Effects of Early Life Events on Health and Human Capital Outcomes

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Dissertation

zur Erlangung des Grades eines Doktors der

wirtschaftlichen Staatswissenschaften

(Dr. rer. pol.)

des Fachbereichs Rechts- und Wirtschaftswissenschaften

der Johannes Gutenberg-Universität Mainz

vorgelegt von

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in Mainz

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im Jahre 2022

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Tag der mündlichen Prüfung: 24.01.2022

Acknowledgements

I would like to express my gratitude to my supervisor, Reyn Joris. The trust that he put in me enabled me to be creative, take time to advance my understanding and develop new project ideas. I greatly benefited from his methodological knowledge and experience in interdisciplinary projects. The open-door policy at the chair as well as his honesty and constant advice made this journey valuable. I especially appreciate the academic freedom I had over the past years. Besides co-authoring chapter 2 and chapter 4 of this thesis, developing new ideas and writing research applications together with you and Sabine was one of the most intensive, inspiring and rewarding experiences during the past years.

Special thanks go to my former colleague and co-author on chapter 4 and chapter 5 Birgit. Sharing an office with her was one of the luckiest incidents of my life. It has been a privilege to work with her on the Mainz Survey Study on Ramadan during Pregnancy and to share our joy in project management. Her pragmatic view on life and academia in combination with a great sense of humor have always encouraged me. Thanks for being my most demanding critic and greatest supporter. I hope we will still regularly go for walks when we are old and happy.

Several people played a decisive role with respect to the Mainz Survey Study on Ramadan during Pregnancy. The work on chapter 4 and chapter 5 would not have been possible without the women who took part in our study, only shortly after having given birth. I would also like to thank our student assistants Asmaa, Yara, Asiye, Ayse, Ranna, Kheira and Hatem for their reliability, professionalism and perseverance. The smooth cooperation with the staff of the obstetric wards in Mainz (University Medical Center and Katholisches Klinikum Mainz) was pivotal to the success of the project. I would especially like to thank Dr. med. Anja F. and PD Dr. med. Annette Q.

I gratefully acknowledge financial support for this research by the German Research Association (DFG, grant number 260639091). I would also like to acknowledge my colleagues at the chair of Statistics and Econometrics and the many researchers who commented on my research in seminars and conferences over the past years.

Working on the PhD with three little children was wonderful most of the time. The joy and laughter of Suvi, Anouk and Mascha at home grounded – and distracted – me when things did not work out as planned. However, working on the dissertation through pregnancies and with kids at home was also challenging sometimes and even more so in times of a pandemic. My greatest appreciation goes out to the wonderful people who reliably took care of our daughters. My mother and mother-in-law are so supportive that I am lacking the right words to thank them. All children spent a considerable amount of their infant and toddler ages with their daycare mum Jutta. Our former Au Pairs Holy and Zhenya have become part of the family. While I was attending conferences or evening meetings, these people were often in the background.

Lastly, I would like to thank my family and friends. My parents' unwavering support has always made me believe in myself. Simultaneously working on a dissertation with my brother Marian was a highly interdisciplinary – and often funny – experience. My grandparents always reassured me that I would make the best decisions for myself. I am aware that I am living a life that was unachievable for my grandmothers when they were young. Back then, both of them gave up many dreams and aspirations, and I can hardly imagine how difficult that must have been. This dissertation is dedicated to both of them.

Heiner – look how far we've come.

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List of Abbreviations

APGAR	Appearance, Pulse, Grimace, Activity and Respiration (measurement of newborn health)
AUSAID	Australian Agency for International Development
cf.	confer ('compare')
CI	Confidence interval
DFG	Deutsche Forschungsgemeinschaft (German Research Foundation)
DHS	Demographic and Health Surveys Program
DID	Difference-in-Differences
DNA	Deoxyribonucleic acid
DOHaD	Developmental Origins of Health and Disease
e.g.	exempli gratia ('for example')
FE	Fixed effects
i.e.	id est ('that is')
IFLS	Indonesian Family Life Survey
MICS	Multiple Indicator Cluster Surveys program
NCHS	US National Center of Health Statistics
OLS	Ordinary least squares
OR	Odds ratio
POLS	Pooled ordinary least squares
QUAG	Gesellschaft für Qualität in der außerklinischen Geburtshilfe (Society for Quality in Out-of-Clinic Obstetrics in Germany)
RAND	RAND ('Research and Development') Corporation, US nonprofit global policy think tank
UK	United Kingdom of Great Britain and Northern Ireland
UNFPA	United Nations Population Fund
UNICEF	United Nations Children’s Fund
US	United States of America
vs.	versus
WHO	World Health Organization

Chapter 1
Introductory Essay

The exploration of how health in early life is associated with outcomes in adulthood has become a central theme within health economics. Connecting insights from economics and the medical sciences, the research field quests to identify the determinants of health and human capital outcomes over the life course. Over the past decades, a literature on the early life origins of later-life outcomes has emerged at the intersection between epidemiology, medical sciences, (epi-) genetics and economics. It is based on the idea that conditions early in life, starting at its earliest stages in utero, may affect health, educational performance and labor market outcomes throughout the entire lifespan. This concept was first formalized as the 'fetal origins hypothesis' (Barker, 1990; Barker, 2004b). A burgeoning interdisciplinary literature on the developmental origins of health and disease has identified various short- and long-term adverse effects of multiple dimensions of prenatal shocks. While the earlier literature focused on extreme prenatal shocks such as famines, more recent research has detected associations between more subtle adverse prenatal conditions and later-life outcomes, including environmental conditions such as air pollution, disease environments and socio-economic conditions such as income shocks (Moore et al., 1999; Barker, 2004c; Almond, 2006; Roseboom et al., 2006; Black et al., 2007; Chen & Zhou, 2007; Stein et al., 2007; Painter, Westendorp, et al., 2008; Victora et al., 2008; Almond et al., 2009; Maccini & Yang, 2009; Almond et al., 2010; Huang et al., 2010; Schulz, 2010; Lumey et al., 2011; Roseboom et al., 2011; Van Ewijk, 2011; Sanders, 2012; Veenendaal et al., 2012; Veenendaal et al., 2013; Chen, 2014; Currie et al., 2014; Almond et al., 2015; Cornwell & Inder, 2015; Lindeboom & Van Ewijk, 2015; Majid, 2015; Scholte et al., 2015; Tan et al., 2015; Schultz-Nielsen et al., 2016; Caruso, 2017; Miller, 2017; Van den Bergh et al., 2017; Rosales-Rueda, 2018; Schoeps et al., 2018; Black et al., 2019; Cumming et al., 2019; Majid et al., 2019; Rosales-Rueda & Triyana, 2019).

This dissertation both contributes to the empirical evidence on the effects of more subtle prenatal shocks on later-life outcomes and conceptual advancements in the fetal origins literature. Central to all chapters is the exploration of Ramadan during pregnancy and its associations with health outcomes among Muslim offspring. During Ramadan, the 9th months of the Islamic calendar and the Muslim holy month of fasting, many pregnant Muslims decide to adhere to an intermittent fast. Intermittent daytime fasting during Ramadan, with unrestricted nutritional intake during nighttime, is a more subtle prenatal shock than famines and has been linked to various later-life health and human capital outcomes. However, the mechanisms linking Ramadan during pregnancy to later-life outcomes have remained under-researched, as well as effects on the functionality of specific organs and metabolic functions. By investigating the effects of Ramadan during pregnancy on respiratory function in adulthood (chapter 2), linear growth and infectious disease occurrence in childhood (chapter 3), as well as reproductive outcomes among women (chapter 3) using data from the

Indonesian Family Life Survey (IFLS), this dissertation adds to this evidence base. Moreover, the effects of Ramadan during pregnancy are largely attributed to the maternal intermittent fasting. However, besides daytime fasting, the practice of Ramadan involves further behavioral changes related to nutritional composition and sleep rhythm. Using data from the Mainz Survey Study on Ramadan during Pregnancy, chapter 4 and chapter 5 focus on the Ramadan-related behavior of pregnant Muslims in Germany and link those behaviors to newborn health outcomes. While earlier research has acknowledged that behaviors such as sleep and nutrition during Ramadan might impact the association between Ramadan during pregnancy and later-life outcomes, this is the first time that such potential moderating effects are explicitly considered. Furthermore, first evidence on the practice of Ramadan among pregnant Muslims in Germany is provided.

From a conceptual perspective, this dissertation accounts for several recent advances in the literature. Besides the consideration of further behavioral changes beyond the decision to fast (chapter 4, chapter 5), the role of the preconceptional period (chapter 3) and potential interactions between prenatal shocks and postnatal living circumstances are inspected empirically (chapter 2, chapter 3). Moreover, the dissertation puts a focus on identifying causal relationships between Ramadan during pregnancy and outcomes along the life course. Taken together, the four chapters of this dissertation contribute to an improved understanding of the conditions and populations among which the effects of Ramadan during pregnancy are most likely to materialize, which is pivotal to policy design. The adherence to the Ramadan fast is largely a religious tradition and not only guided by health considerations. Identifying factors that might moderate the association between Ramadan during pregnancy and offspring health outcomes is therefore highly relevant from a public health perspective.

This introductory chapter places the dissertation within the literature and gives an outlook on the dissertation chapters. First, the fetal origins hypothesis is introduced. Second, the main contributions of economics to the field are summarized. Third, recent advances in the research on the effects of prenatal adverse conditions on outcomes along the life course are explicated. Against this background, I then present the general contributions of this dissertation to the literature and briefly discuss methodological challenges in the identification of the effects of Ramadan during pregnancy on later-life outcomes. In the last section of this chapter, a preview of the main findings of each chapter as well as the respective contributions to the literature is provided.

1.1. Prenatal experiences cast long shadows: the fetal origins hypothesis

The prenatal period is characterized by critical growth phases of the embryo/fetus[1], including rapid cell divisions leading to the formation and of organs as well as the general development of body parts, organs and neurological, cognitive and metabolic functions, which occur at different times and at different pace throughout gestation (Mone et al., 2004; Uylings, 2006; Sandman et al., 2011; Miller et al., 2014). The fetus used to be regarded as 'perfect parasite', provided with all necessary nutrients but unaffected by maternal nutritional and behavioral decisions during pregnancy, until into the second half of the 20th century (Susser & Stein, 1994; Almond & Currie, 2011). This notion has radically changed over the last decades. Instead of regarding an individual's prenatal time and postnatal developments over the life course as disconnected from each other, the prenatal environment has been identified as a co-determinant of a multiplicity of later-life health, educational and labor market outcomes, providing support to the fetal origins hypothesis. Central to the fetal origins hypothesis is its prediction that the effects of prenatal adverse conditions are persistent and may remain latent for a long time, i.e. that long-term effects can also appear if examinations earlier in life remain without pathological findings (Almond & Currie, 2011; Almond et al., 2018). From early research on the fetal origins hypothesis onwards, the empirical evidence has shown associations between prenatal shocks and chronic diseases that are prevalent among adults, often after mid-age (Godfrey & Barker, 2001).

The mechanisms by which the prenatal environment is linked to later-life outcomes include direct damage to the developing fetus and long term structural, metabolic – often epigenetic – adaptations in response to the prenatal environment. The latter adaptations are referred to as 'fetal programming' or 'developmental plasticity' and describe how the combination of an individual's genotype and the environmental conditions experienced while in utero leads to the formation of a specific phenotype via so-called 'predictive adaptive responses' (Gluckman & Hanson, 2004c; Gluckman et al., 2005; Bateson et al., 2014). Simplified, the genotype of an individual consists of her genetic endowments, mainly the DNA acquired via parental inheritance. Based on these genetic endowments, her phenotype is formed, which embraces the individual's physiological appearance, behavior and development. Predictive adaptive responses describe a mechanism that allows an organism to adapt its phenotype to environmental circumstances without genetic adaptations, since only the expression of the DNA is adapted (Bateson et al., 2014).

[1] The term embryo refers to the early developing organism before main organs have been formed (until gestation week 10), thereafter it is referred to as fetus (Gluckman & Hanson, 2004b).

Interactions between genotype and prenatal environmental stressors have been shown to lead to phenotypic switching. The prenatal environment can be understood as providing cues about the expectable postnatal environment, for which the developing organism's phenotype is then optimized. This essentially means that an organism's phenotype is adjusted to the predicted adult environment based on environmental cues during gestation via predictive adaptive responses (Lea et al., 2017; Burggren, 2019). Such developmental plasticity is beneficial if the prenatal circumstances are a correct prediction of the circumstances faced later in life, since it allows a species to quickly adapt to variations in living circumstances. Whenever there is a mismatch between prenatal and postnatal circumstances, however, the adaption to the prenatal exposure may have a harmful effect. For example, if nutrition is scarce during pregnancy (such as during a famine), the fetus is prepared for a life in a world with scarce nutrition. If nutrition after birth is not scarce, however, the individual exhibits higher risks for developing conditions such as obesity and obesity-related chronic diseases, since its metabolism was programmed to energy conservation. In addition to predictive adaptive responses to prenatal environments, phenotype formation is informed by the postnatal living environment, epigenetic inheritance, as well as interactions between genetic endowments and environmental influences (Lassi & Teperino, 2020). It is important to note that besides epigenetic adaptations, direct damage to a fetus' developing organs can occur, for instance upon exposure to toxic substances during pregnancy or nutritional deficits (Bateson et al., 2014).

1.2. Economics and the fetal origins hypothesis

The fetal programming literature originates from epidemiology and early contributions mainly focused on suboptimal nutrition during pregnancy and health outcomes such as cardiovascular diseases, obesity, hypertension and type II diabetes (Barker, 2002; Moritz et al., 2003; Barker, 2004b). One major contribution of economics to the literature has been the consideration of potential effects of prenatal shocks on human capital outcomes, i.e. the formation of the cognitive and non-cognitive skill set of individuals shaped by factors such as education, training, health and socio-emotional development (Attanasio, 2015). Health, forming the basis for all human activity, is considered as an integral part of human capital (Becker, 2007). This is also a main rationale for economics to investigate the determinants of health throughout the life course. Currie (2020) argues that child health is to be regarded as a special component of human capital accumulation, since health in childhood is associated with various physical as well as cognitive and non-cognitive skill and health outcomes over the life cycle.

Prenatal shocks have been found to be associated with a variety of human capital outcomes including grades at school or success on the labor market (for an overview see Almond & Currie (2011); Almond et al. (2018)). At the micro level, the determinants of human capital formation are diverse and context-specific (Park et al., 2020). In the Global South context, factors such as prenatal exposure to infectious diseases and limited access to improved sanitation have been identified as predictors of impaired human capital accumulation. Another comparatively subtle in utero shock that has been found to be associated with outcomes such as reduced labor market success is prenatal exposure to higher mean temperatures (Attanasio, 2015; Isen et al., 2017). At the macro level, higher levels of human capital have been found to be associated with higher innovation and economic growth in various contexts (Hanushek, 2013; Altinok & Aydemir, 2017).

The human capital dimension of the investigation of the associations between prenatal shocks and later-life health outcomes has also been taken up by formal modeling in economics. Originally, human capital formation had been modeled more narrowly with a strong focus on education and skills attainment. Grossman (1972) first included health in the human capital concept. In his model, a health stock that depreciates over an individual's lifetime was included. While investments in health were also deemed possible, their efficacy was not considered to be influenced by the original health stock (Almond & Currie, 2011). In response to the emerging fetal origins literature, Heckman (2007) remodeled the original health stock as having a persistent impact on health and human capital formation. In the Heckman (2007) model, investments in health are subdivided into pre- and postnatal inputs. Based on the notions of 'dynamic complementarities' and 'self-productivity' of abilities in capacity formation, it is suggested that investments at earlier stages (here: the prenatal period) increase the returns to investments in later stages (here: the postnatal period) in terms of multiplier effects[2]. The model furthermore only includes a depreciation rate for postnatal health investments, predicting persistent and potentially latent effects of early life events (Almond & Currie, 2011; Currie & Almond, 2011). From a public policy perspective, such potential complementarities between prenatal and postnatal investments in long-term health and human capital accumulation imply that investments early in life may be very cost-efficient (Cunha & Heckman, 2007; Heckman & Masterov, 2007; Attanasio, 2015).

Another important contribution of economics to the fetal origins literature are methodological advances. While earlier epidemiological work largely reported correlations between prenatal conditions and later-life outcomes (Currie, 2009; Almond & Currie, 2011), the application of micro-

[2] More detailed insights into Heckman (2007)'s conceptualization of human capital formation are provided in chapter 5.2.2.

econometric methods has contributed to the identification of causal relationships between prenatal conditions and the health and human capital trajectories of individuals. The identification of causal pathways between adverse in utero conditions and later-life outcomes is not straight forward, since the effects of prenatal exposures are often confounded with family background characteristics. At the same time, randomized controlled trials are unfeasible or highly unethical in the study of most prenatal shocks. In order to circumvent these threats to identification, econometricians have made use of naturally occurring events that expose one group to a certain treatment (i.e. the treatment group), while another group remains unexposed (i.e. the control group), independent of personal characteristics. Exposure is beyond the control of the investigator and the study subjects in such quasi-experimental settings (also often referred to as natural experiments). Econometrics contributes its set of tools to analyze such quasi-experiments, in the quest to draw causal inference in the absence of experimental data. Among these identification strategies are established approaches such as Regression Discontinuity Designs and Difference-in-Difference analyses, and the econometric toolkit is continuously advancing (Angrist & Pischke, 2014; Athey & Imbens, 2017). Additional statistical methodological advances have improved the inspection of potential confounding, to ensure that exposure is random and that the identified effects are not due to omitted variable bias or attrition.

