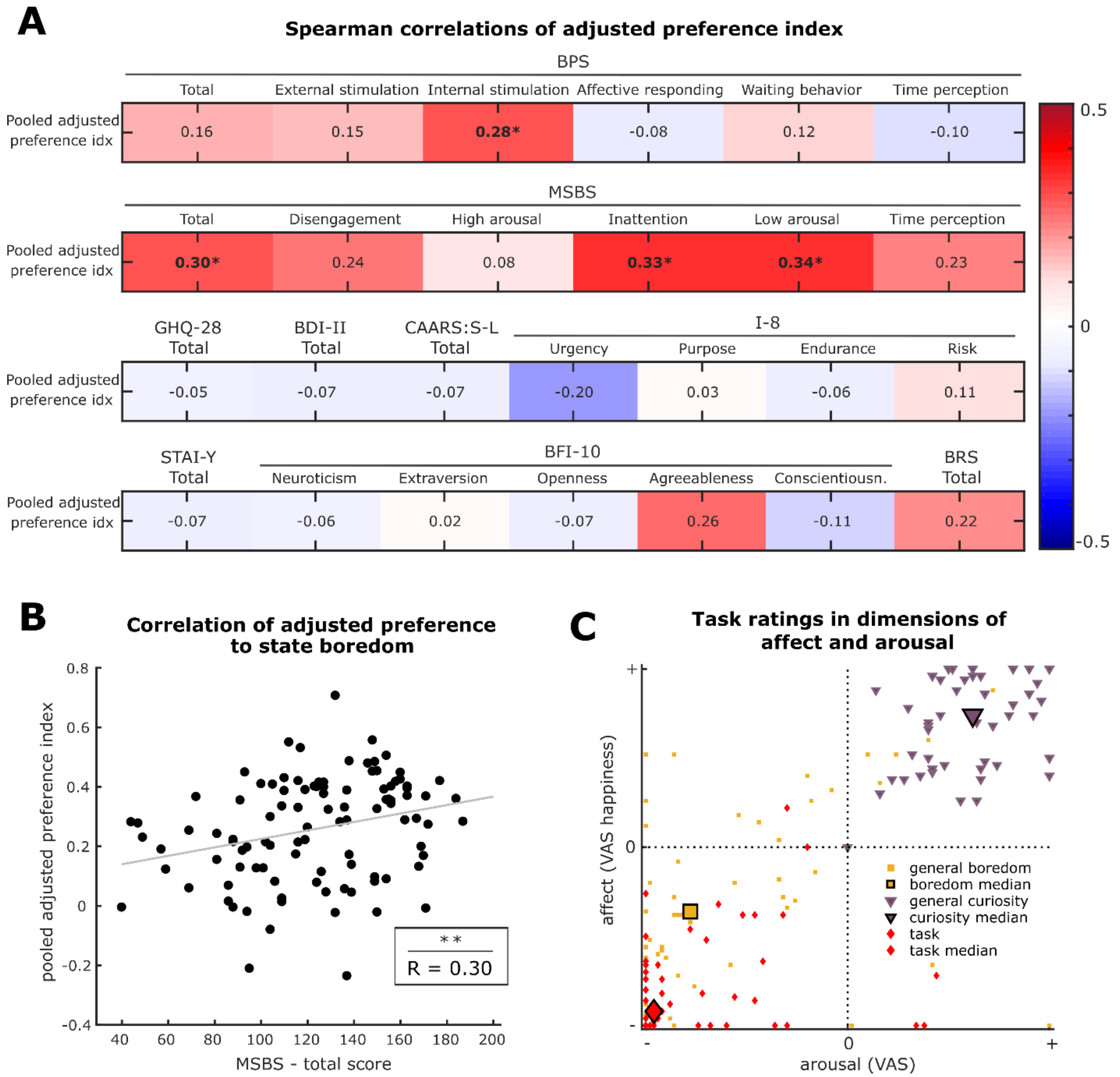


**Figure 11– Construct validation of the Boredom Choice Task:** (**A**) Exploratory investigation of Spearman correlations of adjusted preference indices to psychometric self-reports. Each correlation is computed over n = 49 participants from Experiment I. The color of each cell displays the magnitude of correlation and bold letters reflects statistical significance, where *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$. (**B**) Correlation scatter plot of adjusted preference scores and participants' MSBS state boredom reports (pooled over Experiment I and II with n = 102 participants; R = 0.30, **: p = 0.002). The grey line indicates the best linear fit. (**C**) Scatter plot of participants' visual analogue ratings of affect and arousal for imagined boredom, imagined curiosity and the Boredom Choice Task experience (n = 53 participants from Experiment II). Large markers indicate the overall median of the respective condition.

Thirdly, the validation aimed at differentiating the BCT from other novelty-seeking-related phenomena like curiosity in respect to the two dimensions of affect and arousal, which are often applied to characterize emotions. Experience during the BCT was classified in these dimensions and checked against conditions of imagined boredom and curiosity, where visual

analogue scales were used to assess each condition (Figure 11 C). Thereby, in line with its definition, boredom was found to be mostly rated as an aversive and low arousing state, whereas curiosity on the other hand involves positive valence and high arousal. The BCT was likewise rated strongly aversive and poorly arousing, thus having high similarity to the boredom condition. This similarity was statistically confirmed in form of a significant positive correlation between subjects' boredom and BCT ratings of affect and arousal (Table 2).
All in all, these observations support the assumption that the Boredom Choice Task measures a construct which widely matches and reflects state boredom.

| | **Boredom Choice Task vs. Imagined Boredom** | **Boredom Choice Task vs. Imagined Curiosity** | **Imagined Boredom vs. Imagined Curiosity** |
|---|---|---|---|
| **Affect** | **R = 0.32**, p = 0.02 | R = 0.06, p = 0.69 | R = -0.16, p = 0.25 |
| **Arousal** | **R = 0.48**, p < 0.001 | R = 0.04, p = 0.78 | R = -0.02, p = 0.91 |

**Table 2 – Correlations of affect and arousal ratings:** Spearman correlations of the visual analogue ratings of imagined curiosity, imagined boredom and the Boredom Choice Task. Each correlation is computed over n = 49 participants from Experiment II. Bold letters indicate statistically significant correlation coefficients with $p < 0.05$.

### 3.2.4) Differences between laboratory and online experiments

As previously shown (Chapter 3.2.1), the extent of monotony avoidance when performing the Boredom Choice Task in a controlled laboratory environment shows a slightly higher amplitude compared to the task results under less controlled online conditions. To investigate behavioral differences that could underlie this finding, the average inter-trial time intervals and the mean amount of switches between alternatives were compared for both settings.
In the online condition, participants showed notably longer response latencies in each trial (Wilcoxon rank sum test: $p < 0.001$; Figure 12 A) as well as increased switching between alternatives (Wilcoxon rank sum test: $p = 0.05$; Figure 12 B). Furthermore, the inter-trial latencies showed greater variance across online subjects, suggesting a generally more heterogeneous behavior in this condition (Wilcoxon rank sum test of inter-trial time standard deviations: $p < 0.001$).

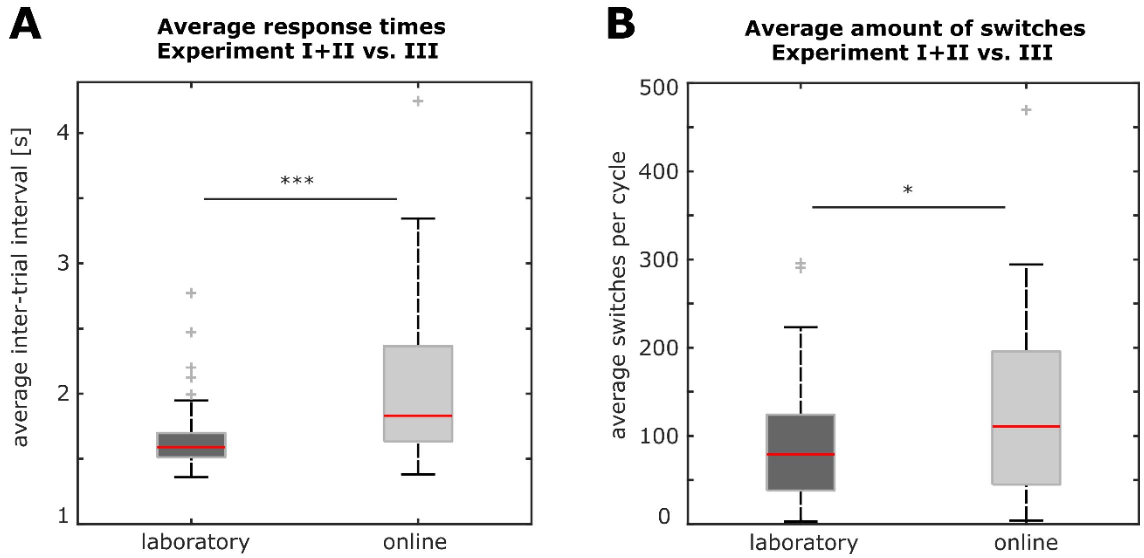


**Figure 12 – Comparison of laboratory and online experiments:** (**A**) Boxplot of average response latencies from the laboratory (n = 102 participants) versus online study (n = 40 participants). Stimulus presentation time was 1 s, which explains the minimal values (**B**) Boxplot of the average amount of switches per task cycle (n of each distribution corresponds to subplot A). Both panels follow the aforementioned plotting criteria and show a significant difference between distributions (*: $p < 0.05$, ***: $p < 0.001$ in Wilcoxon ranked sum tests).

## 3.3) Experiment IV

### 3.3.1) A descriptive function of preference over varying degrees of monotony

In a first sanity check, it was investigated whether subjects responded to the shorter version of the Boredom Choice Task in Experiment IV similar to the setting from Experiment I, II and III. Therefore, average raw preference values were analyzed in a bin of trials over the duration of each cycle. In line with the previous findings from Experiment I-III, subjects exhibited similar adaptation curves, increasing their choice bias of monotony avoidance within and across all 13 games (Supplementary Figure 2 B and C). Furthermore, there was no significant difference in state boredom ratings compared to the previous test series (Wilcoxon ranked sum test: $p = 0.92$; Supplementary Figure 3).