1.3. Recent advances in fetal programming research

An increasing body of empirical research on the fetal origins hypothesis, mainly in economics and epidemiology, has investigated how what happens in utero impacts later-life health and human capital outcomes. The fetal origins hypothesis has been placed within the wider research field on the Developmental Origins of Health and Disease (DOHaD), which regards the first 1000 days of early life, from conception until the 2nd birthday, as key to later disease development. While Barker (2004b) notes that the notation 'developmental origins hypothesis' might therefore be more suitable, this dissertation focuses on the associations between prenatal experiences and later-life health outcomes and therefore uses the fetal programming terminology.

Major recent advances in fetal programming research are informed by progress in epigenetics, underlining the highly interdisciplinary nature of the field. Many empirical studies found that prenatal shocks are particularly harmful when an overlap coincides with early pregnancy. Genetic studies corroborate this finding by showing that DNA methylation is particularly sensitive to environmental influences during early pregnancy (Tobi et al., 2015). Advances in the measurement of genetic markers are commencing to allow more detailed insights into the materialization of the effects of prenatal shocks. Most recently, the preconception phase has been proposed to be an important determinant of offspring later-life health by medical research, in addition to the offspring's time in utero (King, 2016; Fleming et al., 2018; Stephenson et al., 2018; Young & Ramakrishnan, 2021). Despite these advances in epigenetics, the biological understanding of the mechanisms of fetal programming remains a major challenge. The emergence of different phenotypes in response to gene-environment-interactions has been observed with respect to various species and settings, yet the identification of the genes driving phenotypic switching remains unresolved, in particular with respect to humans (Lassi & Teperino, 2020). Current developments suggest that developmental plasticity is driven by multiple genes, which can both interact with the environment and with each other (Lea et al., 2017; Goldstein & Ehrenreich, 2021).

Another emerging theme in research on the fetal origins hypothesis are intergenerational effects. While the idea that health impairments early in life might be associated with health and human capital outcomes that span across generations is not new (Currie, 2009), recent findings in epigenetics have underlined the relevance of this potential pathway from prenatal shock to cross-generational effects (Burggren, 2019). To date, the large majority of studies on intergenerational effects of prenatal shocks is based on animal studies. However, as more rich administrative datasets become available, first studies on humans have emerged (Painter, Osmond, et al., 2008; Veenendaal et al., 2013; Lee, 2014; Caruso & Miller, 2015; Tan et al., 2015; Caruso, 2017; Black et al., 2019).

Lastly, the health and human capital effects of more subtle prenatal shocks have come to shape the recent development of the field. The earlier fetal programming literature focused on the effects of extreme in utero events such as famines or wars. Against an abundance of available evidence, the associations between such extreme prenatal shocks and later-life health and human capital outcomes have become widely accepted (Almond et al., 2018). However, since many of these shocks are very extreme and unusual, it has been put into question to what extent the findings are transferable to other settings (Maccini & Yang, 2009). More subtle prenatal shocks are more common in many contemporary settings, yet have been studied to a lesser extent. Main reasons for this are that milder shocks are either seldom as clearly definable as more extreme events and in case of risky behavior during pregnancy, the effects of the prenatal shock can hardly be differentiated from maternal background characteristics. Among the more subtle prenatal shocks that have been investigated over the past decade are income shocks, nutritional supplementation, stress or air pollution. They have been shown to be associated with an equally diverse range of outcome measures including performance at school, anthropometric measures in childhood and adulthood or health at birth (an extensive review of the evidence can be found in Almond et al. (2018)).

1.4. Ramadan during pregnancy

The chapters of this dissertation examine how Ramadan during pregnancy, a common and widely spread practice during pregnancy among Muslims, is causally related with health outcomes across the life span, from infancy to adulthood. Ramadan is the Muslim holy month of fasting, during which able-bodied Muslims are required to adhere to a daytime fast which lasts from dawn to sunset for 29-30 days. Adherence to the fast is one of the core beliefs and practices of Islam and the prenatal period of roughly 75% of the approximately 1.8 billion Muslims worldwide overlaps with a Ramadan. Ramadan during pregnancy has been found to be associated with symptoms indicative of type II diabetes and coronary heart disease (Van Ewijk, 2011), adverse anthropometric outcomes (Van Ewijk et al., 2013; Karimi & Basu, 2018; Kunto & Mandemakers, 2019; Chaudhry & Mir, 2021), an increased mortality among under 5 year-old children (Schoeps et al., 2018) as well as reduced success at school and on the labor market (Almond et al., 2015; Majid, 2015; Majid et al., 2019). With respect to short-term effects on newborn health, the evidence is mixed. While several studies do not find Ramadan during pregnancy to be associated with newborn health (for a review see Glazier et al. (2018)), Almond & Mazumder (2011) find a sex ratio that is skewed in favor of girls and lower birthweights among the exposed.

The practice of Ramadan involves a form of intermittent fasting, since food and drink intake are unrestricted during nighttime. Adherence to the fast has been shown to have beneficial health effects among healthy, non-pregnant Muslims (Abdeen & Elinav, 2021; Su et al., 2021). Among fasting pregnant women, deficits in caloric intakes (Arab, 2004) as well as changes of the maternal metabolic and hormonal systems that are comparable those of starving individuals have been documented (Prentice et al., 1983; Malhotra et al., 1989; Arab, 2004). Alwasel et al. (2010) observed impaired placental growth among pregnant Muslims who fasted during Ramadan. Survey-based investigations show that the share of Muslim women fasting at least one day during pregnancy ranges from around 50% in the Netherlands (Savitri et al., 2014) to 99% in Bangladesh (Seiermann et al., 2021). Similarly, dietary adjustment to Ramadan among pregnant women is highly context-specific, with an increased dietary diversity in some settings and deficits in nutritional intake among pregnant women in other settings (Savitri et al., 2018; Seiermann et al., 2021). Due to the intermittent nature of the fast, Ramadan fasting during pregnancy is considered as a comparatively subtle nutritional restriction.

Since the start and end dates of Ramadan are determined by moon sightings, Ramadan during pregnancy is a clearly defined occurrence. Evidence from different settings shows that there is no relationship between whether a person's time in utero overlapped with a Ramadan and her parents' characteristics, implying that Muslim parents do not systematically plan pregnancies as to avoid or promote a Ramadan during pregnancy (Almond & Mazumder, 2011; Van Ewijk, 2011; Majid, 2015; Schoeps et al., 2018; Karimi et al., 2020). Ramadan during pregnancy can thus be reasonably assumed to occur quasi-randomly. Making use of this, a first strand of research has exploited Ramadan during pregnancy as a natural experiment. A potential remaining concern could be that even though parents do not time their pregnancy in relation to Ramadan, underlying characteristics could determine whether a woman adheres to the practice of Ramadan while being pregnant, which could therefore bias results. However, the identification strategy underlying the natural experiment approach is to compare outcomes of Muslims whose own time in utero overlapped with a Ramadan to those of Muslims without such an overlap between their own time in utero and a Ramadan. Importantly, exposure is defined solely based on whether an individual's own time in utero overlapped with a Ramadan, while it remains unknown whether that individual's mother actually fasted or not. This intention-to-treat approach circumvents the issue of underlying factors driving the decision to fast. In general, a lower bound effect of the effects of Ramadan during pregnancy is measured in this approach, since not all mothers to individuals whose own time in utero overlapped with a Ramadan will have fasted.

A second strand of research has attempted to identify the determinants of fasting among pregnant Muslim mothers, in order to identify the target population of interventions in prenatal care (Joosoph et al., 2004; Robinson & Raisler, 2005; Mubeen et al., 2012; Petherick et al., 2014; Savitri et al., 2014; van Bilsen et al., 2016). Based on survey data, these studies compare fasting to non-fasting pregnant Muslims and attempt to link newborn health to maternal fasting behavior. A main threat to the identification of causal effects in this approach is that the decision to fast is not random and potentially subject to confounding by (unobserved) background characteristics. However, recent methodological advances have improved testing for selection of observables and unobservables (Oster, 2017). In the framework of this dissertation, contributions to both strands of research are made.

It is important to note that the practice of Ramadan is not restricted to daytime fasting. Other adjustments to Ramadan include the adaptation of sleep rhythms to the intake of food very early in the morning and late at night and changes in nutrient intake due to traditional meals being consumed at the breaking of the fast after sunset and before sunrise (Faris et al., 2020; Seiermann & Gabrysch, 2020). This implies that associations between Ramadan during pregnancy and later-life outcomes detected in natural experiment set-ups should not solely be attributed to maternal fasting during pregnancy. As actual maternal behavior during Ramadan often remains unknown, any potentially detected effects are to be interpreted as the effects of an overlap of a pregnancy with a Ramadan, which includes all Ramadan-related behavioral and lifestyle adjustments, including but not restricted to the fasting. At the same time, Ramadan-related behaviors such as sleep deficits as such have been shown to be associated with adverse health effects among the offspring (Chang et al., 2010; Reutrakul et al., 2018; Warland et al., 2018). The supposition that the maternal fasting during Ramadan drives any health effects in the offspring has thus remained a hypothesis and in the framework of this dissertation, first evidence on the combined effects of fasting and other Ramadan-related behaviors will be provided.

1.5. Outlook on the dissertation chapters

In the following, I summarize the four chapters of this dissertation and lay out their contributions to the literature on the health and human capital effects of Ramadan during pregnancy as well as the broader fetal programming literature. Chapter 2 and Chapter 3 use individual-level based data from the Indonesian Family Life Survey (IFLS). Indonesia is the country with the largest Muslim population worldwide. Exploiting Ramadan during pregnancy as a natural experiment, Muslims calculated to have had an overlap between their own time in utero and a Ramadan based on their birth date and historic dates of Ramadan are considered to be exposed. The control group in all analyses are Muslims without such a calculated overlap between their own time in utero and a Ramadan. As Non-Muslims naturally do not observe the Ramadan fast, they form a suitable group for placebo tests. Since no effects among Non-Muslims are found in any of the analyses in Chapter 2 and Chapter 3, this speaks against the concern that other Ramadan-related shocks that are independent of the practice of Ramadan – such as rising food prices during Ramadan – might be driving the results.

In Chapter 2, the associations between Ramadan during pregnancy and respiratory function among Indonesian adult Muslims are examined. This investigation speaks to the literature on the long-term effects of Ramadan during pregnancy and the fetal programming literature in general in that the empirical evidence on effects on the functionality of specific organs has remained scarce. With respect to the effects on lung function, the only prior larger-scale study on prenatal shocks and respiratory function showed that prenatal famine exposure increases the risks for experiencing symptoms indicative of obstructive airways disease in adulthood (Lopuhaä et al., 2000). At the same time, diseases of the respiratory tract rank among the main causes of death and disability worldwide (Ferkol & Schraufnagel, 2014; Soriano et al., 2020). Chapter 2 enriches the literature by for the first time exploring the effects of a more subtle prenatal shock on adulthood lung function. We show that the prevalence of wheezing – a whistling sound produced during breathing, indicative of obstructive airways disease – is higher among adult Muslims who had been in utero during

Ramadan, independent of the pregnancy phase during which the individual's time in utero overlapped with a Ramadan. Since the respiratory system development is subject to critical growth phases during all pregnancy phases, this finding is consistent with medical theory. Moreover, we find that the association increases with age and is strongest in the age group 45+.

Another contribution of Chapter 2 is that we test whether the manifestation of the effects in response to adverse prenatal events co-depends on later-life influences. We investigate whether the effects of Ramadan during pregnancy on wheezing occurrence in adulthood vary by smoking status by interacting prenatal exposure to a Ramadan and adulthood smoking status. Our findings show that the effects are concentrated among prenatally exposed smokers. This indicates that the manifestation of the effects in response to prenatal adverse experiences may co-depend on postnatal lifestyle decisions and living circumstances. In the case of respiratory function, it might be that Ramadan during pregnancy has weakened the exposed's respiratory system's capacity to cope with postnatal adverse influences such as smoking. This direction of research is novel in the fetal programming literature.

In Chapter 3, the main health outcome studied is linear (i.e. height) growth among children and adolescents, which has been shown to be positively associated with various health and human capital outcomes (Abbott et al., 1998; Case & Paxson, 2008b; Perkins et al., 2016). In accordance with a large share of the emerging literature on more subtle prenatal shocks and linear growth (Miller, 2017; Kunto & Mandemakers, 2019; Chaudhry & Mir, 2021), I find negative effects of Ramadan during pregnancy on linear growth among adolescents, but not among younger children. In order to explain this finding, I explore two potential intervening pathways. First, infectious disease occurrence in response to Ramadan during pregnancy is studied, since recurrent infections in childhood (such as episodes of diarrhea and respiratory disease) are a main risk factor for impaired linear growth (Stephensen, 1999; Dewey & Mayers, 2011; Salam et al., 2015; Hedges et al., 2017). I find that children whose own time in utero overlapped with a Ramadan are more likely to exhibit respiratory symptoms. No effects on the occurrence of diarrhea and fever are identified. While earlier research had hypothesized that Ramadan during pregnancy might impair the immune function among children (Schoeps et al., 2018), this is the first paper to explicitly study such infectious disease outcomes in response to Ramadan during pregnancy in children. Moreover, inadequate sanitary conditions have been shown to be associated with an increased risk of obtaining infectious diseases and in this way to be associated with impaired linear growth among children (Merchant et al., 2003; Dillingham & Guerrant, 2004; Mara et al., 2010; Fuller et al., 2014; Torlesse et al., 2016; Cumming et al., 2019). An exploration of whether postnatal access to improved sanitary facilities moderates the relationship between Ramadan during pregnancy and linear growth effects finds suggestive evidence for the adverse effects on linear growth to be concentrated among those adolescents without access to adequate sanitation. Similar to the findings of chapter 2, it appears that the immune system of the exposed is less well prepared to counteract later-life adverse living circumstances such as unimproved sanitary conditions. Taken together, these findings suggest that Ramadan during pregnancy might be associated with impaired linear growth via the infectious disease channel and encourage future research on the effects of Ramadan during pregnancy on immune function.

A second potential mechanism linking Ramadan during pregnancy to impaired linear growth among adolescents is sexual maturation, which coincides with adolescence. It might be that predictive adaptive responses to Ramadan during pregnancy lead to the emergence of a 'fertile phenotype', guided by a (predicted) increased mortality risk and in face of limited available nutritional resources. Moreover, it has been proposed that from an evolutionary perspective, predictive adaptive responses target species survival, i.e. reproductive success (Bateson et al., 2014). Previous research showed that prenatal exposure to a famine is associated with increased reproductive success such as a younger age at first childbirth (Painter, Westendorp, et al., 2008), although no causal evidence on more subtle prenatal shocks has been presented until now. For this analysis, I use the sample of ever-married Indonesian Muslim women in IFLS, which contains information on sexual maturation and childbirth history. There are no associations between Ramadan during pregnancy and age at menarche, which can be considered as biological marker of the onset of puberty. By contrast, I find that prenatally exposed women are younger when they first give birth, which corroborates the findings of Painter, Westendorp, et al. (2008). While there is thus some evidence supporting a potential tradeoff between linear growth and reproductive capacity, I am cautious to infer a direct link based on these preliminary findings. A major concern is that the age at first childbirth is co-determined by other factors such as educational attainment, which have also been shown to be associated with Ramadan during pregnancy. However, the finding that Ramadan during pregnancy is associated with reproductive outcomes suggests that this is a relevant direction for future research.

Turning away from the natural experiment setting, Chapter 4 and Chapter 5 aim to unravel some of the unknowns surrounding the practice of Ramadan by pregnant Muslims using survey data from Mainz, Germany. Data were collected in the framework of the cross-sectional Mainz Survey Study on Ramadan during Pregnancy. Information obtained in interviews of pregnant Muslims and new Muslim mothers whose pregnancy overlapped with a Ramadan was linked with medical data on offspring health at birth and maternal health background. This is the first dataset on Ramadan during pregnancy that contains extensive maternal background information, including ancestry and degree of religiosity as well as information on behavioral changes during Ramadan such as sleeping habits and nutritional adjustments. A first contribution of this research is to provide first evidence on the determinants of fasting during Ramadan among pregnant Muslims in Germany. Moreover, the potential impact of other Ramadan-related adjustments such as changes to dietary or sleep patterns could not be distinguished from the effects of fasting during Ramadan in earlier research. Using a rich dataset and innovative statistical methods to eliminate concerns about confounding, we examine the characteristics of fasting vs. non-fasting Muslim mothers in Germany as well as the effects of Ramadan-related behavior on offspring health outcomes.