Next, the average adjusted preference for each pairing of stimulus library sizes was computed, by adjusting each individual's raw preference to inherent preference asymmetries in the control conditions, according to the aforementioned method (Chapter 2.4.2).

Presenting the adjusted choice bias over the task conditions depicts, that average preference for an alternative increases gradually as the variability of this option raises (Figure 13). In other words, the more monotonous one alternative is, the stronger it is avoided. Surprisingly, this relation is neither linear nor symmetrical for both sides of the curve. By way of example, the comparison of 8:1 and 64:8 stimuli shows highly different levels of preference, even though the ratio of both library sizes is equal.


**Figure 13 – Adjusted preference index over stimulus library pairings:** Average adjusted preference index is computed over all subjects from Experiment IV (n = 148) for each of the 13 stimulus library pairings independently. Vertical bars indicate the standard error of the mean.

In addition, according to this simple presentation monotony avoidance behavior seems to reach a plateau level, as it is not further raising after adding variability to more than approximately 8 stimuli. Due to this observation, working memory capacity, typically reported to cover around seven chunks of information (Miller, 1956), was hypothesized to have a moderating effect on task performance. Previously, such a moderation has been found between working memory capacity and mind-wandering (Kane et al., 2007), typically reported to be linked to boredom (see Chapter 1.2). This consideration was tested by grouping subjects according to their working memory score into two evenly sized clusters and comparing the total difference between their preference curves to random grouping of individuals. Working memory capacity did not show a significant effect on average preference levels compared to random grouping of subjects (Wilcoxon ranked sum test: $p = 0.17$; Supplementary Figure 3; for methodological information see Chapter 2.2.5) and the group difference lies within the one-standard-deviation interval around the mean of a bootstrap sampling distribution.

### 3.3.2) Monotony avoidance is driven by experienced entropy

Based on this description of monotony avoidance through differences in experienced sensory variability, this subchapter develops a deeper quantitative approach to explain the emergence of different levels of monotony avoidance based on *experienced entropy*. This parameter was used to respect the real experience of subjects in each task cycle, rather than only considering the experimental setting in form of stimulus libraries. For instance, the exemplary 64:8 stimuli task condition could theoretically lead to a perception of very similar variability of both alternatives, due to sparse sampling of the alternative associated to 8 stimuli. On the opposite, frequent sampling of the 8 stimuli in this example would reveal more stimulus repetitions and thus lead to higher discrepancy in variability experience between both alternatives. This example underlines, how experienced variability is modulated by individual behavior and furthermore illustrates the benefit of scaling experienced variability based on a more complex measure than the simple pairing of stimulus libraries.

Hence, empirical entropy was computed trialwise for each of the task's alternatives and the stimuli they provided up to each trial, giving an estimation of an individual's currently experienced level of variety (see Chapter 2.4.3 and Supplementary Figure 5 for an illustration of entropy over the task duration). Both alternatives were then related to each other by building the difference between their entropy scores.

In consequence, participant's average cumulated entropy difference over each monotony condition was found to show a strong positive linear correlation to average raw preference for the less monotonous option (Pearson's $R = 0.91$, $p < 0.001$; Supplementary Figure 6). This finding indicates, that high entropy experience from one alternative enhances its future usage, leading to an increased overall preference. To test this hypothesis in a clear temporal resolution, entropy difference was computed for each trial in all different test cycles and related to the consecutive choice. Averaging choice probability over subjects in equally sized bins of entropy difference revealed a symmetrical sigmoid-shaped curve (Figure 14).

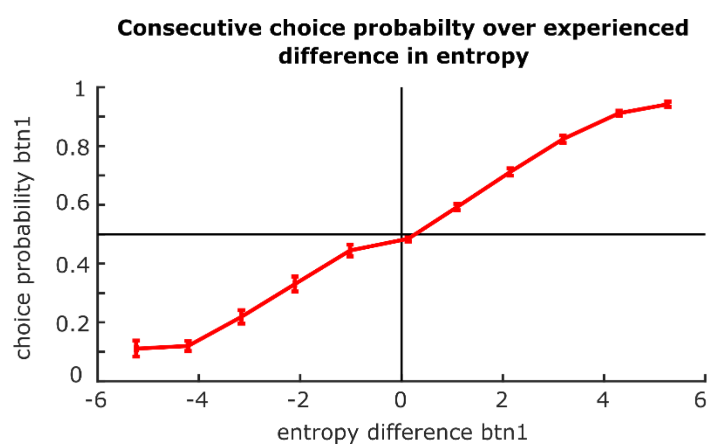


**Figure 14 – Choice probability over difference in experienced entropies:** For each subject all 1,287 decisions with the corresponding previous entropy experience (99 trials per 13 cycles) are sorted

in 11 evenly sized bins in the range of [-6, 6] according to their entropy difference value. Next, choice probability is calculated for each of these bins. The individual data points of entropy difference and choice probability are then averaged over all 148 subjects, leading to the curve plotted in red, where the bars indicate the standard error of the mean. For the right side of the abscissa the reference alternative is associated with higher entropy in the previous trial than the other option and vice versa.

This shape reflects increased choice probability of an alternative, which has previously been offering higher entropy and therefore less monotony. Thus, average choice behavior can be characterized quantitatively in dependence of experienced environmental entropy.

### 3.3.3) A model to capture the dynamics of boredom-related decision-making

In a final step of this study, a model was developed to bring together the previously described experience dependent impact factors within the Boredom Choice Task and make them quantifiable for individual subjects.

Therefore, a full logistic regression model was fitted to each participant's complete dataset of choices (Chapter 2.4.4). This yielded three best fitted parameter weights for each subject: *inherent side preference* (see Lebovich et al., 2019; Baum, 1974), *sensitivity to entropy* and behavioral inertia, describing the tendency to simply repeat the previous choice (see Alós-Ferrer et al., 2016; Akaishi et al., 2014), which is referred to as *momentum* (for a detailed explanation of the model formulation see Chapter 2.4.4).

To test the goodness of this model in a readily comprehensible manner, it was used as a classifier to predict the outcome of participants' single choices based on previous experience, where for each subject the proportion of correctly predicted choices was calculated. The model could on average predict 67% of all trials correctly (Figure 15 B), importantly the prediction of some participants' behavior however even showed more than 90% accurate choice classifications. Furthermore, the influence of each parameter on model goodness was investigated by comparing the full regression model to shortened models with one of the parameters neglected (Figure 15 C). Efron's Pseudo $R^2$ (Efron, 1978) was computed as a more precise measure for logistic model goodness, which in opposite to the accuracy of choice classifications does not binarily approximate the decision probability, thus allowing a better gradual comparison. Sensitivity to entropy was found to be essential for good model performance, whereas inherent side preference and momentum showed less impact, when being removed (one-tailed Wilcoxon signed rank test, comparing the full model to partial models: in all cases $p < 0.001$). Additionally, for each participant the relative parameter contribution of entropy sensitivity – expressed as the average product of fitted weight and current parameter value (see Chapter 2.4.4) – was computed in relation to momentum (Figure 15 D). Here, subjects showed stronger contribution of sensitivity to entropy compared to momentum, identifying it to be the key parameter that drives boredom-related decision-making in the task. It was further tested, whether the contributions of the model parameters correlate to self-reported psychometric properties, which however did not demonstrate significantly prominent interactions (Supplementary Table 1).

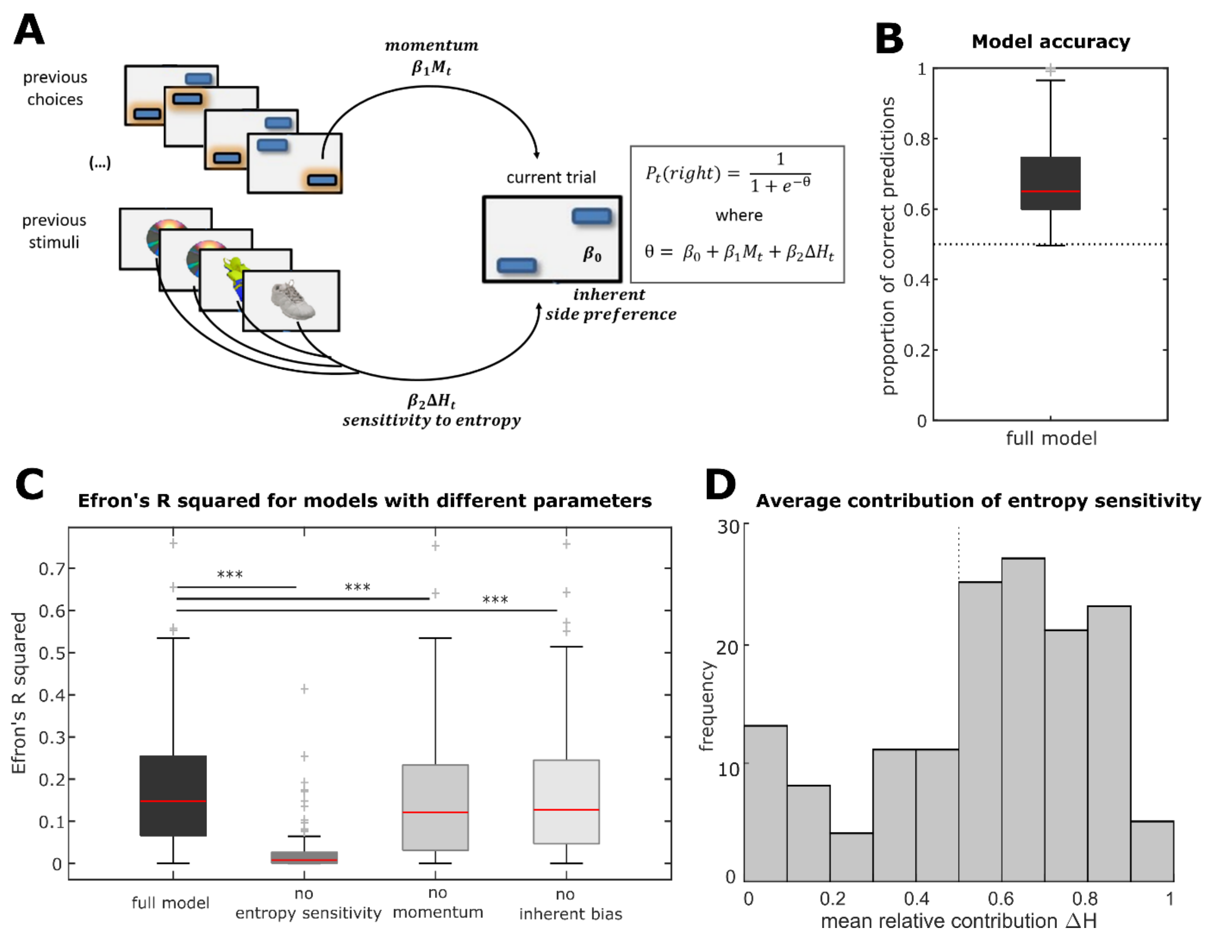


**Figure 15 – Logistic regression model for choice behavior in the Boredom Choice Task:** (**A**) Schematic presentation of the model and how its parameters are derived from participants' experience. (**B**) Boxplot of the proportion of correctly predicted choices by the model, used as a binary choice classifier (distribution of n = 148 participants). The dotted line reflects chance level and the boxplot presentation corresponds to the previously mentioned criteria. (**C**) Comparison of the model goodness (Efron's Pseudo $R^2$) between the full regression model and partial models with one of the parameters removed (each distribution spans n = 148 participants). All partial models show a decreased goodness on an individual level in comparison to the full model (one-tailed Wilcoxon signed rank test with $p < 0.001$ for all conditions). (**D**) Distribution of the average relative contribution of the model parameter *sensitivity to entropy* for each individual relative to the total contribution of *sensitivity to entropy* and *momentum* (n = 148 participants). Values larger than 0.5 indicate a higher impact of entropy on individuals' choice behavior.

# 4) DISCUSSION

The current study presents the paradigm and implementation of a novel modified choice task, which quantifies behavioral aversion of monotonous sensory stimulation. Human subjects in this Boredom Choice Task are found to reliably avoid the alternative with relatively higher monotony, where the extent of this choice bias correlates positively to self-reported state boredom. Furthermore, a theoretical model is presented that allows a quantification and interpretation of dynamic individual behavioral features, involved in the processing and execution of the BCT.

This discussion section will put light on general aspects of the study results, in terms of experimental sample and test environment, before critically examining the construct measured by the task and its link to boredom. Based on this understanding of the BCT, the influences of particular task settings are discussed and their interpretation through the mathematical decision-making model is reviewed. Finally, all these limiting aspects of the study are bundled and hypothetical approaches are presented at each step of the discussion to tackle these limitations in future investigations.

## 4.1) Study sample and replicability in different experimental environments

In four independent experiments the Boredom Choice Task was applied to distinct samples of healthy humans, where all experiments demonstrated the same pattern of monotony avoidance, when comparing a highly repetitive alternative to a more variable one. The sample of participants, which underwent the laboratory Experiments I, II and IV, due to recruitment from a pool of undergraduate students, was homogenous in regard to young adult age, high education and psychiatric health. On the other hand, the online test series of Experiment III was conducted with participants, who were uncontrolled in these regards. Although the basic trend of behavioral monotony avoidance was present across all subjects, there were significant differences between both groups of participants in respect to the average response latency and the total amount of switches. These diverging behaviors could reflect less adherence to the task, in line with the assumption of a more distracting environment under online conditions, which impacts behavior and competes with the stimulation within the task. Similar differences in reaction times between online and laboratory task conditions have been described for other task paradigms (Crump et al., 2013). Other critical issues of online studies relate to instruction comprehension (Crump et al., 2013) and increased dropout rates (Rand, 2012; Arechar et al., 2018). Despite the discrepancy in choice bias amplitudes between groups, the congruency of the basic pattern marks an important reliability criterion of the BCT, demonstrating that the paradigm is applicable in broad collectives of humans. Future work however will be needed to characterize the concrete behavioral similarities and differences between individuals with divergent psychosocial backgrounds. The general applicability in an online setting thereby offers a reproducible, money and time efficient way of distributing experiments among a diverse pool of subjects (Mason and Suri, 2012).

## 4.2) Scrutiny of the construct behind the Boredom Choice Task

The most fundamental question, raised by the finding of a behavioral monotony avoidance bias, relates to the interpretation of this effect. The study at hand developed the Boredom Choice Task to find a readout of boredom. Thereby, a simplified definition of boredom was operationalized, characterizing it as an aversive state, which is elicited by repetition and under-challenge. This simplistic definition does not incorporate the full range of experiential dimensions, which have been used for the development of other assessment tools. For instance, Fahlman and colleagues (2013) suggested a five factor structure of state boredom, including the subdimensions high arousal, low arousal, inattention, disengagement and time perception. These multidimensional approaches offer a holistic perspective on human boredom experience, but, as described in the introduction of this work, are weak when trying to translate them to global, species-overlapping approaches. These however are necessary to fully explore the neural mechanisms behind it. In this regard, Vodanovich and Watt (2016) pointed out, that a search for novel boredom definitions appears less beneficial for future boredom research than operationalizing particular aspects that already found wide experimental evidence and approval. The simplistic characterization of boredom in this study fulfills this criterion and allows uncomplicated translations to other experimental surroundings.

To test the validity of the monotony avoidance choice bias as a readout of boredom, we used correlative comparisons to self-report assessments, which so far in the research field represent the gold standard measures of boredom (Vodanovich, 2003; Vodanovich and Watt, 2016). Here, monotony avoidance was found to correlate positively to state boredom, which was afterwards confirmed in an independent replication experiment to avoid confoundings with multiple testing. In particular, there was a positive association with low arousal and inattention, which is congruent to the repetitive task paradigm and which supports the previously mentioned finding of different bias levels in the online study with an environment that presumably hinders concentration. Importantly, there were no strong interactions with trait boredom, except a positive link to its subdimension of internal stimulation. Together with the lacking correlation to other psychopathology-related self-reports, the Boredom Choice Task thus states a method to capture physiological state boredom specifically. This is an important observation, because it deviates from previous ways of operationalization, which have mostly tried to quantify boredom based on wide definitions as a syndrome of various cognitive, emotional and behavioral symptoms, hence aiming more at sensitivity rather than specificity. These issues of specificity lead to the central question, whether tedium, as measured by the BCT, shall be regarded as a unitary construct, or if there are distinct boredom types, and if this would be true, which type of boredom is measured by the BCT.

Previous research has on the one hand demonstrated different levels of valence and arousal for tedium experience (Goetz et al., 2014; Danckert et al., 2018) and also found different factors underlying the measurement tools of boredom (Struk et al., 2017; Fahlman et al., 2013). By way of example, Goetz et al. (2014) in this manner clustered different ennui ratings into five distinct subtypes of boredom, from apathetic over reactant, searching and calibrating up to indifferent boredom experience. On the other hand, Elpidorou (2020) has argued that although boredom might be heterogeneous in respect to its experiential fingerprint, it is unified by the common function of driving an individual's attentional focus and behavior away from the current monotonous action. Since the Boredom Choice Task as assessment tool quantifies exactly this general behavioral component of boredom, it hence has great advantage over previously used methods that only quantify the perceptional and cognitive subdimensions of tedium. Nevertheless, the BCT certainly does not account for all multidimensional aspects of human ennui. When classifying the Boredom Choice Task according to previously described criteria of affect and arousal, this study found it to be linked to strong negative affect and low arousal. Together with the abovementioned positive interaction to inattention and deficient internal stimulation, the BCT thus puts its focus on measuring a type of state boredom, which most likely arises from the inability to self-generate meaning from the repetitive task stimulation.

Despite all theoretical graduations of human boredom, it furthermore remains unclear, if other species even share this width of experiences. Somehow or other, the future goal of investigating animal boredom would make it inevitable to operationalize experience in form of observable behavioral effects (Burn, 2017). These behaviors widely match the criteria of novelty-seeking (Cain et al., 2005), making it necessary to distinguish them from other effects that facilitate novelty-appreciation. This study controlled the observed monotony avoidance for influence due to curiosity, where the task was found to be correlated to boredom ratings without relevant relation to curiousness. Thus, all in all the BCT can be considered as a novel method to specifically quantify boredom-related behavior without prominent interference with psychopathology or curiosity.

## 4.3) Task settings and their impact on the measured behavior

One general aspect to consider when interpreting the study results is that all findings have to be understood in regard to the task settings of the respective experiment. For instance, subjects underwent multiple BCT cycles, where the total set of stimuli was constant across cycles. Thus, the participants were not naïve to the stimuli in the test cycles at the end of the experiment. This pre-exposure effect probably contributed to the behavioral adaptation, which was observed over the task cycles. In the future, a more detailed investigation of respective task settings and their impact on behavioral performance will be beneficial, in order to establish a standard presentation of the Boredom Choice Task. In this manner, the total task duration, the applied set of stimuli and their presentation time could be altered, to systematically test their influence on the extent of the choice bias and its relation to boredom. Here, it could be possible that different task settings also lead to a variant interaction pattern with other subdimensions of ennui. The settings used here present an experimental fundament, which is already capable of robustly inducing and measuring boredom in the aforementioned structure.

This study found the main effect of monotony avoidance in two conditions of either visual or auditory sensory stimulation, where both modalities on average showed the same potential of choice bias elicitation. Still, there might be inter-individual differences in boredom susceptibility for different sensory modalities, which could build the subject of future studies. Such insights would in turn facilitate the development of novel targeted therapeutic strategies and skills in order to reduce boredom in individuals that chronically suffer from it. Especially, it would be interesting to test, how far the length of the task could be reduced, while still allowing sufficient bias quantification. In this work, subjects already reached a steady state of preference after approximately 50 trials. Such a shortening of the BCT would facilitate its application in other contexts and experiments, where often time efficiency is a critical component.