Chapter 4 focuses on the determinants of Ramadan fasting among pregnant Muslims in Germany using data from the Mainz Survey Study on Ramadan during Pregnancy 2016/2017 (N=116). We provide first insights into the Ramadan-related behavior of pregnant Muslims in Germany. Studies in the Netherlands (54%) and the UK (43%) show lower fasting rates than studies in non-European countries such as Pakistan (88%) or rural Bangladesh (99%) (Mubeen et al., 2012; Petherick et al., 2014; Savitri et al., 2014; Seiermann et al., 2021). Yet, Muslim communities are highly diverse across Europe so that the detection of Ramadan-related habits among pregnant Muslims in Germany and an improved understanding of the parameters that influence a pregnant Muslim's decision about her behavior during Ramadan has a high practical relevance to healthcare professionals.

We show that Ramadan fasting during pregnancy is common in Germany, with 38% of the interviewed women fasting at least one day during their pregnancy. Moreover, many non-fasting pregnant Muslims were found to live in households with fasting members and to participate in religious festivities and thus to adapt to a Ramadan-specific diet even if they did not fast. Fasting rates were highest during the first pregnancy trimester and the majority of fasting women fasted for more than 20 days. Based on mean comparisons, we find that younger and less educated women as well as women wearing of a headscarf during the interview are more likely to fast. Our study further suggests that (perceived) expectations among the religious community might play an important role in a woman's fasting decision, since 20% of the fasting women decide to fast in spite of concerns about potential adverse health impacts on their offspring. Less than 2% of the study participants reported that they had been proactively approached by their gynecologists to discuss their behavior during Ramadan. Among the gynecologists that the study participants had asked for advice, 73% discouraged from fasting; yet, 27% of women reported that they were not made aware of potential negative effects of fasting.

In Chapter 5, we transition to studying the health of newborns born to mothers who had vs. had not adapted their behavior to a Ramadan that overlapped with the respective pregnancy. We thereby focus on fasting behavior as well as adaptations to sleep rhythm and dietary intake during Ramadan. In this chapter, data of the Mainz Survey Study on Ramadan during Pregnancy 2017/18 are used (N=326). We find that the offspring to mothers who fasted during Ramadan is significantly lighter at birth, while no associations between fasting and APGAR score (a scoring system to assess newborn health) and gestational age are identified. The negative association between fasting and birthweight is robust to controlling for Ramadan-related sleep and nutritional adjustments, which themselves are however not found to be associated with any of the above-mentioned birth outcomes. Closer inspection indicates that maternal diet during Ramadan could play a moderating role: when interacting fasting during pregnancy with other Ramadan-related adjustments, the negative fasting-birthweight association disappears among women who increased their consumption of sweet and/or fatty foods during Ramadan. These findings suggest that nutrition during Ramadan meals influences how the effects of Ramadan intermittent fasting during pregnancy materialize. This study thus adds to the topical discussion on whether the effects of Ramadan during pregnancy can be narrowed down to the effects of Ramadan fasting (Seiermann & Gabrysch, 2020).

As noted earlier, there is a potential threat of confounding bias to the comparison of offspring to fasting vs offspring to non-fasting Muslim mothers, since the assignment to the fasting or non-fasting group is non-random. Factors that could influence the fasting decision could also potentially affect birth outcomes. We address this threat to identification by using the extensive set of control variables included in the Mainz Survey Study on Ramadan during Pregnancy data as well as by testing whether the identified correlations are robust to controlling for unobserved confounders. Since the decision to fast is not exogenous, this is indispensable in non-experimental settings. As rigorous testing based on the Oster (2017) method shows, the detected associations are unlikely to result from residual confounding.

It is also noteworthy that we find fasting rates to differ strongly by country of origin. Previous studies that did not find Ramadan during pregnancy to be associated with birthweight either used intention-to-treat analyses in which exposure was solely determined based on whether a Ramadan occurred during pregnancy or survey-based studies that could not control for important covariates such as maternal country of birth, maternal BMI or maternal religiosity. Detailed maternal ancestry information is rarely available in registries on which many intention-to-treat analyses are based. This implies that the finding from previous registry-based studies that there is on average little or no effect on birth outcomes, does not necessarily imply that there are no sub groups for which effects do exist.

The interdisciplinary nature of this dissertation at the boundary between economics and epidemiology goes along with its practical relevance transcending the boundaries of several scientific disciplines. At the most general level, it enriches the literature by closely investigating the effects of a more subtle prenatal shock on health outcomes along the entire life span, from birth to adulthood. A distinctive feature of this dissertation is that the intervening pathways linking in utero shocks and the materialization of health effects later in life are explored. Since the outcomes studied – including birthweight, linear growth and respiratory symptoms – are associated with various health and socioeconomic outcomes, this dissertation can also be more broadly placed within the human capital literature, underlining that human capital formation already starts in utero.

Besides its contribution to the scientific literature, this dissertation has practical implications for public health. Ramadan during pregnancy is a highly sensitive, religious topic and fasting decisions of pregnant Muslims are shaped by both health and religious motivations. An improved understanding of the mechanisms that stand behind the health effects in the offspring can contribute to the development of guidelines for advising pregnant Muslim women and Muslims of childbearing age on their behavior during Ramadan. Pregnant Muslims who wish to adhere to the Ramadan fast for religious reasons but are at the same time concerned about their health or the health of their unborn child need information about possibilities how fasting can be managed more safely. On a more general level, while extremer in utero shocks such as famines occur rather seldom in most contemporary societies, more subtle prenatal shocks concern many people. A sensitization of professionals in the health care sector to the short- and long-term effects of more subtle prenatal shocks could improve the health and human capital outcomes among future generations.

Chapter 2
As Long as the Breath Lasts: In Utero Exposure to Ramadan and the Occurrence of Wheezing in Adulthood[3]

by Fabienne Pradella[4] & Reyn van Ewijk[5]

This chapter has been published in the American Journal of Epidemiology: Pradella, F. & van Ewijk, R. (2018). As Long as the Breath Lasts: In Utero Exposure to Ramadan and the Occurrence of Wheezing in Adulthood. *American Journal of Epidemiology, 187*(10), 2100-2108.

This research was funded by the German Research Foundation (DFG grant 260639091).

[3] This paper uses data from IFLS waves 1, 2, 3 and 4. Please see Frankenberg & Karoly (1995); Frankenberg & Thomas (2000); Strauss et al. (2004); Strauss et al. (2009) for methodological details. The IFLS data collection is a collaboration between RAND, the Center for Population and Policy Studies of the University of Gadjah Mada and Survey Meter. Funding was provided by the US National Institute of Aging, the US National Institute for Child Health and Human Development, the World Bank, Indonesia and AUSAID.

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2.1. Introduction

Respiratory diseases caused by airflow limitations rank among the top causes of death (Carraro et al., 2014). Next to cigarette smoke, shocks experienced in utero and early life are main risk factors for lung dysfunction in adulthood (Bush, 2008; Stocks & Sonnappa, 2013). As the respiratory system develops from the embryonic period onwards, shocks incurred during all pregnancy trimesters potentially impair its development. One type of prenatal shock is exposure to nutritional shortages. Lopuhaä et al. (2000) found higher risks of chronic obstructive airway disease after in utero exposure to the 1944–1945 Dutch famine. However, to our knowledge, the impact of less extreme nutritional shortages during gestation on the functionability of the respiratory system in adulthood has not yet been explored.

Using data from Indonesia, we investigated whether in utero exposure to Ramadan[6] was associated with the occurrence of wheezing among adult Muslims. The intermittent fasting performed during Ramadan is less extreme than that experienced in a famine. While negative associations between in utero exposure to Ramadan and general health have been detected, studies on specific organs remain scarce. To our knowledge, this is the first study to have explored whether in utero exposure to Ramadan has an effect on lung function. Our outcome variable was wheezing — the occurrence of a whistling sound during exhalation, indicative of illnesses such as asthma, chronic obstructive airway disease, and emphysema. We particularly examined the occurrence of wheezing among smokers, as we hypothesized that prenatal exposure to Ramadan degrades the respiratory system's capability to deal with the ex utero strain of smoking.

More than 22% of the world population adheres to Islam. Moreover, improved knowledge on the early-life origins of obstructive airway disease will contribute to the development of guidelines on topics such as dieting during pregnancy

2.2. Fetal programming and the respiratory system

The in utero environment codetermines an individual's health (Barker, 2004a). The underlying mechanism of fetal programming is that the fetus adapts to the in utero environment, with long-lasting consequences: If nutrient or oxygen transfer is limited, adaptations help the fetus survive in the short run but can have consequences for disease susceptibility in later life. Limited transfer of nutrients during critical growth phases puts fetal organs at risk of remaining underdeveloped. The

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[6] Note that 'in utero exposure to Ramadan' in this chapter refers to the occurrence of an overlap of a person's own time in utero with a Ramadan. It thus cannot be equated with in utero exposure to Ramadan fasting or other Ramadan-related adjustments, since maternal nutrition and behavior during pregnancy is unknown (see section 2.3.3 for details).

development of the lung is characterized by multiple critical growth phases which start in the embryonic period. Therefore, the respiratory system is vulnerable to shocks during all phases of gestation (Kasprian et al., 2006; Joshi & Kotecha, 2007; Harding & Maritz, 2012).[7]

Adult respiratory health is impaired by in utero exposure to tobacco smoking, nutritional deficits, or placental insufficiency. Effects depend on the timing and severity of the exposure (Harding & Maritz, 2012; Pike et al., 2012). Epidemiologic studies have found associations between low birthweight and impaired lung function in adulthood (Barker et al., 1991; Stein et al., 1997; Edwards et al., 2003; Lawlor et al., 2005; Hancox et al., 2009; Pei et al., 2010). Epigenetic studies suggest that in utero shocks can alter DNA methylation patterns, with consequences such as increased allergy risks (Martino & Prescott, 2011).

Studies on maternal malnutrition during pregnancy and its associations with lung development in adulthood remain scarce. Studying people born around the time of the Dutch famine, Lopuhaä et al. (2000) found that symptoms of chronic obstructive airway disease were experienced more frequently by persons whose time in utero overlapped with the extreme food shortage. The associations were strongest for those exposed in midgestation, while a tendency toward higher risks was also found for those exposed in early gestation (Lopuhaä et al., 2000). The associations of less extreme, or intermittent, nutritional restrictions with airway development have not yet been studied.

In this study, we investigated the associations of the intermittent fasting performed during Ramadan with lung function in adulthood. Because many in utero shocks have consequences only at postreproductive ages, we expected to observe the strongest associations in later adulthood (Godfrey & Barker, 2000; Metcalfe & Monaghan, 2001). Moreover, we explored potential interaction effects from the combination of in utero exposure to Ramadan and subsequent ex utero exposure to harmful substances such as cigarette smoke. We hypothesized that prenatally exposed respiratory systems are weakened and more susceptible to complications stemming from other risk factors in adulthood.

[7] For a more elaborate overview on the process of fetal programming, and the difference between adaptations to the in utero environment and direct damage to the developing organs, please refer to Chapter 1.1.

2.2.1. Ramadan during pregnancy

Ramadan constitutes one of the 5 pillars of Islam. For 1 month, Muslims fast during daylight hours. Consequently, the intake of food and drinks is shifted to occur before sunrise and after sunset. Fasting hours depend on the location and time of the year during which Ramadan takes place: Because the dates of Ramadan are determined by the lunar Islamic calendar, its timing shifts over the years (the lunar calendar is about 11 days shorter than the Gregorian calendar).

According to most interpretations of the Koran, pregnant women may refrain from fasting if they believe that fasting will harm their health or the health of the unborn child. However, they are required to make up for the missed days or compensate by way of an expiatory payment. Most Muslim women observe the fast during pregnancy, with varying fasting rates per country (Prentice et al., 1983; Malhotra et al., 1989; Arab & Nasrollahi, 2001; Joosoph et al., 2004; Robinson & Raisler, 2005; Ziaee et al., 2010; Savitri et al., 2014). For Indonesia, Majid (2015) calculated an implied fasting rate of 68%–82%. van Bilsen et al. (2016) conducted a survey among 186 pregnant Muslim women in Jakarta, Indonesia. Among those women, 80% decided to fast on at least 1 day during their pregnancy, and 30% had fasted for more than 20 days.

Research on prenatal Ramadan exposure and health outcomes has shown negative associations with general health and cognitive performance (Almond & Mazumder, 2011; Van Ewijk, 2011; Van Ewijk et al., 2013; Chen, 2014; Almond et al., 2015; Majid, 2015). An important implication of these findings is that malnutrition during gestation also has effects when it occurs in intermittent forms. Worse general long-term health can largely be traced back to impaired fetal growth. During pregnancy, energy is required for the growth of the fetus and placenta, in addition to a woman's normal energy demands. Because of this increased energy demand, during the second half of pregnancy, a woman's blood levels of metabolic fuels and hormones quickly approach levels comparable to those of women exposed to famines ('accelerated starvation'). In the second and third trimesters of pregnancy, signs of accelerated starvation are already detected when single meals are skipped, particularly during activity-intensive daytime hours (Metzger et al., 1982; Burbos et al., 2009). Adhering to the fast during Ramadan has been shown to lead to symptoms indicative of accelerated starvation (Prentice et al., 1983; Malhotra et al., 1989; Arab, 2004). It can thus be assumed that a fetus in later gestation has to make compromises in its growth to get along with the scarce energy supply. Additionally, during early gestation, fetal growth is vulnerable in response to maternal nutrition, particularly with respect to organ development (Wu et al., 2004; Rifas-Shiman et al., 2006; Heppe et al., 2013). Studies on the Dutch famine have found the strongest associations with adult health for exposure during early gestation (Painter et al., 2005). With regard to Ramadan, changes in the nutritional composition of the mother's diet, as measured in micronutrients (Savitri et al., 2018), lower total caloric intake among fasting Muslims (Larijani et al., 2003; Arab, 2004) or increased levels of stress hormones (Seckl & Holmes, 2007), could explain the associations.

2.3. Methods

2.3.1. Data

We used individual-level data from a longitudinal study conducted by the RAND Corporation (Santa Monica, California), the Indonesian Family Life Survey (IFLS). Indonesia is the country with the largest Muslim population worldwide. We pooled data from IFLS waves 1–4 (1993–2008). When information was available from several waves (except for the outcome measures—see next section), we used the latest available information. Information on breathing difficulties (collected in waves 2–4) was self-reported, and respondents were asked to indicate whether they had experienced wheezing or shortness of breath during the 4 weeks before the interview. From wave 1, only information on date of birth and smoking status was included.

The final sample size was 28,489. Several adjustments to the sample were undertaken: First, only respondents aged 15 years or older were asked whether they had experienced breathing difficulties. Second, people who did not know their exact date of birth were excluded, because in utero Ramadan exposure is calculated on the basis of date of birth. Moreover, we detected 'heaping' of reported dates of birth on several days, such as January 1 or the Indonesian day of independence on August 17. People who indicated these dates of birth were excluded. Third, we excluded all observations that did not indicate a predominantly Muslim province as the place of residence. Thus, we could ascertain that only people living in regions where Ramadan was widely practiced were included in our sample. This prevented noise in our estimation due to different traditions in non-Muslim areas of Indonesia.

2.3.2. Outcome measures

We used 2 outcome measures. In our main analysis, the outcome of interest was wheezing. An individual was considered to have had an occurrence of wheezing if she indicated having wheezed in at least 1 IFLS wave. Wheezing was therefore a dummy variable (occurred/did not occur in the last 4 weeks before the interview). However, because all data on respiratory function were self-reported, it might have happened that some persons misreported or combined symptoms.

Against this background, in a second specification we used the occurrence of any breathing difficulty (wheezing/shortness of breath in the 4 four weeks before the interview; ever being diagnosed with asthma or another lung condition) as the outcome measure. Because the question on diagnosed asthma or other lung conditions was only introduced in wave 4, we only used data from wave 4 for this specification.

2.3.3. Categories of exposure to Ramadan

Anyone whose time in utero overlapped with Ramadan was classified as having been prenatally exposed. We calculated this overlap on the basis of the person's date of birth and the historical starting and ending dates of Ramadan. Our calculations were based on the average length of human pregnancies (266 days from the day of conception). Thus, if there was an overlap between the most recent Ramadan before a person's date of birth and the 266 days before the date of birth, he or she was considered exposed. The control group consisted of Muslims whose own time in utero did not overlap with Ramadan. These people were conceived after the end of Ramadan and more than 266 days before the start of the next Ramadan, so that no overlap between Ramadan and their time in utero occurred.

If one compared children born to fasting Muslims with those born to nonfasting Muslims, there would be many sources of confounding; but if one compares Muslims who (because of their birth dates) were in utero during Ramadan with Muslims who (because of their birth dates) were not in utero during Ramadan, there is much less scope for confounding. Any confounder that was to bias our results would then need to be correlated with both wheezing and moment of birth in the Islamic year.

It is important to note that we studied the health impacts of exposure to Ramadan — in any form — during pregnancy, not specifically of Ramadan fasting. Ramadan includes other aspects besides fasting, such as altered sleeping patterns and changes in nutrition (high–glycemic-content foods). Moreover, information on the actual fasting behavior of the mothers of our adult respondents during pregnancy was not available. To the extent that all (or most) of the association was due to fasting (and not to other aspects of Ramadan), our estimation was an intention-to-treat estimation, in which all persons who were Muslim and whose in utero phase overlapped with Ramadan were regarded as exposed.

Besides the binary classification as exposed/not exposed, we divided exposed persons into 5 subgroups in order to investigate whether associations differed with respect to the timing of Ramadan during gestation. First, we created subgroups for those who were born or conceived during Ramadan and whose own time in utero thus overlapped with only a part of Ramadan. Second, we subdivided those who were exposed to an entire Ramadan according to the pregnancy trimester during which the overlap between Ramadan and their own time in utero started (first trimester: days 1–89 of gestation; second trimester: days 90–178 of gestation; third trimester: days 179–266 of gestation) (Table 2-1). Each observation was classified into 1 exposure category. In order to prevent noise in the control group, we classified all persons whose conception was calculated to have occurred less than 21 days after the end of Ramadan into a separate group ('probably not exposed'); hence, they were effectively taken out of the control group. The reason for this is that if those people were born postterm and had thus been exposed to Ramadan during their first weeks in utero, they would have been erroneously classified as not exposed (see also Van Ewijk (2011)).

A further reason for the separate 'probably not exposed' group is the Eid al-Fitr celebration, which takes place immediately after Ramadan. The celebration, commonly referred to as 'Lebaran' in Indonesia, is a festival of breaking the fast for which many Muslims travel to their home villages. The celebration lasts about 1 week. At least 7 days prior to Lebaran, all employed Muslims receive a mandatory holiday bonus of at least 1 full month’s salary. Consequently, despite higher food prices during Ramadan, people can afford more and better-quality food towards the end of Ramadan. It is possible that the health impacts of Ramadan and Lebaran are confounded during the last days of Ramadan. The diurnal fast continues, and most Muslims rather use the holiday bonus to pay for traveling to their home village, gifts for the family, or food for the celebrations. Because of the traveling, selective fertility needs to be taken into consideration. We assumed that persons who conceived around Lebaran might differ systematically from persons who did not conceive during a holiday. Even though the direction of any bias is unclear because of the complex interdependency of an extra salary, rising food prices, and celebrations, we avoided noise by excluding persons conceived during Lebaran from our control group.

2.3.4. Statistical methods

We compared data on the breathing difficulties of Muslims who were prenatally exposed to Ramadan with those of Muslims who were certainly not in utero during Ramadan. Standard errors were clustered at the household level, as within-family correlations on health outcomes were likely. The average size of Muslim households in our sample was 3.06 persons (standard deviation: 1.66).

We performed logistic regression analyses and controlled for age at the time of the interview and age squared, month of birth, sex, and IFLS wave. The results of our analyses are displayed as odds ratios. Because the timing of Ramadan shifts over the years, the effects of Ramadan can be separated from seasonal effects by including month-of-birth dummy variables as covariates (Almond & Mazumder, 2011; Van Ewijk, 2011). Because it lies on the equator, the times of sunrise and sunset do not vary considerably over the course of the year in Indonesia. This implies that the duration of fasting does not vary over the years and that our results were not biased due to a correlation between year of Ramadan exposure and number of hours of Ramadan exposure.

We further differentiated between the various times of prenatal Ramadan exposure (conception, first trimester, second trimester, third trimester, and birth). In addition to performing the analysis for all Muslims, we conducted separate regressions by sex and by age group. Moreover, we allowed the association to vary by smoking status by including a term for interaction between exposure and smoking status.

Since exposure was measured as the occurrence of an overlap between Ramadan and pregnancy, our study can be regarded as a natural experiment. Overlap between Ramadan and pregnancy occurs quasi-randomly, since selective timing of pregnancy to avoid or promote Ramadan during pregnancy is rare or absent in Indonesia (Van Ewijk, 2011). The quasirandom prenatal exposure meant that potential confounders such as maternal characteristics, body mass index, or exposure to air pollution were canceled out; that is, we were unable to control for all factors that might influence the occurrence of breathing difficulties, but this did not bias our results, since these factors did not affect whether Ramadan occurred during pregnancy.

In order to test the robustness of our results, we conducted a difference-in-differences (DID) analysis. DID entails the comparison of treatment effects between 2 groups. We included the non-Muslims and an indicator variable for exposure status, an indicator variable for religion, and an interaction of all covariates with religion. The interaction term 'religion × exposed' compares the strength of the association of Ramadan occurrence during pregnancy with wheezing between Muslims and non-Muslims. Naturally, non-Muslims do not observe Ramadan. Hence, any 'effect' of overlap between Ramadan and pregnancy among non-Muslims has to be due to residual confounding. It is this residual confounding that we therefore took out in the DID analysis. As in our main analyses, we conducted separate regressions by age group.

2.4. Results

2.4.1. Baseline characteristics

Our sample consisted of 28,489 observations (26,313 Muslims and 2,176 non-Muslims). Indonesia has a young population, which was reflected in our sample: The largest age group was people between 15 and 29 years of age (Table 2-1).

Table 2-1: Characteristics of 26,313 Muslims and 2,176 Non-Muslims Living in Predominantly Muslim Areas (Ages ≥15 Years), Indonesian Family Life Survey, 1993–2008

	Muslims			Non-Muslims		
Characteristic	**%**	**No. With Characteristic[a]**	**No. With Data Available[b]**	**%**	**No. With Characteristic[a]**	**No. With Data Available[b]**
Mean age, years[c]	34.9 (14.7)		26,313	36.5 (16.2)		2,176
Age group, years						
15-29	45.7	12,021	26,313	43.6	949	2,176
30-39	23.4	6,155	26,313	20.7	451	2,176
40-49	14.5	3,808	26,313	14.1	306	2,176
50-59	9.1	2,387	26,313	11.2	244	2,176
≥60	7.4	1,942	26,313	10.4	226	2,176
Male sex	49.5	13,019	26,313	49.4	1,074	2,176
Presence of lung condition						
Any breathing difficulty[d]	10.9	2,489	22,893	11.7	200	1,706
Wheezing in past 4 weeks	3.4	893	26,313	3.2	69	2,176
Smoking status						
Smoker[e]	35.9	9,423	26,283	33.0	716	2,172
Male subsample	69.4	9,023	13,005	61.3	656	1,070
Female subsample	3.0	400	13,278	5.4	60	1,102
Ramadan exposure category						
Certainly not in utero during Ram.	11.3	2,974	26,313	11.2	243	2,176
Probably not in utero during Ram.	5.7	1,490	26,313	6.7	145	2,176
In utero during Ramadan	83.0	21,849	26,313	82.2	1,788	2,176
Conceived during Ramadan	9.1	2,401	26,313	8.6	186	2,176
Ramadan started in trimester 1	25.3	6,662	26,313	24.4	532	2,176
Ramadan started in trimester 2	24.1	6,342	26,313	24.7	537	2,176
Ramadan started in trimester 3	16.3	4,284	26,313	17.0	369	2,176
Born during Ramadan	8.2	2,160	26,313	7.5	164	2,176

[a] Number of participants with the characteristic (for binary variables).
[b] Number of participants for whom data were available.
[c] Values are expressed as mean (standard deviation).
[d] Information on any breathing difficulty was available only for persons observed in the fourth wave of the survey.
[e] Information on smoking status was unavailable for several persons.

Table 2-2. Associations Between In Utero Exposure to Ramadan and Development of a Lung Condition in Adulthood (Ages ≥ 15 Years), Overall and by Sex, Among Muslims Living in Predominantly Muslim Areas, Indonesian Family Life Survey, 1997–2008

Ramadan Exposure Category	All Muslims						Female Muslims						Male Muslims					
	Any Breathing Difficulty[a] (n=22,893)			Wheezing[b] (n=26,313)			Any Breathing Difficulty[a] (n=11,768)			Wheezing[b] (n=13,294)			Any Breathing Difficulty[a] (n=11,125)			Wheezing[b] (n=13,019)		
	OR	95% CI	P-Value	OR	95% CI	P-Value	OR	95% CI	P-Value	OR	95% CI	P-Value	OR	95% CI	P-Value	OR	95% CI	P-Value
In utero during Ramadan[c]	1.17	1.02, 1.35	0.022	1.26	0.97, 1.63	0.087	1.14	0.94, 1.39	0.176	1.09	0.75, 1.57	0.657	1.21	0.99, 1.47	0.061	1.45	1.00, 2.12	0.051
Exposure period																		
Conceived during Ram.	1.17	0.97, 1.41	0.100	1.11	0.77, 1.58	0.582	1.14	0.88, 1.48	0.334	0.78	0.46, 1.34	0.371	1.20	0.91, 1.57	0.197	1.47	0.90, 2.42	0.124
Ramadan started in trimester 1	1.21	1.04, 1.41	0.015	1.28	1.00, 1.71	0.099	1.17	0.94, 1.46	0.151	1.18	0.78, 1.78	0.431	1.26	1.01, 1.57	0.038	1.40	0.93, 2.12	0.111
Ramadan started in trimester 2	1.15	0.99, 1.34	0.068	1.30	0.97, 1.74	0.076	1.12	0.90, 1.39	0.324	1.12	0.75, 1.690	0.578	1.19	0.96, 1.48	0.119	1.49	0.99, 2.25	0.058
Ramadan started in trimester 3	1.20	1.02, 1.41	0.032	1.25	0.92, 1.69	0.156	1.17	0.93, 1.48	0.174	1.07	0.69, 1.66	0.761	1.22	0.96, 1.54	0.105	1.46	0.94, 2.27	0.091
Born during Ramadan	1.08	0.89, 1.32	0.439	1.27	0.89, 1.81	0.197	1.09	0.83, 1.43	0.557	1.10	0.67, 1.82	0.705	1.08	0.81, 1.43	0.615	1.49	0.89, 2.49	0.127
Probably not in utero during Ramadan	1.20	0.96, 1.49	0.103	1.35	0.91, 2.01	0.133	1.22	0.90, 1.66	0.205	1.23	0.74, 2.23	0.364	1.19	0.87, 1.62	0.280	1.45	0.82, 2.57	0.200

Abbreviations: CI, confidence interval; OR, odds ratio.

[a] Ever having suffered from any breathing difficulty. The analyses of general breathing difficulties were based on data from the fourth wave of the survey only.

[b] Having experienced wheezing in the past 4 weeks.

[c] Results stem from 2 separate logistic regressions per column (first row: exposed vs. not exposed; exposure periods: classification of exposure into different pregnancy phases) that adjusted for age, age^2, sex, and month of birth. In the wheezing analyses, results were additionally adjusted for survey wave. Standard errors were clustered by household.

Table 2-3. Influence of Smoking Status on Associations Between In Utero Exposure to Ramadan and the Occurrence of Wheezing in Adulthood (Ages ≥15 Years) among 13,005 Male Muslims Living in Predominantly Muslims Areas, Indonesian Family Life Survey, 1997-2008 [a]

Ramadan Exposure Category	Smokers			Nonsmokers		
	OR	95% CI	P-Value	OR	95% CI	P-Value
In utero during Ramadan	1.58	1.02, 2.44	0.042	1.24	0.67, 2.28	0.494
Exposure period						
Conceived during Ramadan	1.78	1.01, 3.12	0.045	0.69	0.24, 2.00	0.496
Ram. started in trimester 1	1.58	0.98, 2.55	0.059	1.03	0.50, 2.13	0.936
Ram. started in trimester 2	1.64	1.02, 2.65	0.042	1.17	0.57, 2.41	0.665
Ram. started in trimester 3	1.44	0.85, 2.41	0.174	1.63	0.79, 3.37	0.186
Born during Ramadan	1.40	0.76, 2.58	0.279	1.93	0.83, 4.50	0.129

Abbreviations: CI, confidence interval; OR, odds ratio.

[a] Results from 2 separate logistic regressions (first row: exposed vs. not exposed; exposure periods: classification of exposure into different pregnancy phases) that controlled for age, age^2, month of birth, survey wave, and the interaction between Ramadan exposure and smoking status. Standard errors were clustered by household.

2.4.2. In utero exposure to Ramadan and breathing difficulties

Prenatal exposure to Ramadan was associated with higher risks for lung conditions in adulthood, in terms of both general breathing difficulties and wheezing (Table 2-2). In comparison with nonexposed Muslims, the risk of experiencing a symptom of any breathing difficulty (wheezing, shortness of breath) or being diagnosed with a lung disease (asthma, other lung condition) was 17.3% higher. For exposed men, the risk of experiencing any breathing difficulty was 20.5% higher.

The results for wheezing confirmed those for any breathing difficulty. Associations were found for exposure during all pregnancy phases except for birth during Ramadan. Significant associations were found only among males. The lower levels of significance may be explained by the lower number of incidences of wheezing in our sample and limited statistical power in the analysis.

Table 2-4. Associations Between In Utero Exposure to Ramadan and the Occurrence of Wheezing in Adulthood (Ages ≥ 15 Years), by Age Group, Among Muslims Living in Predominantly Muslim Areas, Indonesian Family Life Survey, 1997-2008[a]

Ramadan Exposure Category	Age Group, Years																	
	<40 (n = 18,176)			≥40 (n = 8,137)			≥45 (n = 6,061)			≥50 (n = 4,329)			≥55 (n = 2,987)			≥60 (n = 1,942)		
	OR	95% CI	P-Value	OR	95% CI	P-Value	OR	95% CI	P-Value	OR	95% CI	P-Value	OR	95% CI	P-Value	OR	95% CI	P-Value
In utero during Ramadan	1.16	0.81, 1.66	0.423	1.35	0.90, 2.03	0.150	1.41	0.89, 2.23	0.141	1.59	0.95, 2.66	0.080	1.83	1.02, 3.30	0.045	1.98	0.98, 3.99	0.055
Exposure period																		
Conceived during Ram.	1.24	0.78, 1.99	0.367	0.95	0.53, 1.69	0.856	1.10	0.59, 2.05	0.774	1.15	0.57, 2.31	0.696	0.95	0.42, 2.15	0.898	1.00	0.38, 2.61	0.996
Ram. started in trimester 1	1.19	0.79, 1.79	0.394	1.36	0.87, 2.12	0.177	1.37	0.83, 2.26	0.223	1.62	0.92, 2.86	0.096	1.97	1.03, 3.78	0.041	2.18	1.01, 4.71	0.048
Ram. started in trimester 2	1.29	0.87, 1.93	0.208	1.29	0.82, 2.02	0.279	1.33	0.80, 2.22	0.275	1.61	0.91, 2.85	0.102	2.15	1.11, 4.17	0.024	2.86	1.28, 6.36	0.010
Ram. started in trimester 3	0.97	0.64, 1.49	0.903	1.55	0.97, 2.46	0.064	1.73	1.04, 2.88	0.035	1.73	0.97, 3.10	0.064	1.87	0.97, 3.62	0.064	1.71	0.75, 3.94	0.205
Born during Ramadan	1.03	0.62, 1.70	0.918	1.54	0.91, 2.62	0.108	1.44	0.79, 2.63	0.232	1.62	0.83, 3.14	0.155	1.85	0.88, 3.89	0.103	1.97	0.83, 4.64	0.123
Probably not in utero during Ram.	1.69	1.03, 2.76	0.038	0.87	0.44, 1.75	0.703	0.96	0.45, 2.04	0.921	1.22	0.53, 2.80	0.644	1.49	0.59, 3.76	0.402	2.06	0.74, 5.79	0.168

Abbreviations: CI, confidence interval; OR, odds ratio.

[a] Results stem from 2 separate logistic regressions per column (first row: exposed vs not exposed; exposure periods: classification of exposure into different pregnancy phases) that adjusted for age, age^2, sex, month of birth, and survey wave. Standard errors were clustered by household. A separate regression was carried out for each age group.

2.4.3. Smokers and nonsmokers

A majority of Indonesian men smoke (69.38% of Muslim men vs. 3.01% of Muslim women in our sample smoked). We allowed the estimates of exposure to vary by smoking status among the male Muslims. The negative associations were consistently stronger for exposed smokers (Table 2-3).

Note that smoking status does not vary with Ramadan exposure (69.4% of unexposed male Muslims vs. 69.3% of exposed male Muslims in our sample smoked). A $\chi 2$ test of independence was performed to examine the relationship between Ramadan exposure and smoking status. The relationship between these variables was not significant ($\chi 2 = 0.009$, $P = 0.927$).

2.4.4. Associations by age group

As Table 2-4 shows, the risk of experiencing wheezing after in utero exposure to Ramadan increased with age. Significant associations were found when we limited the sample to respondents aged 40 years or more, and they tended to get more pronounced when we limited the sample to even older age groups.

2.4.5. Robustness checks

We replicated our results using a DID design (Table 2-5). The estimates for exposed Muslims (upper half of Table 2-5) confirmed that the strength of the association increased with age. The DID analysis further allowed us to show that associations were not caused by shocks incurred during Ramadan that were independent of religion (such as rising food prices). No associations between wheezing and Ramadan exposure during pregnancy were found for non-Muslims who lived in predominantly Muslim areas (lower half of Table 2-5). This was confirmed by separately conducting our analyses for non-Muslims. These results again demonstrated that prenatal Ramadan exposure was not correlated with seasonality in our analyses, which also means it is unlikely that our results for Muslims were driven by residual confounding by seasonality.