## 4.4) Model-based analysis of behavioral driving factors in the task

Based on the effect of tedium-related monotony aversion, Experiment IV further disentangled individual factors that contributed to this behavior. Gradual manipulations of the monotony associated with both alternatives revealed a non-linear relation between relative monotony and avoidance probability on the level of collective behavior. This marks an important finding, illustrating that the behavioral consequences of boredom are not binary, but steady and that the concrete behavioral drive to pursue an alternative goal does not only depend on the uniformity of the current action, but also on the expected difference from the other alternative. Thus, the task's relation to situational state boredom is underlined, but furthermore this finding allows to draw a quantitative inference from a certain environmental property and its capability of inducing boredom to the resulting behavior. As a concrete index of the experienced monotony empirical entropy was used, showing to be a positively correlated predictor of the following choice probability. Among all the various qualitative methods, which have so far been used to induce boredom (Merrifield and Danckert, 2014; Markey et al., 2014), the BCT hence is the first one to offer an objective measure of current situational monotony. Multiple authors in the field have demanded such a factual operationalization (see Eastwood et al., 2012; Raffaelli et al., 2017), which offers better access to investigate the physiological processes linked to ennui.

This quantitative approach further enabled the creation of a theoretical framework to describe individual decision-making, based on the current state of monotony. The linear regression model used here, was created on three main assumptions that were incorporated as parameters: Firstly, the parameter of entropy sensitivity reflected the abovementioned behavioral adaptation based on the previously experienced difference in stimulation variety between both alternatives. Secondly, a general inertia, namely the tendency to repeat previous decisions, that has widely been reported for various choice tasks (Alós-Ferrer et al., 2016; Akaishi et al., 2014), was incorporated as a parameter termed momentum. Thirdly, a parameter of inherent side preference was implemented, that also has commonly been described in two-alternative forced-choice tasks (Lebovich et al., 2019; Baum, 1974). Together, the applied regression model with all three parameters could predict 67% of participants' choices correctly. However, the fact that some datasets were predicted with a much higher accuracy of more than 90% illustrates the potential of the model for explaining the behavior of a subgroup of participants. That not all participants are predicted with such a goodness could be influenced by different behavioral strategies between individuals, or personality features, which so far are not covered by the model. All three parameters improved the model goodness, however sensitivity to entropy was identified as the most critical parameter for accuracy, indicating that indeed sensory stimulation is the central property of the task that drives differential behaviors. More experimental effort however will be needed to fully examine the role and dynamics of each parameter for individual decision-making and to clarify the parameters' dependence on different task settings.

Furthermore, this study examined whether the individually best fitted model parameters correlated to personality and psychopathological features. This however did not uncover statistically relevant interactions. Working memory was also suggested to modulate behavioral adaptation to different degrees of monotony, which could not be statistically confirmed. One reason, underlying this lack of relations, could be the homogeneity within the sample of participants. In future experiments it will be interesting to test the fitted model parameters in individuals with wider psychosocial and cognitive disparity, where potential mediating variable would be more explicit.

## 4.5) General limitations and open questions

The aforementioned aspects in this discussion reveal some general limitations of the BCT methodology, which have to be considered in its interpretation and which are summarized in this subchapter.

Although the Boredom Choice Task was developed to overcome the problem of subjectivity, which generally impairs self-report measures, the choice behavior in the task to some extent is still vulnerable to individual manipulation or disengagement. To minimize the influence of this problem, subjects were left uninformed about boredom, being the key issue of this study, but nevertheless it cannot be excluded that some individuals responded unnaturally to the task, due to thoughts about its cause and the potentially desired behavior. In addition, the BCT assessment might be confounded by the individual capability to focus on the paradigm and pay it sustained attention. Therefore, the behavior of some subjects might not be fully explained by the selection of parameters that are presented here, in order to capture differences in decision-making. This problem is of minor importance when averaging the behavioral scores over large groups of individuals for comparisons, but might lead to difficulties when trying to reliably describe individual properties, especially in humans that are vulnerable to distractions. Another issue that contributes to this complication of interpreting individual results is the high variability in a single subject's behavior from consecutive BCT cycles. Ideally, future work should therefore identify the properties that predict a decreased task engagement and quantify these for each individual undergoing the task, in order to optimally interpret its behavioral profile, or alternatively the BCT could primarily be used for experimental group comparisons.

One research field that is particularly vulnerable to these limitations due to task adherence includes clinical and psychiatric studies, since some disorders could systematically disallow an application of the BCT. By way of example, individuals suffering from ADHD typically exhibit high distractibility and problems in continuous performance tasks (Hult et al., 2015). This could potentially impede the utilization of the Boredom Choice Task with such patients. Nevertheless, the important fact that boredom is involved in psychopathologies is supported by this study, since self-reported scores of state and trait boredom were found to be positively associated with indicators of depression, ADHD, anxiety and impulsivity. These interactions, especially the similarities and dissimilarities between self-reported boredom and behavioral tedium assessments, demand a further investigation, but also demonstrate a starting point for such clinical investigations.

Despite these unsolved considerations, the current study all in all provides solid empirical evidence for a quantifiable boredom-related choice bias in a manipulable task environment together with a theoretical framework to interpret this behavior. These findings together with the underlying Boredom Choice Task do not unravel all debates concerning the plethora of boredom concepts, but nevertheless present a useful tool to set up future systematical studies. The major advantages of this new assessment over previous ones are its simple and quantitative operationalization, its objectivity and the potential of translation to animal studies in basic research. The following chapter presents some exemplary hypotheses and potential fields of application for this Boredom Choice Task, which could be tested in future studies.

# 5) OUTLOOK

As aforementioned, the interest in boredom has grown over the last years, where tedium has been identified to be involved in psychosocially important behaviors. Nonetheless, many questions about its neural and physiological correlates remain open. The potential use of a novel assessment of boredom, in form of behavioral avoidance of monotonous stimulation, is illustrated by portraying three experimental starting points for future research: firstly, using the task in a clinical environment, secondly, investigating boredom-related brain activity and thirdly, translating boredom research to animal models.

***Setting I – Boredom under clinical conditions***

As previously explained, boredom is a stress factor of various psychiatric and neurological disorders, ranging from traumatic brain injury (Isacescu and Danckert, 2016) up to impulse-control deficits (Abramson and Stinson, 1977; Blaszczynski et al., 1990). But also in other somatic medical departments, boredom often afflicts patients during hospital treatments (Hashem et al., 2016; Newell et al., 2011), leading to reduced therapy adherence and complicated rehabilitation (Kenah et al., 2018). The Boredom Choice Task could help to further investigate boredom under clinical conditions and develop prevention strategies against this complicating factor. Thereby, the BCT should in a first step be tested for its applicability in standard daily hospital routines. Furthermore, possible confounding, due to certain personality features or other mental or bodily deficits, which have so far not been brought in relation to boredom, should be tested and excluded. Then, if these criteria of establishment are fulfilled, the BCT could provide a convenient standard tool to survey and monitor patient's boredom during hospital care. Based on the identification of highly bored individuals, these could in a next step receive particular therapeutic attention to mitigate tedium and promote their compliance.

***Setting II – Neural components of boredom***

The neural underpinnings of boredom state a scientific field that so far has received relatively little research focus (Eastwood et al., 2012; Raffaelli et al., 2017), amongst others due to a lack of standardized induction methods. The BCT targets this problem and in parallel provides an assessment that is well combinable with functional brain activity measures. For instance electroencephalography could be used to investigate differences in stimulus processing between the monotonous and variable choice alternative. Here, based on previous findings, one would for instance expect to find a tonic, more synchronized activity (Miyauchi and Kawasaki, 2018) while using the monotonous alternative. In particular, these boredom-related effects should be opposed to the so called "*mere exposure effect*", which describes the observation of increased affective liking of stimuli, which have been previously experienced (Zajonc, 2001; Leynes and Addante, 2016). In addition, functional magnetic resonance imaging could be used to identify brain regions, which are involved while working on the task. Here, besides the known association of modulated activity in the default mode network and the anterior insula (Danckert and Merrifield, 2016), it would be outstandingly interesting to investigate the representation of boredom in different sensory systems, in order to understand the processing of it. Taken together, particularly the combination of behavioral characterization and the corresponding brain activity could, through application of the Boredom Choice Task, be mapped to a discrete level of environmental monotony. This gradual classification of situation, behavior and brain activity is a benefit, which previous methodologies in boredom research hardly provided.

***Setting III – Translational approaches to boredom***

Finally, another key component of the behavioral access to boredom is the possibility to apply similar paradigms in animal studies. Thereby, multiple-alternative forced-choice tasks are already well-established methods in diverse mammalian species (Mustafar et al., 2018) and could readily be adopted to match the Boredom Choice Task by adding sensory stimulation. However, since this sort of choice tasks with animals mostly goes along with rewards to motivate them for their choices, it would be important to control for potential interferences between reinforcement- and boredom-driven behaviors. These translational studies could not only yield novel insights about how laboratory animals, most often held in sparse environments (Burn, 2017), experience boredom, they furthermore open a door for systematic neurophysiological experiments. Those mechanistic approaches are experimentally much better accessible in model organisms, for example by applying structural, pharmacological or genetic manipulations.

All together, these suggested directions only represent a small cutout of potential areas of application for the Boredom Choice Task. Independent from the actual scope, this novel methodology can be used in various ways to gain insights about the biological implementation of boredom and its role for functional, adaptive behavior.

# 6) SUMMARY

Boredom, as often experienced in everyday life, has been defined as an aversive mental state that is associated with the disability to engage in satisfying activity with a monotonous environment and was furthermore implicated in several clinical conditions, including ADHD and depression. However, research on boredom is still scarce and current measures of boredom mostly rely on subjective self-report questionnaires. Here, a novel psychophysical task is presented, which in human experiments allows the induction, quantification and operationalization of boredom. Concretely, a two-alternative choice preference task was used in a laboratory and online environment, with the two alternatives being associated with different sensory stimuli, either monotonous or variable. The stimulation was either visual, with images of daily-life objects, or auditory, with recordings of spoken German words. This task robustly induced state boredom experience. Furthermore, a choice bias towards the variable over monotonous alternative was found, that significantly correlated positively to the self-reported level of state boredom. Interestingly, this effect was comparable between experiments using visual and auditory stimuli, consistent with the idea that boredom is independent of a specific sensory modality. We next quantified the monotony avoidance bias over a range of varying degrees of monotony, by controlling the size of the stimulus libraries that were associated with each of the two alternatives. This revealed empirical entropy of experienced stimulation to be a substantial driver of consecutive behavior. A theoretical framework is proposed to quantify and interpret factors, which account for participants' individual behavior. Taken together, this study establishes an objective behavioral task that captures aspects of subjectively reported state boredom in humans. The simplicity of this paradigm will potentially enable future investigations of boredom in translational and neurophysiological research conditions, which have hardly been accessible with previous assessment tools.