2.5. Discussion

In this study, in utero exposure to Ramadan led to an increased risk of breathing difficulties—specifically wheezing—in adulthood. The associations were most pronounced for smokers. The respiratory systems of prenatally exposed Muslims thus seem to perform worse in mitigating ex utero harmful influences.

Our results partly confirm the findings of Lopuhaä et al. (2000). Similar to their research on famines, we most consistently found associations between the occurrence of lung dysfunction and exposure to Ramadan for exposure during the first and second trimesters. However, the detected sizes of the

Table 2-5. Associations Between In Utero Exposure to Ramadan (Exposed vs. Certainly Not Exposed) and the Occurrence of Wheezing in Adulthood (Ages ≥ 15 Years) Among Muslims and Non-Muslims Living in Predominantly Muslim Areas (Difference-in-Differences Analysis[a]), Indonesian Family Life Survey, 1997-2008[b]

Parameter and Age Group, years	***OR***	***95% CI***	***P Value***
Muslims living in Muslim areas (exposed × Muslim)			
All ages	*1.71*	*0.82, 3.59*	*0.156*
≥ 45	*1.41*	*0.39, 5.13*	*0.601*
≥ 50	*2.09*	*0.55, 7.99*	*0.280*
≥ 55	*3.38*	*0.82, 13.91*	*0.091*
Non-Muslims living in Muslim areas (exposed)			
All ages	*0.65*	*0.32, 1.32*	*0.232*
≥ 45	*0.80*	*0.23, 2.71*	*0.714*
≥ 50	*0.63*	*0.18, 2.22*	*0.472*
≥ 55	*0.46*	*0.12, 1.71*	*0.248*

Abbreviations: CI, confidence interval; Or, odds ratio.
[a] The interaction of all covariates with religion was included in the analyses.
[b] Results from logistic regression analyses that controlled for religion, exposure to Ramadan, religion × exposure to Ramadan, probably not being exposed, religion × probably not being exposed, age, religion × age, age^2, religion × age^2, month of birth, religion × month of birth, sex, religion × sex, survey wave, and religion × survey wave. A separate regression was carried out for each age group. Standard errors were clustered by household.

associations were independent of the timing of exposure, and associations were also found for exposure during the third trimester. Moreover, the association seemed to increase with age and was strongest in the age group 45 years or more. This is in line with fetal programming theory, suggesting that many consequences of prenatal shocks only manifest in postreproductive age.

Our results are to be regarded as intention-to-treat estimates and underestimates of the real strength of the associations. All persons with an overlap between Ramadan and pregnancy were classified as exposed, although we lacked information on actual maternal behavior during Ramadan. Consequently, children of nonfasting mothers were also classified as exposed, which biased the results towards zero. Moreover, all estimates were conditional upon survival, as all persons in the analysis were aged 15 years or older. The health outcomes of persons lost in the womb or before age 15 years and of younger children were not observed.

Selectively timing pregnancies to avoid Ramadan during pregnancy is not common in Indonesia. It has been shown that parents of children who were prenatally exposed to Ramadan do not differ from parents of children without prenatal Ramadan exposure (Van Ewijk, 2011). Consequently, self-selection of healthy persons into the control group did not confound our results. It has furthermore been shown that persons who were exposed to Ramadan while in utero do not have a general tendency to complain more about their health (Van Ewijk, 2011).

A main limitation of this study is that our analysis was based on self-reported health indicators that were not diagnosed by qualified personnel. However, because we found similar results for wheezing and general breathing difficulties, a potential mixup of symptoms by the interviewees was accounted for. The transferability of our results to other countries might be limited, because most Indonesian smokers consume kreteks (clove cigarettes). While the scientific evidence on whether kreteks are more or less harmful than conventional cigarettes is inconclusive, we cannot exclude the possibility that special interaction effects between kretek smoking and prenatal Ramadan exposure occur.

Because obstructive airway diseases rank among the top causes of death, further research on their origins is essential. The identified effect of interaction between in utero exposure to Ramadan and ex utero exposure to smoking might also be relevant with regard to air pollution and other risk factors for airway diseases. Ramadan behavior during pregnancy is relevant for a large part of the population. Moreover, meal-skipping and dieting during pregnancy resemble intermittent fasting and might lead to similar long-term impacts on health. Sensitization of medical personnel and women of childbearing age to this issue is recommended.

Chapter 3
Programmed to be Short? An Exploration of the Pathways from Ramadan during Pregnancy to Linear Growth Impairment[8]

by Fabienne Pradella[9]

This research was funded by the German Research Foundation (DFG grant 260639091).

[8] This paper uses data from IFLS waves 1, 2, 3, 4 and 5. For methodological details see Frankenberg & Karoly (1995); Frankenberg & Thomas (2000); Strauss et al. (2004); Strauss et al. (2009); Strauss et al. (2016). The IFLS data collection is a collaboration between RAND, the Center for Population and Policy Studies of the University of Gadjah Mada and Survey Meter. Funding was provided by the US National Institute of Aging, the US National Institute for Child Health and Human Development, the World Bank, Indonesia and AUSAID.

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3.1. Introduction

Shocks in early life, starting at the earliest stages in utero, are associated with health, education and labor market outcomes in adulthood (Godfrey & Barker, 2001; Bateson et al., 2004; Almond & Currie, 2011; Langley-Evans, 2015). Even though the evidence on the later-life health and human capital effects of prenatal shocks is substantial and increasing, the pathways to these effects remain largely unexplored, also with respect to linear growth. Linear growth describes how children and adolescents grow in height, which often occurs in growth spurts: the term thus does not refer to linear, continuous growth patterns (Rosenbloom, 2007). While previous research showed that prenatal shocks, including Ramadan during pregnancy, are associated with lower final attained height in adulthood (Van Ewijk et al., 2013), it remains unclear whether impaired growth appears at an early age and persists into adulthood or if the growth patterns of the exposed deviate from those of the non-exposed at a later age. Since humans attain their final height around the age of 19, linear growth is restricted to childhood and adolescence. Bringing the growth dynamics among the younger generation into focus is therefore indispensable to understand how prenatal shocks affect growth patterns.

Research about Ramadan during pregnancy and linear growth across childhood and adolescence has remained inconclusive. Some studies find indications for impaired linear growth among under 5-year-old Muslim children whose time in utero overlapped with a Ramadan, others only find Ramadan during pregnancy to be associated with impaired linear growth among adolescents (Karimi & Basu, 2018; Kunto & Mandemakers, 2019; Karimi et al., 2020; Chaudhry & Mir, 2021). In this paper, I add to this evidence base by investigating if and when Ramadan during pregnancy affects linear growth in children and adolescents. Moreover, I go beyond effect documentation and explore the role of potential background mechanisms that might shed light on how Ramadan during pregnancy is associated with impaired linear growth.

This paper uses individual level data from the Indonesian Family Life Survey (IFLS) (waves 1 – 5) to study the dynamics between Ramadan during pregnancy and linear growth patterns. In all analyses, linear growth outcomes among children and adolescents are measured in sex- and age-standardized height-for-age z-scores according to WHO conventions, while final height in adulthood is measured in centimeters. In a first set of analyses, I investigate when linear growth effects start to materialize and if there are effects on adult final attained height in my sample. An improved understanding of the timing of growth impairment effects can yield insights into the dynamics of growth in response to in utero shocks and contribute to the design of interventions aimed at improving child linear growth patterns.

In a second set of analyses, I explore potential pathways to linear growth impairment. The rationale for these analyses is that designing adequate policies requires in-depth information on effect mechanisms. Besides being a risk factor for compromised growth in itself, Ramadan during pregnancy may be associated with other risk factors for impaired growth. First, I investigate if Ramadan during pregnancy increases the risk to experience infectious diseases among children. I hypothesize that exposure leads to a weakened immune system, and subsequently an increased susceptibility to infectious diseases. The latter in turn is associated with a higher probability to remain below one's growth potential (Moore et al., 1999; Stephensen, 1999; Salam et al., 2015; Hedges et al., 2017). This analysis further considers postnatal sanitary standards as potential risk factors for effect materialization. Chapter 2 of this dissertation has shown that the manifestation of effects in response to prenatal shocks might co-depend on postnatal living circumstances. Since inadequate sanitary standards are associated with an increased risk of experiencing infectious diseases (Merchant et al., 2003; Dillingham & Guerrant, 2004; Fuller et al., 2014; Torlesse et al., 2016), I investigate whether improved sanitary standards are a potential moderating factor to mitigate the detrimental effects of Ramadan during pregnancy on children's growth trajectories.

A third set of analyses addresses the hypothesis that linear growth might be compromised in favor of earlier reproductive maturation, in order to ensure survival. This hypothesis is inspired by life history regulation theory, which holds that organisms have to divide a limited available amount of energy between fertility, growth and body maintenance, thus trading off investments in one of these traits by the investment in others (Stearns, 2000). Previous research has found in utero exposure to a famine to be associated with female reproductive trajectories, leading to a younger age at first childbirth and a higher number of children (Painter, Westendorp, et al., 2008). It might thus be that a suboptimal prenatal environment due to Ramadan during pregnancy programs the offspring's body functions to devote more energy to the rapid development of reproductive ability at the expense of linear growth. In order to test this hypothesis, I study the associations between Ramadan during pregnancy and age at menarche as well as age at first childbirth in a sample of ever-married adult Muslim women.

My results confirm that Ramadan during pregnancy is associated with lower final attained height among adult Muslims. The effects materialize during later adolescence and are concentrated among those Muslim adolescents whose time in utero overlapped with a Ramadan during early pregnancy, and those who were conceived shortly after a Ramadan. My further findings suggest that the effects of Ramadan during pregnancy on impaired growth might run via the infectious disease channel. I both find indications that Ramadan during pregnancy is associated with an increased risk of experiencing respiratory symptoms in childhood and that the effects of Ramadan during pregnancy on linear growth are concentrated among those Muslim adolescents who grew up with unimproved sanitary conditions. The results with respect to a potential tradeoff between linear growth and reproductive capacity are less clear. While Ramadan during pregnancy is associated with an earlier age at first childbirth among ever-married Muslim women, no evidence was found for an association between Ramadan during pregnancy and a younger age at menarche.

The paper starts with an overview of the research on the Developmental Origins of Health and Disease (DOHaD) at the intersection between economics and epidemiology. I focus on research on the associations between in utero shocks and child linear growth as well as final adult height. Results from earlier research on the health and human capital effects of Ramadan during pregnancy are summarized. Against this background, the research questions and hypotheses of this paper are introduced. Second, the dataset as well as the empirical strategy are explained. Third, I present my results. The final sections discuss the results and conclude, including an outline of implications for practice and policymaking, as well as an outlook for potential avenues for future research.

3.2. Background

A central theme of DOHaD research is the fetal origins hypothesis, which links diseases in later life to in utero and early life ('first 1000 days') experiences. This chapter places this paper within research on the fetal origins hypothesis and provides an overview of previous research on the associations of Ramadan during pregnancy with various health and human capital outcomes. Subsequently focusing on linear growth, I summarize the empirical evidence on the associations between early life shocks and linear growth, including research on Ramadan during pregnancy. An outlook on the different health and human capital effects associated with impaired growth demonstrates the relevance of this research. Since adverse in utero experiences are not the only risk factors for impaired growth, this section also includes an overview of postnatal risk factors and general mechanisms associated with linear growth trajectories. Finally, I derive my research hypotheses and highlight the contributions of this paper to the literature.

3.2.1. Prenatal environment and postnatal outcomes: the fetal origins hypothesis

Research on Ramadan during pregnancy can be placed within the DOHaD literature on early life effects centered on the fetal origins hypothesis. The fetal origins hypothesis posits that diseases in later life are associated with in utero experiences. The mechanism through which in utero experiences may affect the occurrence of diseases is called fetal programming, which describes a fetus' adaptation to the in utero environment. This may come in the form of 'predictive adaptive responses', which are physical (often epigenetic) adaptations in the fetus that adapt ('program') it to life in an ex utero environment that matches the prenatal environment (Godfrey & Barker, 2001;

Bateson et al., 2004; Almond & Currie, 2011; Barouki et al., 2012; Langley-Evans, 2015). From the perspective of epigenetics, predictive adaptive responses are an example for developmental plasticity. Developmental plasticity describes the phenomenon that depending on the environmental conditions, such as the in utero environment, a specific phenotype is formed based on the genotype, without changes to the underlying DNA. Since cells are most prone to epigenetic changes around the time of conception, early pregnancy is deemed to be the most important period (Toivonen et al., 2017; Fleming et al., 2018).

Predictive adaptive responses can be illustrated by looking at a case of mismatch between prenatal and postnatal environments: Children who face a nutritionally deficient environment in utero, but are born into an environment without nutritional scarcity are at risk to be 'misprogrammed' for a life in this richer environment since their system was prepared for a living environment where nutrition is scarce. These children quickly catch up growth in the postnatal environment. However, due to long-term structural, physiological and metabolic effects of the in utero experience (i.e. the predictive adaptive response), they have an increased risk of obesity in adulthood. A distinctive feature of the fetal programming theory is its prediction that effects may remain latent until adulthood and appear even if health at birth or during childhood is without pathological findings (Godfrey & Barker, 2000; Metcalfe & Monaghan, 2001; Gluckman et al., 2005; Almond & Currie, 2011). While it is central to the fetal origins hypothesis that in utero experiences may affect long-term health beyond direct organ damage, adverse in utero conditions may also cause direct damage to the developing organs, especially those that are in critical growth phases. Both with respect to fetal programming and direct organ damage, the effects of in utero experiences vary by pregnancy phase of exposure, i.e. by the fetal developmental stage with which the exposure to an adverse condition coincides (Hanson et al., 1995; Gluckman & Hanson, 2004a; Gicquel et al., 2008).

Research on the fetal origins hypothesis has its roots in medicine and epidemiology. Sometimes referred to as 'Barker hypothesis' following its first formulation by Barker (1990), research on the fetal origins hypothesis has developed into a highly interdisciplinary research field with contributions from epidemiology, health economics, developmental economics, economic history and others (Almond & Currie, 2011). Various in utero conditions have by now been linked to later-life health and human capital outcomes. These encompass nutritional constraints, exposure to harmful maternal behaviors such as smoking, infectious diseases such as the Spanish Flu, pollution and economic shocks around birth (Almond, 2006; Chen & Zhou, 2007; Banerjee et al., 2010; Almond & Currie, 2011; Sanders, 2012; Currie et al., 2014; Simon, 2016; Rosales-Rueda & Triyana, 2019). The Dutch hunger winter, an unanticipated and severe famine in the Netherlands, counts among the most extensively studied nutritional constraints during pregnancy. Individuals who were exposed to the famine while in utero have been found to be at an increased risk of health impairments such as type 2 diabetes in adulthood (Roseboom et al., 2011). Moreover, negative effects on labor market performance among the exposed have been detected (Scholte et al., 2015). While prenatal exposure to a famine can be classified as exposure to an extreme prenatal shock, exposure to milder in utero shocks is more common. As an example for a milder prenatal shock, Miller (2017) shows that seasonal food scarcity during pregnancy is associated with impaired linear growth in childhood.

3.2.2. Ramadan during pregnancy

Another field of research on milder in utero shocks is Ramadan during pregnancy. During Ramadan, the 9th month of the Islamic calendar, healthy Muslims are required to fast during daylight hours. The beginning and end dates of Ramadan are determined by the lunar calendar and moon sightings. Ramadan shifts over the years in the Gregorian calendar, which is about 11 days longer than the lunar calendar, and lasts 29 or 30 days. Since food and drink consumption are unrestricted between sunset and sunrise, Ramadan is a form of intermittent fasting. Research has shown that among healthy Muslims, fasting during Ramadan has similar positive metabolic effects as other forms of intermittent fasting (Abdeen & Elinav, 2021; Su et al., 2021). While the elderly, children, travelers, breastfeeding women and other vulnerable groups are exempt from adherence to the fast, the requirements for pregnant Muslim women depend on the interpretation of the Qur'an. While pregnant women are allowed to opt out of fasting according to most interpretations, they are generally expected to make up for the non-fasted days by fasting at a later point in time when they are no longer pregnant or breastfeeding, or to make an expiatory payment to feed the poor. A substantial fraction of pregnant Muslims report fasting during Ramadan, with considerable cross-country variation. Whereas 43% of pregnant Muslims reported fasting for at least one day in Germany (chapter 4 of this dissertation), 87% of pregnant Muslim women in Singapore and Pakistan (Joosoph et al., 2004; Mubeen et al., 2012) and 99% in Bangladesh reported to have fasted (Seiermann et al., 2021). The estimated fasting rate among pregnant Muslims in Indonesia is 68-82% (Majid, 2015; van Bilsen et al., 2016).