Langeweile als ein ubiquitär erlebtes Alltagsphänomen ist charakterisiert als ein aversiver mentaler Status, typischerweise ausgelöst durch unzufriedenstellende Interaktion mit einem monotonen Umfeld. Zudem findet sich eine robuste Assoziation von Langeweile und verschiedenen psychopathologischen Zuständen, vom Aufmerksamkeitsdefizit-Hyperaktivitäts-Syndrom, über Impulskontrollstörungen, bis hin zur Depression. Trotz der dadurch aufgezeigten psychosozialen Bedeutung, ist der aktuelle Wissensstand bezüglich der neuronalen Verarbeitung und Modulierbarkeit von Langeweile karg und die experimentellen Methoden zur systematischen Erfassung von Langeweile stark begrenzt auf Fragebogen-basierte Ansätze. Diese Arbeit präsentiert einen neuen psychophysikalischen Ansatz zur verhaltensbasierten Erfassung von Langeweile. Im Konkreten beruht dieser auf der Kombination eines Zwei-Alternativen-Auswahlparadigmas mit monotoner und variabler sensorischer Stimulation. Dieser Test umfasste entweder visuelle Reize, in Form abgebildeter Alltagsgegenstände, oder auditorische Stimuli, in Gestalt von Aufnahmen gesprochener deutscher Wörter. Hierbei zeigte er eine verlässliche Induktion von Langeweile im Teilnehmerkollektiv. Zudem fand sich ein starker Vermeidungsbias gegenüber der monotonen Alternative, welcher positiv mit der während des Tests erlebten Langeweile korrelierte. Das Ausmaß dieses Effekts war zwischen beiden Modalitäten ähnlich stark ausgeprägt, was die Hypothese von Langeweile als ein globales sensorisches Phänomen unterstützt. In einem nächsten Schritt wurde der Grad an Monotonie beider Alternativen durch Anpassung der Stimulusmenge systematisch verändert. Interessanterweise stellte sich hier die empirische Entropie der erlebten Stimulation als relevanter Prädiktor des folgenden Wahlverhaltens dar. Basierend auf dieser Beobachtung erfolgt die Darstellung eines theoretischen Modells, das die Quantifizierung und Interpretation individueller Verhaltensunterschiede anhand von wenigen Kernvariablen erlaubt. In Zusammenschau dieser Ergebnisse legt die aktuelle Studie eine neue verhaltensabhängige Messmethode subjektiv erlebter Langeweile vor. Die Einfachheit dieses Tests bietet das Potential für eine zukünftige Anwendung in verschiedenen experimentellen Kontexten zur translationalen und neurophysiologischen Erforschung der Langeweile.

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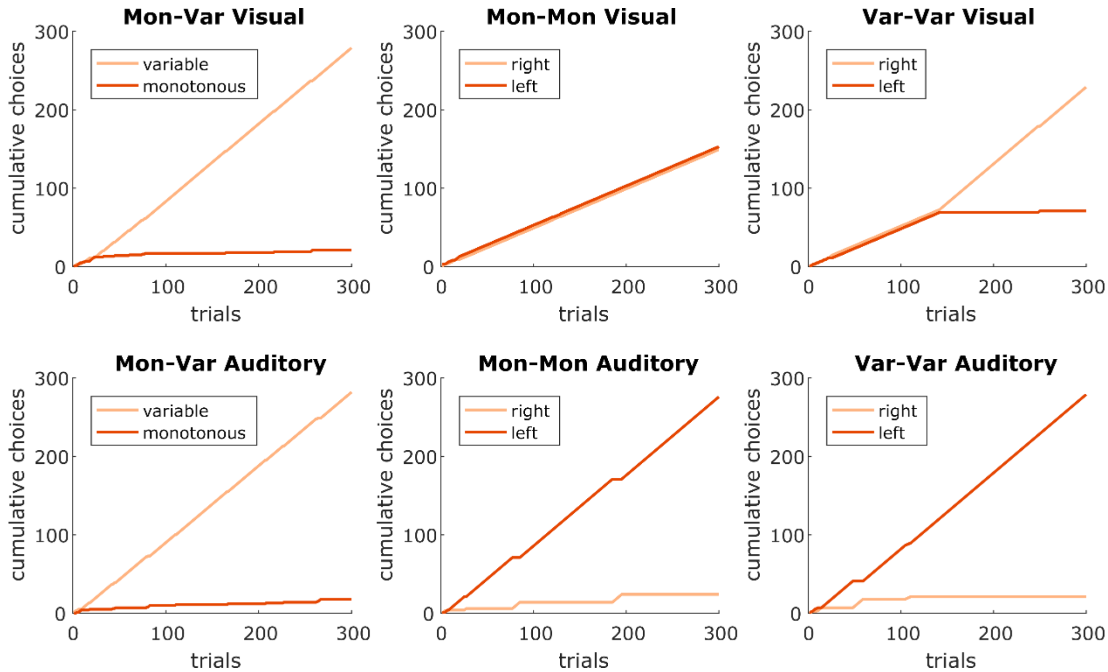
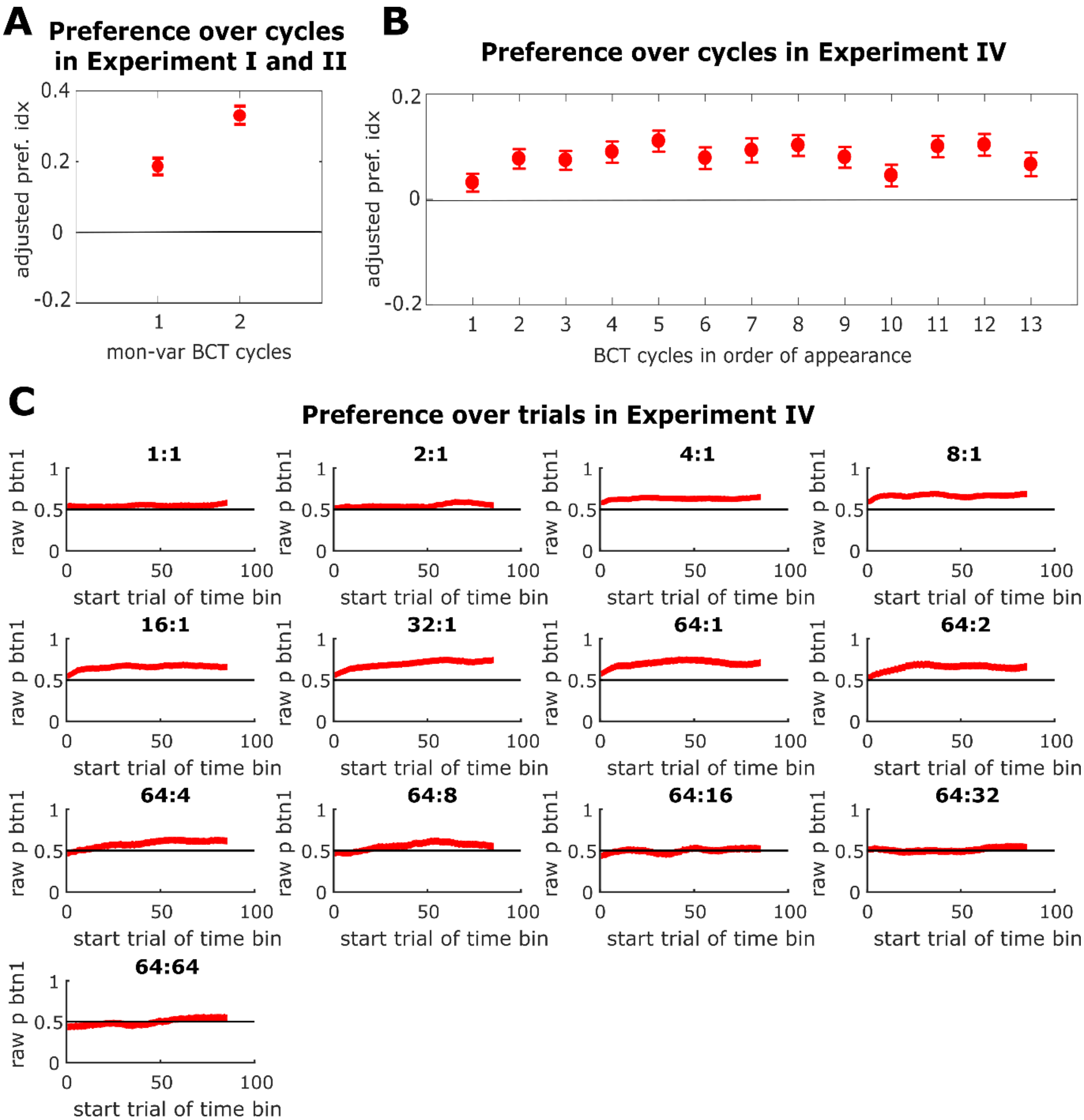
# 8) APPENDIX