As a form of intermittent fasting with unrestricted nutrient intake during night hours, Ramadan during pregnancy is a comparatively mild in utero shock. Previous studies have identified various health and human capital outcomes associated with having experienced a Ramadan during pregnancy. Physical health outcomes include higher risks to develop symptoms indicative of type 2 diabetes, coronary heart disease and to experience respiratory diseases. Moreover, higher mortality risks among young children and a sex ratio skewed in favor of girls have been identified. Cognitive health and human capital outcomes include worse performances in the school and on the job market (chapter 2 of this dissertation; Almond & Mazumder, 2011; Van Ewijk, 2011; Van Ewijk et al., 2013; Almond et al., 2015; Schoeps et al., 2018; Majid et al., 2019). Recent studies have established that the effects are stronger among the offspring to more religious Muslim mothers who are more likely to fast during pregnancy (Kunto & Mandemakers, 2019; Majid et al., 2019). Most of the identified effects are strongest in older age groups (45 years of age and older) and when exposure occurred in early pregnancy, i.e. when an overlap between Ramadan and pregnancy occurred during conception or the first and second pregnancy trimesters. This is in line with fetal programming theory suggesting that effects may remain latent until later adulthood and epigenetic research underlining that early pregnancy is an important developmental period.

The materialization of the effects of Ramadan during pregnancy may also co-depend on postnatal circumstances. For example, the associations between Ramadan during pregnancy and the risk of experiencing respiratory symptoms in adulthood have been found to be stronger among smokers (chapter 2 of this dissertation). Even though such interactions between prenatal and postnatal circumstances have been documented in biology and epigenetics, they have rarely been empirically investigated in humans (Costa & Eaton, 2006). At the same time, interactions between genetic predispositions and prenatal and postnatal influences are also expected to occur in humans (Hunter, 2005). The basic idea is that the emergence of a specific phenotype depends on gene-environment-interactions, whereas the interaction with the environment occurs both prenatally and postnatally (Lassi & Teperino, 2020). The consideration of the postnatal environment, in addition to prenatal shocks, allows to identify additional, potentially modifiable risk factors, and respective policy options. Consequently, while associations between prenatal shocks and later-life health and human capital outcomes have by now been documented with respect to many prenatal conditions and in various populations, it remains largely unknown to which extent the materialization of the effects varies by postnatal living conditions and behavioral choices. For example, Ramadan during pregnancy is hypothesized to be associated with a weaker immune system, which might in turn weaken an individual's capacity to defend later-life adverse influences (Schoeps et al., 2018). As a result, the long-term effects of Ramadan during pregnancy might be more likely to materialize among those exposed individuals who are additionally exposed to postnatal risk factors, such as smoking (chapter 2 of this dissertation).

The effects of Ramadan during pregnancy are largely attributed to the maternal abstinence from food and drink during daylight hours. Pregnant women have higher energy demands, since embryo/fetus and placenta need to be provided for in addition to the normal body functions. In the second half of pregnancy, a fasting pregnant woman's metabolism quickly shows signs that are otherwise detected in women exposed to famines, for instance with regard to blood levels of metabolic fuels and hormones. This phenomenon, known as 'accelerated starvation', has already been detected after the skipping of single meals during pregnancy and also among women adhering to the Ramadan fast (Metzger et al., 1982; Prentice et al., 1983; Malhotra et al., 1989; Arab, 2004). During early gestation, when cells are most prone to epigenetic changes, a fetus is highly sensitive to maternal nutrition. Prenatal exposure to Ramadan in early pregnancy may change the maternal intake of macronutrients or lower the amount of calories consumed during Ramadan, which could explain part of the effects (Larijani et al., 2003; Arab, 2004; Savitri et al., 2018). Besides intermittent fasting, Ramadan during pregnancy is associated with dietary and lifestyle changes, since traditional foods are consumed during Ramadan and food preparation and intake are shifted to nighttime hours, to which sleep rhythms are adapted[10].

3.2.3. Linear growth and shocks early in life

This paper focuses on if and how Ramadan during pregnancy is associated with linear growth. Low childhood height-for-age is a predictor of future cognitive, physical and mental health impairments in both childhood and adulthood (Walker et al., 2007; Galler et al., 2010; Black et al., 2013), as further outlined in the first part of this section. Subsequently, I summarize the existing research on predictors of linear growth and which role the prenatal environment may play in linear growth, including a summary of the evidence on the associations between Ramadan during pregnancy and linear growth.

3.2.3.1. Linear growth, health, and human capital

Since linear growth is a dynamic process before final height is reached around the age of 19, the height of children and adolescents is always regarded in relation to their age, i.e. the height-for-age. Standardized measures of height in children and adolescents are height-for-age z-scores (standard deviation scores), describing the distance from the WHO international reference population's mean. The international reference population is a population of children whose growth data were combined by the National Center for Health Statistics (NCHS). It consists of an international reference population of children living in conditions that are favorable to growth, based on whose growth trajectories the WHO provides Child Growth Standards. The height-for-age z-scores take sex and age into account. While a z-score of 0 describes accordance with the median, a z-score <0 stands for a height-for-age that is below average. If a child's z-score falls below -2, s/he is classified as stunted, indicating that the child is too short for its age.

[10] An extensive discussion of the role of Ramadan-related dietary and lifestyle adjustments beyond the binary fasting decision is provided in Chapter 5 of this dissertation.

Child linear growth patterns are primarily monitored to detect long-term nutritional deprivation and malnutrition (Waterlow, 1973; Prendergast & Humphrey, 2014). Particularly in countries of the Global South, the risk for childhood mortality is increased among children with low height-for-age z-scores (Caulfield et al., 2004; Black et al., 2008; Olofin et al., 2013; Prendergast & Humphrey, 2014; Briend et al., 2015). Policies aiming at improving child linear growth often also address outcomes such as disease susceptibility and premature death (Rice et al., 2000; Caulfield et al., 2004). On the global level, the prevention of undernutrition and hunger is one of the 2030 Sustainable Development Goals. In this context, the prevalence of low height-for-age as well as the prevalence of diarrhea in children under five years of age are outcome indicators in the Global Nutrition Monitoring Framework (World Health Organization & UNICEF, 2017).

A low height-for-age in childhood is associated with various long-term adverse health and labor market outcomes. A short stature in childhood is associated with short stature in adulthood (Cooper et al., 1997; Coly et al., 2006; Stein et al., 2010; Dewey & Begum, 2011). On average, people with a lower final height live shorter than their taller peers and have higher risks to experience cardiovascular as well as other chronic diseases (Jousilahti et al., 2000; de Onis & Branca, 2016; De Lucia Rolfe et al., 2018; Henriques et al., 2018). Associations between height and cognitive performance have been found among younger and older age groups (Abbott et al., 1998; Case & Paxson, 2008a). Case & Paxson (2008b) find that taller children score higher on test scores, while other research found that low height-for-age children perform worse at school (Mendez & Adair, 1999; Berkman et al., 2002; Woldehanna et al., 2017). Similarly, earnings in adulthood have been found to increase with height and to be adversely associated with low childhood height-for-age (Persico et al., 2004; Hoddinott et al., 2013).

3.2.3.2. Dynamics of linear growth

Aside from genetic predispositions, linear growth is shaped by the periconceptional and prenatal environment as well as cumulative postnatal environmental conditions. This stands in contrast to other anthropometric measurements, such as the body mass index, which rather reflect immediate or acute conditions (Perkins et al., 2016). As an adaptive process, linear growth responds to changing environmental conditions, and then based on processes of gene-environment interactions leads to the emergence of a specific phenotype based on the genotype (Silventoinen, 2003; Meaney, 2010; Perkins et al., 2016; Lampl & Schoen, 2017). While earlier studies proposed around 80% of height attainment to be attributable to genetic factors (McEvoy & Visscher, 2009), more recent studies, based on increased knowledge on the polygenic process of genetic height inheritance, suggest that this share might be closer to 60% (Perkins et al., 2016). Both earlier and later studies suggest that the share of genetic inheritance is smaller in lower income settings, since the role of genetics has been found to decrease when environmental stress increases (Silventoinen, 2003; Perkins et al., 2016).

The environmental factors affecting growth are diverse and include unfavorable nutritional environments, air pollution and poor sanitary conditions (Prentice et al., 2013; Prendergast & Humphrey, 2014). Nutrition is regarded as the most relevant non-genetic driver of linear growth (Portrait et al., 2017). Undernutrition can lead to cellular metabolic stress, compromising linear growth in order to maintain basic metabolic functions. Inadequate nutrition is in itself a main risk factor for low height-for-age z-scores in children, especially when simultaneously occurring with repeated infections (Ricci & Becker, 1993; Briend et al., 2015). Infections impede linear growth via a decreased appetite, weakened immune systems and defective, incomplete or inadequate absorption of nutrients. The body's response to repeated infections requires increased metabolic activity, such as in the form of fever, so that less metabolic activity is available to absorb nutrients and grow (Silventoinen, 2003; Dewey & Mayers, 2011; Perkins et al., 2016; Torlesse et al., 2016). Medical studies have shown that proinflammatory cytokines – i.e. signaling molecules which regulate the immune response to infections – are directly associated with the systemic regulation of bone remodeling and growth via hormones (Stephensen, 1999; Sederquist et al., 2014).

Further environmental risk factors for impaired linear growth are poor water and sanitation quality. When sanitary standards are low, repeated episodes of infections are more likely to occur (Dillingham & Guerrant, 2004; Mulmi et al., 2016). Exposure to environmental pathogens can have adverse and lasting effects on the development of the immune system (Goenka & Kollmann, 2015), which in turn favors recurrent illnesses and infections due to inefficient immune function (Bourke et al., 2016; Bourke et al., 2019). A vicious circle emerges in that infections impede nutritional intake and an unfavorable nutritional intake favors repeated infections. While most empirical studies assessing the association between access to improved sanitation and linear growth outcomes focus on under 5 year-olds (Danaei et al., 2016; Null et al., 2018; Bekele et al., 2020), Dearden et al. (2017) find that access to improved sanitation decreases the risk of stunting also in middle childhood (Danaei et al., 2016).

3.2.4. Early life environment and linear growth

Several studies have shown associations between prenatal shocks and impaired linear growth (Kusin et al., 1992; Schmidt et al., 2002; Miller, 2017; Randell et al., 2020). Considering that the development of the human skeleton starts in the earliest pregnancy stages, i.e. the embryonic period, this is not surprising. Cartilage, which is subsequently transformed into bones via the process of ossification, is formed as early as by 5 weeks of gestation (Sayer & Cooper, 2005). The cells are subsequently differentiated, and mineralization of the skeleton is prepared. Ossification[11] starts around 7 weeks of gestation, while the mineralization of the skeleton mainly takes place during the 3rd pregnancy trimester. Mineralization of the skeleton requires calcium, phosphorus and magnesium as major minerals, which are supplied via the placenta and whose supply stems from maternal circulation (Carter & Beaupré, 2000a; Cooper et al., 2008; Ryan & Kovacs, 2020). However, it remains unclear how much of the growth trajectories and height attainment can be traced back to the prenatal environment. Some studies report that around 20% - 50% of low height-for-age may be attributable to in utero shocks (Schmidt et al., 2002; Dewey & Huffman, 2009; Christian et al., 2013). These estimates are informed by studies of newborns and young children (0 - 36 months of age). Other research posits that these might underestimate the true effects, since growth patterns after birth may also be influenced by fetal programming (Martorell & Zongrone, 2012; de Onis & Branca, 2016). Overall, this suggests that the in utero environment is important for linear growth.

In addition to adverse in utero experiences, some studies point towards the health of the mother prior to the time of conception to potentially affect offspring health along the life course, in particular maternal nutritional status before conception (Fleming et al., 2018; Stephenson et al., 2018). Potential mechanisms behind this include that maternal nutritional status before conception determines how much energy is available to adequately provide for mother and fetus ('maternal-fetal competition for nutrients') and that epigenetic adaptation of the offspring's genes also depends on nutritional signals at fertilization (King, 2016). Empirical evidence on maternal preconception health and offspring health outcomes has remained scarce. Young et al. (2018) use data from a Vietnamese randomized controlled trial of micronutrient supplementation before conception and show that poor maternal preconception nutritional status is associated with a higher risk for stunting among infants.

3.2.5. Linear growth and reproductive trajectories

The fetal origins literature suggests that linear growth trajectories may also be affected indirectly via effects of adverse in utero conditions on other health outcomes, which are linked to linear growth. Gluckman et al. (2007) posit that the core mechanism behind fetal programming are evolutionary adaptive responses to increase a species' chances for survival. Part of such an evolutionary perspective on linear growth is the tradeoff between fertility, growth and body

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[11] Ossification is a highly complex process and a detailed description goes beyond the scope of this paper. Not all bone tissues are preceded by cartilage (for instance, the skull bones develop from intramembranous ossification, based on cells from the neural cest). The interested reader is advised to consult Carter & Beaupré (2000b) for an in-depth description.

maintenance, which has been formalized as the life history theory (Stearns, 1992; Stearns, 2000; Roff & Fairbairn, 2007; Stulp & Barrett, 2016). According to this theory, organisms have to divide a limited available amount of energy between reproduction, growth and body maintenance, thus trading off investments in one of these traits by the investment in others. This leads to the hypothesis that if in utero adverse conditions predict a suboptimal postnatal environment, the offspring's metabolism might be programmed to devote less energy to linear growth in order to secure other body functions that are vital to reproduction and thus species survival. Compatible with life history theory, earlier research revealed that a younger age at menarche and at first childbirth is associated with a shorter stature in adulthood among women (Georgiadis et al., 1997; Okasha et al., 2001; Sear et al., 2004; Onland-Moret et al., 2005; Helle, 2008). Earlier reproduction may have short-term benefits (i.e. increased chances for species survival), while at the same time leading to adverse health and human capital effects in later life. An early age at menarche has been found to be associated with increased risks for diabetes type 2 and cardiovascular diseases (Lakshman et al., 2008; Day et al., 2015).

Reproductive capacity is one of the main body functions indispensable to species survival. During puberty, a growth spurt ('adolescence growth spurt') and reproductive maturation occur in conjunction with further developments, including an adapted body composition and hormonal transitions (Rogol et al., 2002). With respect to the potential tradeoff between linear growth and fertility, the period of adolescence therefore receives special scientific interest. Medical research highlights the complexity of the developments during puberty with respect to both sexual maturation and linear growth. At the core of both are hormonal changes, genetic predispositions and the nutritional environment (Rogol et al., 2002; Saggese et al., 2002). In females, reproductive maturation and linear growth are interconnected via estrogen, a hormone that both drives the onset of menarche and decelerates linear growth (Stulp & Barrett, 2016). From an evolutionary perspective, the growth-reproduction tradeoff should occur when linear growth has resulted in a sufficient skeletal size of pelvic width for giving birth (Ellison, 2009; Stulp & Barrett, 2016). A diversion of energy from linear growth to reproductive capacity before this point in time would not ensure species survival.

Even though the potential for fetal programming in the development of reproductive capacity has been acknowledged for a long time (Davies & Norman, 2002), empirical evidence on the association between adverse in utero conditions and human reproductive trajectories has remained scarce. Research on the Dutch famine shows that prenatal nutritional scarcity is associated with enhanced reproductive capacity among women (Painter, Westendorp, et al., 2008). The authors found that women with prenatal exposure to the Dutch famine start reproducing at younger ages, tend to have more children and give multiple birth more often. In another study on 22 small-scale subsistence-based populations in the tropics, Walker et al. (2006) show that a lower life expectancy at age 15 is associated with a younger age at first childbirth and menarche. While life expectancy at age 15 is not an in utero shock in the traditional sense, it is reasonable to assume that it may already have been reflected in prenatal environmental conditions since life expectancy changes slowly and it is a predictor of how likely it is that an individual reaches reproductive age (Stulp & Barrett, 2016).

3.2.6. Empirical evidence on the early life environment and linear growth

Due to ethical concerns, a large share of the medical research investigating the associations between the prenatal environment and linear growth relies on animal models. For example, experimental animal studies showed an association between maternal nutrition during gestation and offspring bone metabolism (Zheng et al., 2018). Human studies are possible without ethical concerns exploiting quasi-random prenatal shocks as natural experiments. In natural experiments, some persons are quasi-randomly affected by an event, while similar others are not. This leads to estimates that get very close to causality ('near-causality'). While trials on the health effects of early life events are unethical or take decades, the natural experiment approach has proven to be particularly useful in the analysis of long-run effects of adverse prenatal conditions.

Based on natural experiments, a growing strand of literature has provided evidence showing that early life experiences are associated with human linear growth. Most widely studied is the exposure to famines. Based on a difference-in-differences approach, Chen & Zhou (2007) find that people with early life exposure to the Chinese famine 1959-1961 in rural areas are on average 3 cm shorter than they would have been without exposure to the famine. Similarly studying the effects of early life exposure to the Chinese famine, Gørgens et al. (2012) find lower final heights among rural residents who were exposed to the famine before age 5. The authors control for the higher probability of taller individuals to survive and estimate that early life exposure to the famine reduced average height by 1 to 2 cm. The effects are consistently strongest for those individuals who experienced the famine as infants. However, since the available data on the Chinese famine do not contain exact date of birth, both studies cannot differentiate between an overlap with the famine during specific developmental phases in utero or during early infancy. Data on the population exposed to the Dutch famine of 1944/1945 allows for closer analysis of exposure during pregnancy. Stein et al. (2007) compared individuals with in utero exposure to the Dutch famine to their unexposed siblings of the same sex and did not find an association between in utero exposure to the famine and adult final height, independent of the pregnancy trimester of exposure. Investigating exposure to the same famine, but using a different dataset, Portrait et al. (2017) find that women exposed in early life, in particular before their second birthday, were around 4 cm shorter in adulthood.

Besides famines, weather shocks and subsequent food scarcity due to reduced family incomes have been studied to investigate the association between in utero shocks and growth. Maccini & Yang (2009) show that an increased amount of rainfall around the date of birth is associated with increased final height among women (0.57 cm greater height in response to 20 percent higher rainfall). The authors suspect that early life rainfall predicts the quality of nutrition in early life, which is then reflected in height. Banerjee et al. (2010) find that children born at times of severe insect attacks on vineyards in the 19th century, which were associated with severe income losses, remain on average 0.6 to 0.9 cm shorter in adulthood. Miller (2017) investigates the effects of prenatal exposure to seasonal food scarcity on children's height-for-age in Ethiopia. He finds that exposure is associated with lower height-for-age z-scores among 8 (-0.45 cm) and 12 (-0.57cm) year-old children, but not among 1 and 5 year-old children.

Another strand of research investigates the association between Ramadan during pregnancy and linear growth. Van Ewijk et al. (2013) use data from the Indonesian Family Life Survey and show that adult Muslims with an overlap of Ramadan and pregnancy during the first pregnancy trimester attain a lower final height than Muslims whose own time in utero did not overlap with a Ramadan. Kunto & Mandemakers (2019) study the effects on children's height-for-age throughout childhood. They only find height-for-age effects among Muslim adolescents, and no effects among younger children. Effects are stronger when in utero exposure to Ramadan occurred in early and mid-pregnancy and concentrated among offspring to more religious mothers. Karimi et al. (2020) study the effects of Ramadan during pregnancy on height-for-age z-scores among children in Iran. They find effects to be strongest among male children who were 12 years of age or older and when exposure occurred during the second pregnancy trimester.

Some studies specifically investigate the associations between Ramadan during pregnancy and linear growth among under 5 year-old children. Karimi & Basu (2018) assess whether Ramadan during pregnancy affects height-for-age z-scores in this age group using DHS data from 37 countries. They detect effects among 4 year-old boys, in particular when the overlap between Ramadan and a pregnancy occurred in early and mid-pregnancy. No effects were found among female Muslim children. The effects were strongest when the degree of religiosity in a specific country was reported as high. Using UN-supported Multiple Indicator Cluster Survey (MICS) data from Pakistan, Chaudhry & Mir (2021) demonstrate that Ramadan during pregnancy is associated with an increased risk of being stunted among under 5 year-olds when the overlap between Ramadan and a pregnancy coincides with the first or second pregnancy trimester. In contrast to the other studies on children, the authors do not find a concentration of the effects among males. Furthermore, studies scrutinizing length at birth did not find associations between Ramadan during pregnancy and height-for-age at birth or the risk of being small for gestational age (chapter 5 of this dissertation; Savitri et al., 2020)[12].

3.2.7. Contribution and research questions

Since previous research on Ramadan during pregnancy has led to contradicting results, I thoroughly investigate the relationship between Ramadan during pregnancy and linear growth in my dataset. First, I investigate if Ramadan during pregnancy is associated with a lower final adult height and at which point it affects linear growth patterns of children and adolescents. Unlike previous research, this paper then goes on to explore why linear growth effects emerge and which prenatal and postnatal risk factors as well as biological mechanisms might play a role. I set a special focus on the periconceptional period as well as potential interactions between prenatal and postnatal risk factors.

The aforementioned aspects will be integrated in the investigation of the following research questions:

1. **How are linear growth patterns affected by Ramadan during pregnancy?**
   Before analyzing the dynamics behind any potential effects, I need to evaluate the associations between Ramadan during pregnancy and linear growth patterns in my sample. To this end, I study the associations between Ramadan during pregnancy and height in adulthood (i.e. final attained height) as well as growth patterns during childhood (i.e. if and at which age effects on height-for-age z-scores can be observed). The hypothesis is that in utero exposure to Ramadan leads to persistent low-height-for-age effects that emerge in childhood and persist into adulthood.

2. **Does Ramadan during pregnancy increase an individual's susceptibility to infectious diseases?**
   Infectious diseases such as diarrhea and respiratory infections are important risk factors for impaired linear growth. I investigate the associations between Ramadan during pregnancy and the occurrence of episodes of infectious diseases. The hypothesis is that Ramadan disrupts the formation of immune mechanisms and increases the prevalence of infectious

[12] Length at birth is not reported in IFLS, so that an assessment of associations between Ramadan during pregnancy and newborn length was not feasible in this study.

diseases among the exposed, which may in turn be the driver of height-for-age effects. While recent research hypothesized that that the effects of Ramadan during pregnancy on other health outcomes may be driven by a weakening of the immune system (Schoeps et al., 2018), this is the first paper to explicitly study the effects of Ramadan during pregnancy on infectious disease occurrence among children.

Sanitary conditions are a further predictor of low height-for-age among children, since the risk of contracting infections is larger when sanitary conditions are low. Poor sanitary conditions are widespread in many countries, including Indonesia (UNICEF, 2016). Ramadan during pregnancy might hamper the development of metabolic processes that help to cope with suboptimal sanitary conditions, implying that children living with unimproved sanitation are at an increased risk of adverse height-for-age effects in response to Ramadan during pregnancy. The integration of postnatal risk factors is to date scare in the fetal programming literature. By interacting Ramadan during pregnancy with postnatal sanitary conditions, I investigate if the height-for-age effects of Ramadan during pregnancy vary by the sanitary conditions under which children grow up.

3. **Is linear growth compromised to secure other body functions in response to Ramadan during pregnancy?**

   In face of scarce available energy, life history theory predicts that growth, fertility and body maintenance are traded off against each other. I hypothesize that linear growth is traded off against the securing of reproduction in response to Ramadan during pregnancy. To this end, I investigate if women who were prenatally exposed to a Ramadan maturate earlier, to – from an evolutionary perspective – secure reproduction and species conservation. In order to examine this potential pathway to impaired linear growth, the effects of Ramadan during pregnancy on age at menarche and age at first childbirth are assessed.

3.3. Methods

3.3.1. Data

This paper uses data from the Indonesian Family Life Survey (IFLS) – a longitudinal study administered by the RAND corporation. With 225 million Muslims, Indonesia has the largest Muslim population worldwide and at the same time ranges among the countries with the highest prevalence of low height-for-age among children: approximately 37% of all Indonesian children are stunted (Torlesse et al., 2016). IFLS was fielded in 1993/94, 1997/98, 2000, 2007/08 and 2014/15 (also referred to as waves 1, 2, 3, 4 and 5). I pool information from the household rosters of all waves, which allows me to link children to their biological mothers.

The calculated overlap between a person's prenatal period and a Ramadan (based on the exact date of birth and historic dates of Ramadan) is necessary to determine exposure. Therefore, only observations with exact date of birth are included. I also exclude observations with exact birth dates where there is heaping of birth dates in the dataset such as January 1st or August 17th, the Indonesian Day of Independence as well as implausible dates of birth such as September 31st. This data clearing is indispensable since in many countries of the Global South, exact birth dates are unknown for a variety of reasons, including low numeracy or literacy as well as different perceptions of birthday celebrations than in the Global North (Larsen et al., 2019).

Different datasets are built to investigate the previously introduced research questions. These include an adult sample to study the effects of Ramadan during pregnancy on final height and a children sample to examine height-for-age as well as infectious disease susceptibility effects among children. Moreover, a sample of ever-married women is compiled to investigate if Ramadan during pregnancy is associated with reproductive capacity, since only ever-married women were asked to provide information on menarche and child birth history in IFLS. As less than 3% of the Indonesian female population over 30 years is not married (UNFPA, 2015), the reduction of the sample to ever-married women does not induce substantial selection bias. While the children sample is described in more detail in the remainder of this section, descriptive statistics for all samples are provided in Appendix Table 3-1, Appendix Table 3-2 and Appendix Table 3-3.

The children sample includes all observations of 2 to 18-year-old offspring to mothers interviewed by the IFLS team at least once. Since IFLS follows a panel design, many children were observed in multiple waves. Since recent research has shown that the health effects of Ramadan during pregnancy are concentrated among children to more religious mothers who are more likely to adhere to the practice of Ramadan, the children sample is restricted to offspring to more religious Muslim women for the main analyses. A woman is classified to be more religious if she reports praying for at least five times per day. Adherence to the five daily prayers is one of the five pillars of Islam and thus serves as a proxy for a woman's practice of religion. This information is only available in IFLS4 and IFLS5. Assuming that the degree of religiosity remains relatively stable, the information from these waves is assigned to IFLS1, IFLS2 and IFLS3 observations. The level of religiosity is reported for 74% of the observations on offspring to Muslim mothers, with 80% of those having a more religious mother. The degree of religiosity as well as the exact religion of non-Muslim mothers is irrelevant for this research, as non-Muslims do not adhere to the Ramadan fast independent of their faith or level of religiosity. Robustness checks will be performed on children to non-Muslims and less religious Muslims (details in 3.3.7).

Observations without height-for-age measurements are excluded, as well as observations with implausible values on anthropometric measurements based on WHO guidelines (see section 3.3.3 for details) and individuals whose reported religiosity does not match that of their mother. I also exclude observations of children who were younger than 24 months at the time of measurement, since growth trajectories of younger children into adulthood are usually evaluated from the 2nd birthday onwards (Desmond & Casale, 2017) and measurement errors are more likely among young infants (Johnson & Engstrom, 2002; Victora et al., 2010). The total number of child-wave observations is 43,815. This includes 38,882 observations of Muslim children and 4,933 observations of non-Muslim children. The sample for my main analyses on Muslim offspring to more religious Muslim mothers consists of 31,315 observations of children born to 7,629 mothers.

3.3.2. Categories of overlap between Ramadan and pregnancy

The overlap between a Ramadan and a pregnancy is calculated based on date of birth and historic dates of Ramadan. Following Van Ewijk (2011), I calculate 266 days backwards from the date of birth (average length of human pregnancies from the date of conception) and compare this period with the historical dates of Ramadan. A person falls within the main exposure category if the 266 days of calculated gestation overlap with a Ramadan. Those calculated to be conceived less than 21 days after the end of a Ramadan are put in a separate exposure category 'conceived shortly after Ramadan'. The mothers of these individuals experienced a Ramadan shortly before conception. Setting their offspring apart in a separate exposure category aims to assess if periconceptional exposure to Ramadan during pregnancy is associated with offspring linear growth, as recent insights from epigenetics suggest.

In order to evaluate if effects differ by the pregnancy phase of overlap between Ramadan and pregnancy, I subdivide the main exposure category into 5 subgroups (conceived during Ramadan, Ramadan overlap started in pregnancy trimester 1, Ramadan overlap started in pregnancy trimester 2, Ramadan overlap started in pregnancy trimester 3, born during Ramadan). The control group consists of Muslims/Muslim children born to more religious mothers whose time in utero did not overlap with a Ramadan.

3.3.3. Outcome measures

IFLS contains height information on all survey participants, i.e. of all members of households who participated in IFLS and were present during an interview[13]. Trained nurses collected and recorded

[13] Note that the IFLS1 sampling includes “two randomly selected children of the head and the spouse aged 0 to 14”. These children were asked about, inter alia, health and education and anthropometric measurements were only taken of the children that also had been interviewed in detail. Moreover, other

anthropometric data. Height is defined as the distance between the bottom of the foot and the top of the head. In the analyses on adults, the outcome measure is height in centimeters. For the analyses on children, I convert the height measurements from centimeters to WHO height-for-age z-scores[14]. The WHO recommends that observations <-5.0 z-scores and >+3 z-scores from the international reference population's mean should be excluded. These values are implausible and measurement errors are likely. For samples with an observed mean height-for-age z-score below -1.5, the WHO advises a 'flexible exclusion range', which involves the exclusion of values that deviate more than 4 z-score units from the observed mean z-score, with a fixed maximum height-for-age z-score of +3.00 (World Health Organization, 1995). In my sample of Muslim children born to more religious mothers, the observed mean z-score is -1.61. Following the flexible exclusion range approach, I exclude observations with height-for-age z-scores <-5.61 and >3.00 (World Health Organization, 1995). Following WHO conventions, children with a height-for-age z-score <-2 are classified as being stunted (binary outcome measure). Stunting is widespread in Indonesia, with about 37% of all Indonesian children being stunted (Beal et al., 2018).

Susceptibility to infectious diseases is measured by binary variables describing whether an individual experienced an episode of diarrhea (at least 3 times per day), respiratory infections (cough, difficulty with breathing) or fever in the last four weeks before an interview. These outcome measures are all self-reported by the child or the parents.

Further outcome variables are age at menarche and age at first childbirth, which are used to proxy for reproductive maturation. In the sample of ever-married women used for this analysis, each woman is included once (information is used from the first wave in which a woman provided information on the respective outcome variables). With data on pubertal hormones being unavailable in IFLS, age at menarche and age at first childbirth allow a preliminary assessment of the association between Ramadan during pregnancy and maturation. Menarche is a proxy for the biological onset of reproductive capacity. Assessing the effects on age at first childbirth implies going beyond the purely biological aspects of sexual maturation. Age at menarche (in years) and age at first childbirth (in days) are continuous outcome measures. Moreover, early menarche as binary outcome measure is defined as occurring before age 12 (Romans et al., 2003; Yi et al., 2017).

children younger than 6 years who were present during the interview were to be measured. From IFLS2 onwards, all household members were weighed and measured.

[14] I use the STATA macro (last updated in 2019) provided by WHO and UNICEF for the conversion (https://www.who.int/childgrowth/software/en/). The z-scores are based on the following calculation: z-score = (observed value - median value of the reference population) / standard deviation value of reference population.

Observations with a reported age at menarche >20 are excluded (Adams Hillard, 2014). Both outcome measures are self-reported.

3.3.4. Control variables

While I will lay out the specific sets of control variables used in each analysis in the formal model specification (section 3.3.6), I here provide the rationale for why the controls are included. In all regressions, I control for month of birth. Season of birth is a predictor of later-life health, educational attainment and labor market performance as well as mortality (Buckles & Hungerman, 2013; Didikoglu et al., 2020). Since the timing of Ramadan is determined by the Islamic calendar, which is shorter than the Gregorian calendar, Ramadan shifts in the Gregorian calendar each year by 10 to 12 days. This means that Ramadan falls in every month of the Gregorian calendar in a 33-year cycle. Including month of birth as a control variable allows to separate the effects of Ramadan during pregnancy from season of birth effects. In the children sample, birth years range from 1974 to 2014, with most births (90%) after 1982. Ramadan fell into all seasons of the Gregorian calendar within this time period. Note that since Indonesia lies on the equator, the times of sunrise and sunset are quite stable, so that the duration of fasting during Ramadan amounts to approximately 13 hours per day, independent of the timing of Ramadan in the Gregorian calendar. This implies that I do not need to control for the number of daylight hours (i.e. fasting hours) during a specific Ramadan.

Offspring sex is included in the controls since the effects of in utero shocks may materialize differently in boys and girls. Most previous research found male fetuses to be more vulnerable to adverse prenatal conditions (Brown & Susser, 1997; Kraemer, 2000; Di Renzo et al., 2007; Tobi et al., 2009; Aibar et al., 2012). With respect to Ramadan during pregnancy, earlier research has shown that the sex ratio of those with a prenatal overlap with Ramadan is skewed in favor of girls (Almond & Mazumder, 2011; Van Ewijk, 2011). I also control for age in days at the time of interview/height measurement and age squared in order to filter out variation in the outcome variables that is induced by age. In several analyses, age in days is replaced by a categorical variable consisting of age groups (2-4 year-olds, 5-9 year-olds, 10-14 year-olds, 15-19 year-olds), to capture how the effects vary by childhood phase. The division into age groups follows classifications of childhood development into early childhood, middle childhood, early adolescence and late adolescence (Eccles, 1999; UNICEF, 2006). In the robustness checks, age in days is additionally controlled for in the analyses which use age groups.

Birth year captures general time trends in the outcome variables. For instance, average height tended to increase over time in Indonesia, while the mean age at menarche decreased (Sohn, 2016).

I further include birth order dummies in the analyses on height-for-age z-scores, since previous research has identified a birth order gradient with respect to linear growth, with later-born children being at a higher risk of being small for their age (Myrskyla et al., 2013; Jayachandran & Pande, 2017; Sanchez-Escobedo et al., 2020). This effect is largely attributed to within-family allocation of resources and the division of scarce resources between siblings (Black et al., 2016; Dhingra & Pingali, 2021). An additional control variable is urban residency, since living in rural areas is associated with higher risks for impaired linear growth in Indonesia (Beal et al., 2018). This control variable is not included in all analyses using mother fixed effects, since within-siblings variation of urban residency status in childhood is uncommon and thus absorbed by the mother fixed effects.