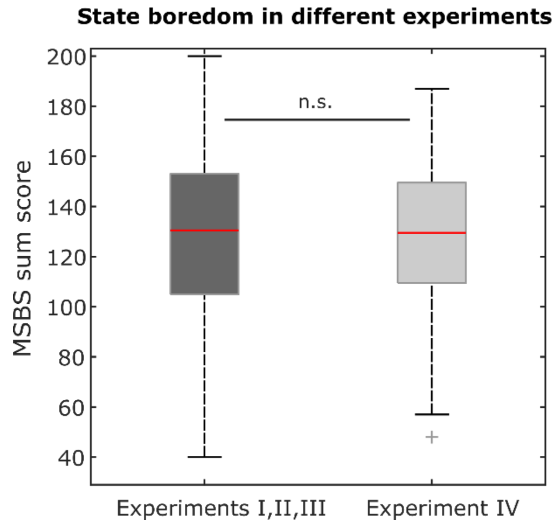
## 8.1) Supplementary analyses



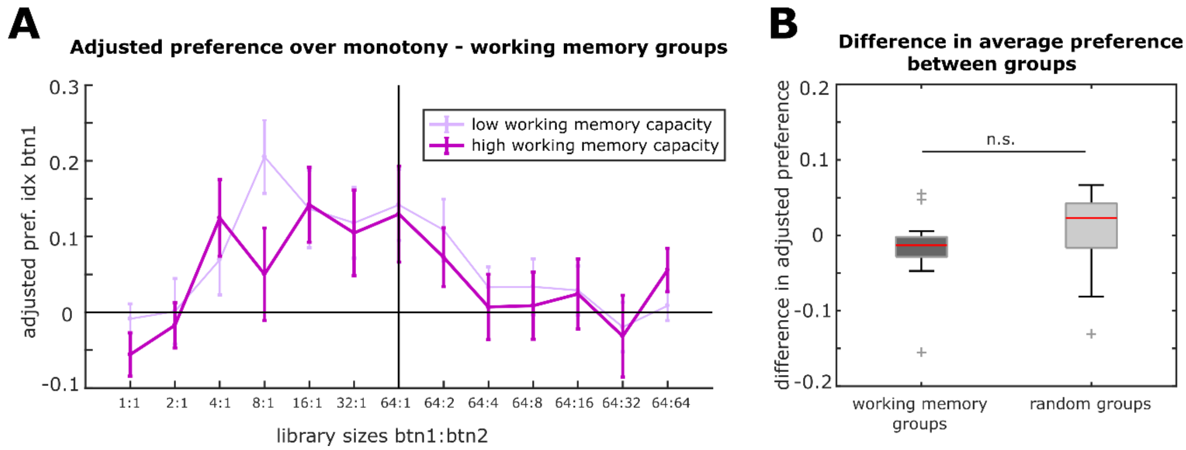

**Supplementary Figure 1 – Choice behavior of one exemplary subject:** The subplots differentiate all six task conditions of Experiment II. The cumulative amount of choices for either alternative is plotted over the respective trial. In the control conditions the participant either preferentially chose one of the equivalent alternatives (see monotonous vs. monotonous auditory) or kept switching throughout the task (see monotonous vs. monotonous visual).



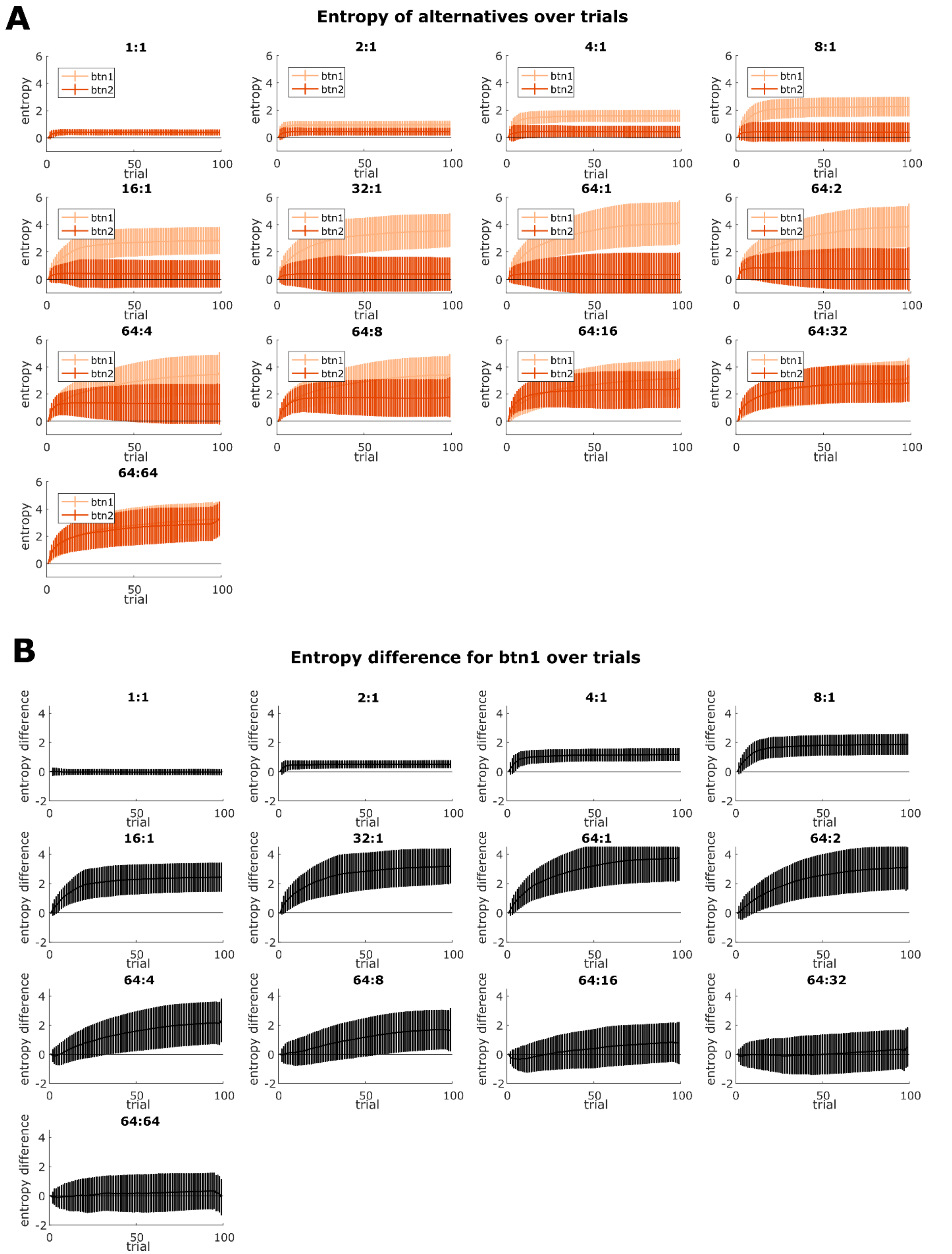

**Supplementary Figure 2 – Preference profiles and adaptations across experiments: (A)** Average adjusted preference over the sequence of task cycles in Experiment I and II (n = 102 participants). (**B**) Same presentation of adjusted preference for Experiment IV (n = 148 participants). (**C**) Average raw preference over the duration of the task conditions of Experiment IV (n = 148 participants). Preference is computed in a bin of 15 trials, which is then shifted stepwise.



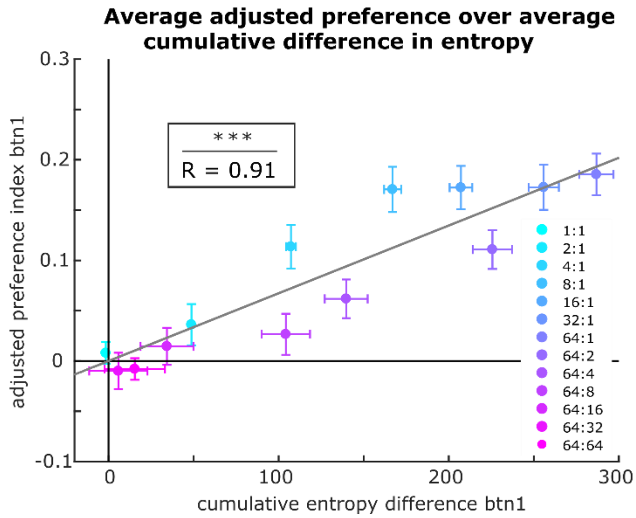

**Supplementary Figure 3 – State boredom ratings across experiments:** Boxplots of state boredom ratings for Experiment I, II and III (n = 142 participants) versus the ratings of Experiment IV (n = 148 participants). The boxplot presentation corresponds to the previous figures. No statistically significant difference was found between conditions (Wilcoxon ranked sum test p = 0.92).




**Supplementary Figure 4 – Preference profiles with different working memory capacity:** (**A**) Average adjusted preference index over the different stimulus library pairings of individuals, grouped according to their working memory capacity. Light magenta indicates the half of participants with working memory scores in the lower 50% quantile of the total distribution (n = 36 participants), whereas dark magenta reflects the upper 50% quantile (n = 36 participants). (**B**) Boxplots comparing the overall difference in adjusted preference between the high and low working memory group to the overall difference from a random grouping of individuals (each distribution includes 13 data points, corresponding to the difference in task cycles with varied stimulus libraries). No significant difference between groups was found (Wilcoxon ranked sum test 0.17). The boxplot presentation corresponds to the previous figures.




**Supplementary Figure 5 – Empirical entropy over task cycles:** (**A**) Average empirical entropy of the stimuli presented at each alternative for each trial in the different task cycles of Experiment IV (n = 148 participants). (**B**) Average entropy difference between alternatives for each trial in the task cycles of Experiment IV (n = 148 participants). All vertical bars in the figure indicate the standard error of the mean.




**Supplementary Figure 6 – Raw preference over cumulative entropy difference:** Correlation scatter plot of the average adjusted preference index for one alternative and the mean cumulative entropy difference for this option in each task cycle of Experiment IV (each data point reflects the average of n = 148 participants). The 13 different conditions are displayed in different color and the bars indicate the standard error of the mean. Both parameters show a significant and strong positive linear correlation (Pearson's $R = 0.91$, ***: $p < 0.001$). The grey line depicts the best linear fit.

| | BPS | | | | | | MSBS | | | | | | GHQ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Ext. S. | Int. S. | Aff. R. | Wait. B. | Time P. | Total | Diseng. | High A. | Inatt. | Low A. | Time p. | Total |
| $\boldsymbol{\beta_2}$ (entropy sen.) | 0.01 | 0.08 | 0.07 | -0.09 | 0.10 | -0.09 | 0.02 | 0.03 | -0.03 | 0.04 | -0.02 | 0.05 | -0.10 |
| $\boldsymbol{\beta_1}$ (momentum) | 0.05 | 0.04 | 0.04 | 0.03 | 0.09 | 0.07 | 0.11 | 0.07 | 0.15 | 0.11 | 0.00 | 0.10 | -0.13 |
| $\overline{c_{\Delta H}}$ (entropy contribution) | 0.02 | -0.03 | 0.12 | 0.05 | -0.05 | 0.00 | 0.04 | 0.05 | -0.02 | 0.09 | 0.04 | 0.00 | -0.05 |

| | BDI-II | CAARS | I-8 | | | | STAI | BFI | | | | | BRS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Total | Urg. | Purp. | Endur. | Risk | Total | Neurot. | Extrav. | Openn. | Agree. | Consc. | Total |
| $\boldsymbol{\beta_2}$ (entropy sen.) | -0.13 | -0.03 | 0.10 | 0.11 | 0.1 | 0.06 | -0.02 | -0.03 | 0.01 | -0.02 | -0.06 | 0.02 | -0.02 |
| $\boldsymbol{\beta_1}$ (momentum) | -0.04 | 0.03 | 0.08 | -0.06 | -0.01 | -0.07 | 0.06 | -0.04 | -0.04 | -0.05 | -0.15 | -0.08 | 0.05 |
| $\overline{c_{\Delta H}}$ (entropy. contribution) | -0.07 | -0.09 | -0.11 | 0.06 | 0.01 | -0.15 | 0.07 | 0.05 | -0.01 | 0.05 | -0.06 | 0.01 | 0.00 |

**Supplementary Table 1 – Correlation of the fitted model parameters and self-report assessments:** Spearman correlations of the main model parameter weights ($\boldsymbol{\beta_2}$: sensitivity to entropy, $\boldsymbol{\beta_1}$ : momentum) and the average relative contribution of entropy sensitivity to the different psychometric self-report assessments. None of the correlations reaches statistical significance (p > 0.05 for all cells).

## 8.2) German versions of self-report boredom assessments

### 8.2.1) Boredom Proneness Scale (BPS)

**BPS**

Die folgenden Aussagen können mehr oder weniger auf Sie zutreffen. Bitte geben Sie bei jeder Aussage an, inwieweit diese auf Sie persönlich zutrifft.

| | trifft überhaupt nicht zu 1 | 2 | 3 | 4 | 5 | 6 | trifft vollkom-men zu 7 |
|---|---|---|---|---|---|---|---|
| 1. Es fällt mir leicht, mich auf meine Aktivitäten zu konzentrieren. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 2. Während ich arbeite, mache ich mir oft Sorgen um andere Dinge. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 3. Die Zeit scheint immer nur langsam zu verstreichen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 4. Ich weiß oft nichts mit mir anzufangen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 5. Ich gerate oft in Situationen, in denen ich mich mit sinnlosen Dingen beschäftigen muss. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 6. Es langweilt mich enorm, Heimvideos oder Urlaubsfotos anderer anzuschauen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 7. Ich beschäftige mich gedanklich immerzu mit Projekten bzw. Dingen, die erledigt werden müssen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 8. Es fällt mir leicht, mich zu beschäftigen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 9. Viele Dinge, die ich tun muss, sind repetitiv und monoton. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 10. Es braucht mehr Stimulation, um mich in Gang zu bringen, als dies bei den meisten Menschen der Fall ist. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 11. Die meisten Dinge, die ich tue, machen mir großen Spaß. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 12. Meine Arbeit begeistert mich nur selten. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 13. Ich kann in der Regel in jeder Situation etwas zu tun oder zu sehen finden, das mich interessiert. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 14. Die meiste Zeit sitze ich nur herum und tue nichts. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 15. Ich kann gut geduldig warten. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 16. Ich habe oft nichts zu tun und zu viel Zeit. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 17. In Situationen, in denen ich warten muss, z. B. in einer Warteschlange, werde ich sehr unruhig. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 18. Ich wache oft mit einer neuen Idee auf. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 19. Es wäre sehr schwierig für mich, eine Arbeitsstelle zu finden, die interessant genug ist. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 20. Ich wünsche mir mehr Herausforderungen im Leben. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 21. Ich bin der Meinung, dass ich die meiste Zeit weit unter meinen Fähigkeiten arbeite. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 22. Viele Leute würden sagen, dass ich kreativ und einfallsreich bin. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 23. Ich habe so viele Interessen, dass ich keine Zeit habe, allen nachzugehen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 24. In meinem Freundeskreis bin ich die Person, die sich am längsten mit einer Sache beschäftigt. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 25. Wenn ich nichts Aufregendes oder sogar Gefährliches mache, fühle ich mich halbtot und langweilig. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 26. Es braucht viel Abwechslung, um mich wirklich glücklich zu machen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 27. Es scheint, dass im Fernsehen oder im Kino immer die gleichen Sachen laufen; das nervt langsam. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 28. Als ich jung war, fand ich mich oft in monotonen und langweiligen Situationen wieder. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

Translation of R. Farmer & N. D. Sundberg, 1986

## 8.2.2) Multidimensional State Boredom Scale (MSBS)

**MSBS**

Die folgenden Aussagen beziehen sich auf ihr **persönliches Empfinden während des eben bearbeiteten Computertests**. Bitte geben Sie bei jeder Aussage an, inwieweit diese auf Sie **während des Tests** zutraf.

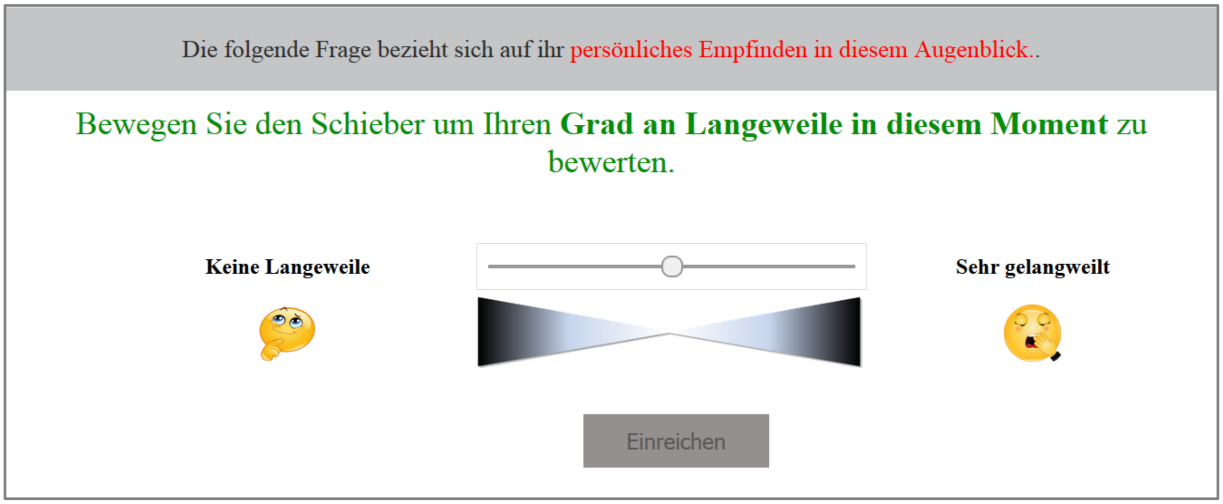
| | trifft überhaupt nicht zu 1 | 2 | 3 | 4 | 5 | 6 | trifft vollkommen zu 7 |
|---|---|---|---|---|---|---|---|
| 1. Die Zeit vergeht langsamer als gewöhnlich. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 2. Ich stecke in einer Situation fest, die ich belanglos finde. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 3. Ich lasse mich leicht ablenken. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 4. Ich bin einsam. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 5. Zurzeit regt mich scheinbar alles auf. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 6. Ich wünschte, die Zeit würde schneller vergehen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 7. Alles erscheint mir monoton und alltäglich. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 8. Ich fühle mich niedergeschlagen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 9. Ich scheine gezwungen zu sein, Dinge zu tun, die für mich keinen Wert haben. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 10. Ich fühle mich gelangweilt. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 11. Die Zeit zieht sich hin. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 12. Ich bin launischer als sonst. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 13. Ich bin unentschlossen oder unsicher, was ich als nächstes tun soll. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 14. Ich fühle mich aufgewühlt. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 15. Ich fühle mich leer. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 16. Es fällt mir schwer, mich zu konzentrieren. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 17. Ich möchte etwas machen, was Spaß macht, aber nichts spricht mich an. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 18. Die Zeit verstreicht nur langsam. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 19. Ich wünschte, ich würde etwas Aufregenderes machen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 20. Meine Aufmerksamkeitsspanne ist kürzer als gewöhnlich. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 21. Ich bin gerade ungeduldig. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 22. Ich verschwende Zeit, die ich besser auf etwas anderes verwenden sollte. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 23. Meine Gedanken wandern. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 24. Ich möchte, dass etwas passiert, aber ich bin mir nicht sicher, was. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 25. Ich fühle mich vom Rest der Welt abgeschnitten. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 26. Im Moment scheint die Zeit nur langsam zu verstreichen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 27. Ich ärgere mich über die Leute in meinem Umfeld. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 28. Mir kommt es vor, als säße ich herum und wartete darauf, dass etwas passiert. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 29. Es scheint, als gäbe es niemanden, mit dem ich reden könnte. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

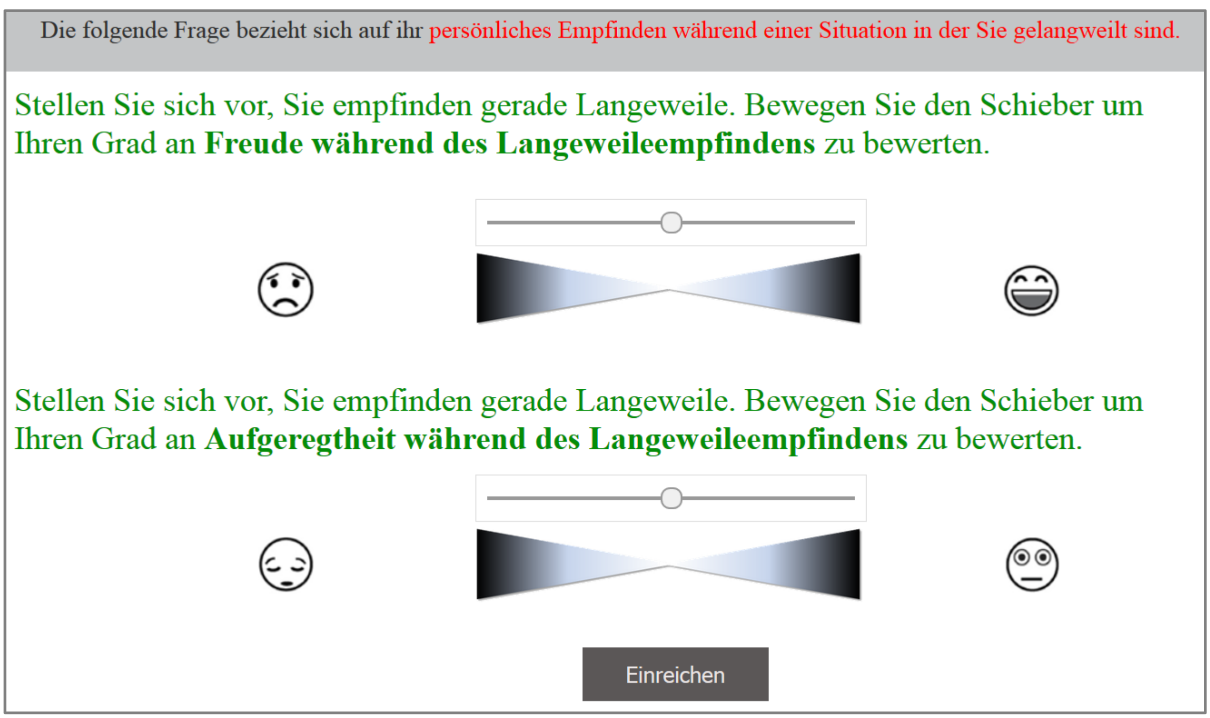
Translation of S. A. Fahlman, K. B. Mercer-Lynn, D. B. Flora, J. D. Eastwood, 2013

## 8.3) Visual analogue assessments of the study

### Visual analogue scale for state boredom (VAS-B)




### Visual analogue scales for affect and arousal (VAS-AA)



## 8.4) Digit span backwards task of the study

*Introduction:* "The following task requires you to memorize some sequences of numbers and write them down in reverse order to the paper in front of you. While listening to the sequence of digits you are not allowed to use any tools or notations. Please write down the sequences in reverse order, meaning that the last named digit should be positioned at the beginning of your answer. The difficulty will increase from sequence to sequence.

First, you are presented two example sequences, before moving to the task condition."

| **Test sequence I:** | **Test sequence II:** |
|---|---|
| 7-2 | 1-6-3 |
| Correct answer: | Correct answer: |
| 2-7 | 3-6-1 |

*(Stepwise presentation of sequences with 1s between each digit)*

| | |
|---|---|
| **Sequence I:**<br>5-1 | **Sequence II:**<br>3-8 |
| **Sequence III:**<br>4-9-3 | **Sequence IV:**<br>5-2-6 |
| **Sequence V:**<br>3-8-1-4 | **Sequence VI:**<br>1-7-9-5 |
| **Sequence VII:**<br>6-2-9-7-2 | **Sequence VIII:**<br>4-8-5-2-7 |
| **Sequence IX:**<br>7-1-5-2-8-6 | **Sequence X:**<br>8-3-1-9-6-4 |
| **Sequence XI:**<br>4-7-3-9-1-2-8 | **Sequence XII:**<br>8-1-2-9-3-6-5 |

## 8.5) Example of entropy computation

**<u>4:1 stimuli condition</u>** ($stimuli_{Alternative1}$ : $stimuli_{Alternative2}$)

$Stimuli_1$: {A, B, C, D}

$Stimuli_2$: {E}

The computation follows the rules described above (see Chapter 2.4.3). This yields an entropy value ($H_j$) for each alternative $j$ for each trial of each game per individual. Additionally, the entropy difference between both alternatives $\Delta H_t$ is computed for each trial $t$. This entropy difference gives an estimate of the difference in variability of both options.

1. **Trial $t$ = 1:**

   The example subject chooses alternative 1 and is presented stimulus A.

   $$choice_{t=1} = \{1\}$$
   $$stimuli_{t=1} = \{A\}$$

   The entropy values are computed as:

   $$H_{1,t=1} = -f_A * log(f_A) = -1 * log(1) = 0$$

   and

   $$H_{2,t=1} = -f_E * log(f_E) = -0 * log(0) \rightarrow H_{2,t=1} = 0$$

   The entropy difference for this trial is

   $$\Delta H_{t=1} = H_1 - H_2 = 0 - 0 = 0$$

2. **Trial $t$ = 2:**

   The example subject chooses alternative 2 and is presented stimulus E.

   $$choice_{t=2} = \{1, 2\}$$
   $$stimuli_{t=2} = \{A, E\}$$

   The entropy values are computed as:

   $$H_{1,t=2} = -f_A * log(f_A) = -\frac{1}{2} * log\left(\frac{1}{2}\right) \approx 0.35$$

   and

   $$H_{2,t=2} = -f_E * log(f_E) = -\frac{1}{2} * log\left(\frac{1}{2}\right) \approx 0.35$$

   The entropy difference for this trial is

   $$\Delta H_{t=2} = H_1 - H_2 = 0.35 - 0.35 = 0$$

3. **Trial $t = 3$:**

   The example subject again chooses alternative 2 and is presented stimulus E.

$$choice_{t=3} = \{1, 2, 2\}$$
$$stimuli_{t=3} = \{A, E, E\}$$

   The entropy values are computed as:

$$H_{1,t=3} \;=\; -f_A * log(f_A) = -\frac{1}{3} * log\left(\frac{1}{3}\right) \;\approx\; 0.37$$

   and

$$H_{2,t=3} \;=\; -f_E * log(f_E) \;= -\frac{2}{3} * log\left(\frac{2}{3}\right) \approx 0.27$$

   The entropy difference for this trial is

$$\Delta H_{t=2} \;=\; H_1 - H_2 \;=\; 0.37 - 0.27 \;=\; 0.10$$

4. **Trial $t = 4$:**

   The example subject switches to alternative 1 and is presented stimulus B.

$$choice_{t=4} = \{1, 2, 2, 1\}$$
$$stimuli_{t=4} = \{A, E, E, B\}$$

   The entropy values are computed as:

$$H_{1,t=4} \;=\; -f_A * log(f_A) - f_B * log(f_B) = \; -\frac{1}{4} * log\left(\frac{1}{4}\right) - \frac{1}{4} * log\left(\frac{1}{4}\right) \approx\; 0.69$$

   and

$$H_{2,t=4} \;=\; -f_E * log(f_E) \;= -\frac{2}{4} * log\left(\frac{2}{4}\right) \;\approx 0.35$$

   The entropy difference for this trial is

$$\Delta H_{t=2} \;=\; H_1 - H_2 \;=\; 0.69 - 0.35 \;=\; 0.34$$

5. **Trial $t = 5$:**

   The example chooses alternative 1 again and is again presented stimulus B.

$$choice_{t=5} = \{1, 2, 2, 1, 1\}$$
$$stimuli_{t=5} = \{A, E, E, B, B\}$$

   The entropy values are computed as:

$$H_{1,t=5} \;=\; -f_A * log(f_A) - f_B * log(f_B) = \; -\frac{1}{5} * log\left(\frac{1}{5}\right) - \frac{2}{5} * log\left(\frac{2}{5}\right) \approx\; 0.30$$

   and

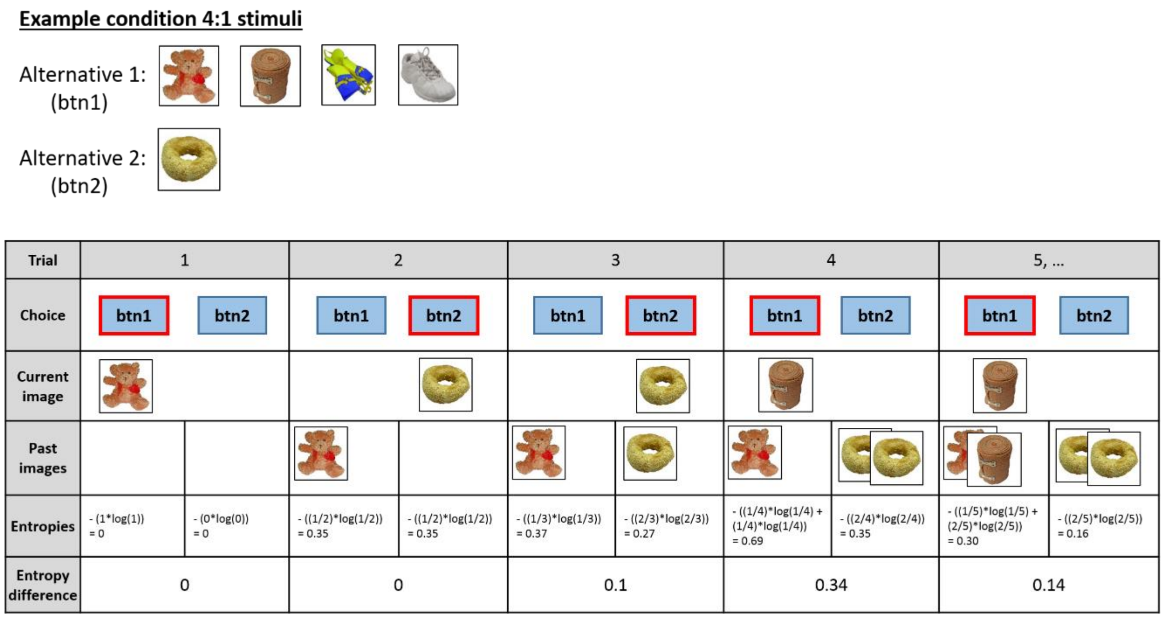
$$H_{2,t=5} = -f_E * log(f_E) = -\frac{2}{5} * log\left(\frac{2}{5}\right) \approx 0.16$$

The entropy difference for this trial is

$$\Delta H_{t=2} = H_1 - H_2 = 0.30 - 0.16 = 0.14$$

6. **Trial $t = 6, \ldots$:**

   This algorithm is continued over all trials of each task cycle.




**Supplementary Figure 7 – Schematic example of entropy computation:** Notice that in these example trials not all possible stimuli from the stimulus library are presented.