In the analyses on infectious disease occurrence, season of interview is also included as a control. Indonesia is characterized by two main seasons, the dry season and the rainy (monsoon) season and earlier research has detected seasonal variations of the occurrence of diseases, including Indonesia (Agtini et al., 2005; Kelly-Hope & Thomson, 2008). Furthermore, unimproved sanitation is associated with an increased risk of experiencing infectious diseases such as diarrhea (Fuller et al., 2014). For the analysis on the potential mediating role of sanitary standards, I construct a binary sanitary standards indicator. The definition of unimproved sanitation applies if household members defecate in the open or use a shared toilet facility. A household is classified to have improved sanitary facilities if it owns a toilet facility. The classification into unimproved and improved sanitary facilities follows WHO guidelines, which only classify non-shared toilets that guarantee that human secreta are separated from contact to other households as improved facilities (UNICEF & World Health Organization, 2008; World Health Organization & UNICEF, 2010).

3.3.5. Empirical approach

I compare health and reproductive capacity outcomes of Muslims who experienced a Ramadan during their own time in utero (exposure group) to the outcomes of Muslims without prenatal overlap with a Ramadan (reference category). In all analyses, Ramadan during pregnancy is exploited as a natural experiment. Ramadan during pregnancy can be regarded as a quasi-random in utero occurrence, since Muslims do not plan pregnancies as to avoid or promote an overlap with a Ramadan (Almond & Mazumder, 2011; Van Ewijk, 2011; Majid, 2015; Schoeps et al., 2018; Karimi et al., 2020). Observations are classified into the exposure and control groups solely based on whether a Ramadan occurred during their own time in utero (see 3.2.). The comparison of exposure and reference groups then allows insights into the causal effects of Ramadan during pregnancy on later-life effects. Since information on maternal behavior during Ramadan is not available, all offspring of Muslim women whose pregnancy overlapped with a Ramadan are classified as exposed. Since it is highly unlikely that all mothers of those with a calculated overlap between Ramadan and pregnancy adhered to the Ramadan fast, all estimates will be biased towards zero and thus underestimate the true effect, provided that fasting is the main effect channel.

The advantage of the natural experiment approach is that many sources of confounding that are present in analyses comparing the offspring of fasting Muslims to the offspring of non-fasting Muslims are avoided. Any confounder that could bias the results would have to be correlated with both my outcome measure (i.e. height/height-for-age, infectious disease occurrence, age at menarche, age at first childbirth) and the timing of pregnancy with respect to Ramadan. In other words, even though I am unable to control for all factors that might influence the outcome variables, my results are not biased, since these factors do not affect whether a person's own time in utero overlapped with a Ramadan. At the same time, I do not adjust for covariates such as birthweight and other health measures: these may themselves be associated with Ramadan during pregnancy and the inclusion of them as control variables could bias the results.

When attempting to identify the associations between Ramadan during pregnancy and later-life linear growth outcomes, a main challenge is that linear growth has a substantial genetic component and many postnatal determinants of linear growth are linked to the household environment. The analyses on adult height consist of cluster-robust household fixed effects regressions, whereby household affiliation is defined based on the household in which an individual was located at her first appearance in IFLS. This follows the approach of Van Ewijk et al. (2013), and attempts to capture the impact of shared characteristics within households such as sanitary standards and nutritional composition. Since information on mothers is not available for most adult individuals in IFLS, mother fixed effects are not feasible.

By contrast, the children sample includes observations to children which are linked to their respective biological mothers. In the analyses on children's height-for-age z-scores, I am therefore able to use mother fixed effects regressions in order to filter out part of the genetic component of linear growth and other systematic differences within families such as the nutritional environment. Mother fixed effects ensure that a mothers' time-invariant characteristics and their influence on the growth of her children are controlled for. This is based on the assumption that the mother's time-invariant characteristics remain constant across her offspring. These time-invariant maternal characteristics include maternal genetics, household circumstances and in most cases also paternal genetics. The consequence of this methodological choice is that the effect of Ramadan exposure can only be identified if there are any within-mothers (i.e. between-siblings) variations in exposure status.

The effects on reproductive maturation are estimated using OLS for continuous outcomes and logistic regressions for binary outcome variables, based on a pooled sample of observations of ever-married women from all ILFS waves. In this analysis, neither mother nor family fixed effects were feasible due to a lack of sufficient data on the women's ancestors.

3.3.6. Analyses

This section formalizes the research questions, following the order in which they were introduced in section 3.2.7.

3.3.6.1. Research question 1: Effects on linear growth over the life course

Ramadan during pregnancy and final attained height

I compare the final height in centimeters (y) of individual adult Muslims aged 19 and older (i) whose own time in utero overlapped with a Ramadan ('exposure') to the final height of unexposed adult Muslims based on the following specification:

(1) $$y_{ih} = \alpha_h + \beta_k \sum_{k=2}^{3} exposure_{kih} + X'_{ih}\gamma + \varepsilon_{ih}$$

The α_h captures household fixed effects, which are used in the adult sample where mother fixed effects are not feasible (as explained in 3.3.5). Exposure is a set of dummies indicating the different exposure categories of prenatal overlap with Ramadan ($k = 1$: no in utero during Ramadan – reference category, $k = 2$: not in utero during Ramadan, $k = 3$: conceived shortly after a Ramadan). In an alternative specification, $k = 2$ is further subdivided into pregnancy phases of exposure as explained in section 3.3.2. I further adjust for a number of control factors (X'): age at the day of measurement (in days), age squared, sex, month of birth and year of birth. Standard errors are clustered at the household level h.

Ramadan during pregnancy and child height-for-age

The effects of Ramadan during pregnancy on height-for-age z-scores of children (2-18 years) are estimated using the following specification:

(2) $$y_{imj} = \alpha_m + \beta_k \sum_{k=2}^{3} exposure_{imj} + X'_{imj}\gamma + \varepsilon_{imj}$$

Where y is the height-for-age z-score of child i to mother m observed in survey wave j. The α_m are mother fixed effects. Exposure is a set of dummies as defined in (1). The control variables (X') include age at the time of the height measurement (measured in days), age squared, sex, year of birth, month of birth and birth order. Standard errors are clustered at the mother level m. In an alternative specification, logistic regressions are used to evaluate the associations between Ramadan during pregnancy and the risk of being stunted.

In order to assess at which age the effects set in, exposure is interacted with age groups, which is a categorical variable equal to 1 for 2-4 year olds, 2 for 5-9 year olds, 3 for 10-14 year olds and 4 for 15-19 year olds. This leads to the following specification:

$$(3) \qquad y_{imj} = \alpha_m + \theta_j \sum_{j=2}^{4} agegroup_{imj} + \beta_{ks}\left(\sum_{k=2}^{3} exposure_{kim} * \sum_{j=1}^{4} agegroup_{simj}\right) + X'_{imj}\gamma + \varepsilon_{imj}$$

The matrix of control variables contains sex, year of birth, month of birth dummies and birth order. It is not necessary to control for age in days as in the previous specifications, as the age effects are captured by the age categories[15]. In an additional specification, I use cluster-robust logistic mother fixed effects regressions to evaluate at which age effects on stunting can be observed. Standard errors are clustered at the mother level in both cases.

3.3.6.2. Research question 2: Infectious disease susceptibility & sanitary conditions

Similar to equations (2) and (3), I use mother fixed effects regressions to identify whether Ramadan during pregnancy is associated with infectious disease occurrence among children (2-18 years) within the last four weeks before the interview. Since the outcome variables are binary (i.e. an infectious disease occurred or not), I perform cluster-robust mother fixed effects logistic regressions:

$$(4) \qquad \log\left(\frac{P(y_{imj}=1)}{1-P(y_{imj}=1)}\right) = \alpha_m + \beta_k \sum_{k=2}^{3} exposure_{im} + X'_{imj}\gamma + \varepsilon_{imj}$$

$P(y_{im})$ describes the probability that a disease y was observed in child i to mother m. The α_m are mother fixed effects and exposure refers to the different categories of prenatal overlap with Ramadan as defined in (1). The matrix of control variables X' contains age, age squared, sex, season of interview (dry/ rainy season), year of birth and month of birth. The results are displayed in odds ratios. In a refined specification, exposure is interacted with age groups in order to evaluate if the effect of Ramadan during pregnancy on infectious disease susceptibility varies by age group, similar to (3). Standard errors are clustered at the mother level.

[15] In a robustness check, age in days is additionally included in the model (see 3.3.7 for details).

To explore the role of postnatal sanitary standards in the materialization of the effects of prenatal overlap with a Ramadan on height (linear growth), an interaction term between exposure and postnatal sanitary standards is included. I estimate the following model:

(5) $$y_{imj} = \beta_0 + \partial\ unimproved\ sanitation_{im}$$

$$+\beta_{k1}\left(\sum_{k=2}^{3} exposure_{im} *\ unimproved\ sanitation_{im}\right)$$

$$+\ \beta_{k\ 2}\left(\beta_k \sum_{k=1}^{3} exposure_{im} *\ improved\ sanitation_{im}\right)$$

$$+X'_{imj}\gamma + \varepsilon_{imj}$$

y_{imj} is the height-for-age z-score of child i to mother m observed in survey wave j. Since sanitary standards are mostly identical across children to the same mother, this is a pooled OLS model and does not include mother fixed effects. The dummy unimproved sanitation describes if a child had access to unimproved sanitary standards postnatally (at her first observation in IFLS). The matrix of control variables X' contains age (in days), age squared, sex, year of birth, month of birth, birth order and urban residency. Robust standard errors are clustered at the mother level. In an explorative analysis, I look at how the effects of the interaction between exposure status and postnatal sanitation status vary by age group by including a three-way-interaction between exposure, sanitary standards and the age groups (as defined in (2)).

3.3.6.3. Research question 3: Earlier maturation

In order to investigate the associations between Ramadan during pregnancy and early maturation, I estimate the following OLS regression on a pooled sample of ever-married women:

(6) $$y_i = \beta_0 + \ \beta_1\ exposure_i + X'_i\gamma\ + \varepsilon_i$$

The outcome variables y of an individual woman i are age at first childbirth (in days) and age at menarche (in years). The control variables X' contain year of birth, month of birth and urban residency. In an alternative specification, early menarche is defined as binary outcome variable and I run a logistic regression to assess if Ramadan during pregnancy increases the probability of experiencing early menarche before age 12.

3.3.7. Sensitivity and heterogeneity analyses

The stability of the results is checked by several sensitivity analyses, in which changes are undertaken to the specifications and functional forms of the models. First, I use different combinations of control variables to test whether the results depend on one unique combination of controls, respectively whether inference is dependent upon the inclusion of individual control variables. Second, year of birth is replaced by survey wave. Since year of birth and age at interview are predictors of survey wave, it was not possible to include age at interview, year of birth and survey wave as controls in the main models. While I decided to include year of birth in the model to control for general time trends in the outcome variables, it might equally be important to control for survey wave since both interview as well as measurement procedures may have changed over time. To get insights into the heterogeneity of my results, I also split the sample by (offspring) sex – except for the analyses on reproductive maturation, where my sample exclusively contains females. The reason for this is that earlier research has shown that male offspring is more vulnerable to adverse prenatal conditions.

Non-Muslims do not observe Ramadan and therefore form a well-suited group to test the robustness of my results. Finding effects of Ramadan during pregnancy on health outcomes among non-Muslims would imply that any potentially detected association between Ramadan during pregnancy and health outcomes in Muslims cannot be clearly attributed to Ramadan. Instead, other common shocks coinciding with Ramadan might play a role. All analyses related to child height-for-age and children's infectious disease outcomes are additionally conducted on the sample of offspring to less religious Muslim mothers. Less religious Muslims are less likely to adhere to the practice of Ramadan during pregnancy than more religious Muslims. Nevertheless, they may participate in the traditional celebrations of the breaking of the fast as well as adapt their sleeping and dietary patterns to Ramadan, even if they decide not to fast themselves. To the extent that the effects of Ramadan during pregnancy are due to the daytime fasting, weaker associations between Ramadan during pregnancy and the outcomes measures are thus expected among less religious Muslims.

Finally, the models using mother fixed effects are additionally estimated using simple pooled OLS/logistic regressions. This explorative analysis is undertaken to test whether the patterns of results remain stable, since the fixed effects models only use within-mothers variation and thus fewer observations for effect identification, leading to a lower statistical power. Yet, only the mother fixed effects approach allows to filter out the unobserved time-constant heterogeneity (such as genetic predispositions) between siblings. Consequently, there is a higher likelihood of bias in the pooled OLS estimates and the mother fixed effects analyses are my preferred specification.

3.3.8. Data quality assessment

Since the WHO recommends an assessment of data quality for all analyses of anthropometric data (World Health Organization, 1995), I assess the quality of my data in two ways. First, the share of extreme and implausible values (height-for-age z-score below -6 or above +6) in the original sample, i.e. before data cleaning as described in section 3.3.1, is reported[16]. In their Technical Report, the World Health Organization (1995) stipulates that the occurrence of many such extreme and implausible values may be due to measurement errors, or due to incorrect age reporting. Measurement errors are unlikely, since specifically trained nurses take height measurements in IFLS. Moreover, the sample is restricted to children who are at least 2 years old in order to reduce measurement errors.

However, date of birth misreporting is a common phenomenon in the Global South. Therefore, I check the role of age misreporting in my dataset following the approach by Larsen et al. (2019). The authors suggest plotting the mean height-for-age z-score of the sample against reported month of birth. An upward trend, i.e. an increasing mean z-score over the birth months, hints at underlying date of birth misreporting, even if misreporting occurs randomly. Intuitively, this can be explained as follows: If a child is born in June but reported to be born in January, she is actually younger than her reported age and thus likely to have a lower height-for-age z-score (since her older, reported age is used for the z-score calculation). By contrast, if a child born in June is reported to be born in December, she is older than her reported age and thus calculated to have a higher z-score (since her younger, reported age is used for the z-score calculation). I first assess mean height-for-age z-scores per reported months of birth among the entire sample of 2-18 year-olds. Second, the sample is restricted to those children whose parents provided a birth certificate in IFLS wave 5[17]. Since the provision of a birth certificate makes month of birth misreporting less probable, I expect that potential hints at misreporting of month of birth should be less pronounced in the latter examination.

3.4. Results

3.4.1. Descriptive statistics

Descriptive statistics for the entire sample of children are provided in Table 3-1. The mean height-for-age z-score is clearly below zero among offspring to more religious Muslims, less religious Muslims as well as non-Muslims, which reflects the poor linear growth status of Indonesian children in general (Beal et al., 2018). This is also reflected by the large share of children in my sample

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[16] Note that in contrast to the procedure reported in 3.3.1., for this data quality assessment no 'flexible exclusion range' approach is suggested.

[17] In earlier IFLS waves, parents were not asked to provide a birth certificate.

classified as being stunted. The descriptive statistics for the adult sample as well as the samples on ever-married women for the analyses on early maturation (age at menarche, age at first childbirth) are provided in Appendix Table 3-1, Appendix Table 3-2 and Appendix Table 3-3.

3.4.2. Ramadan during pregnancy and linear growth

Adults: Effects on final attained height

My findings show that adult Muslims who were prenatally exposed to a Ramadan in early pregnancy are shorter than Muslims without prenatal overlap with a Ramadan (Table 3-2). The effects are concentrated among adult Muslims conceived during a Ramadan (-0.441 cm, p-value < 0.05) and those with periconceptional overlap with a Ramadan (-0.393 cm, p-value < 0.05). Splitting the sample by sex indicates that the effects are concentrated among male adult Muslims (Appendix Table 3-4).

Children: Effects on height-for-age z-scores throughout childhood

When looking at the entire sample of observations on 2 to 18-year-old children to more religious Muslim mothers (Table 3-3, column 1), there are indications that those conceived during Ramadan are 0.065 SD shorter than their siblings whose own time in utero did not overlap with a Ramadan (marginally significant, p-value < 0.10). However, when interacting exposure with age groups, an association between Ramadan during pregnancy and impaired linear growth is detected among 15 to 18 year-old adolescents for all trimesters of exposure, except those born during Ramadan (Table 3-3, column 5). The effects are strongest when the overlap with a Ramadan occurred in early pregnancy, including the periconceptional period. The negative effects on height-for-age z-scores are concentrated among male offspring (Appendix Table 3-5) – no effects are detected among female offspring (Appendix Table 3-6).

Table 3-1. Characteristics of the Children Sample

	Muslim children to more religious mothers		**Muslim children to less religious mothers**		**Non-Muslim children**	
	%	N	%	N	%	N
Age (in years) (Mean (SD))	9.89 (4.72)	31,315	9.07 (4.59)	7,567	9.90 (4.68)	4,933
Age 2 – 4	19.37	6,066	23.81	1,802	18.77	926
Age 5 – 9	32.93	10,312	35.92	2,718	33.37	1,646
Age 10 – 14	29.59	9,265	26.73	2,023	30.20	1,490
Age 15 – 18	18.11	5,672	13.53	1,024	17.66	871
Height-for-age z-score (Mean (SD))	-1.61 (1.12)	31,315	-1.63 (1.15)	7,567	-1.53 (1.19)	4,933
Stunted	35.93	31,315	36.92	7,567	33.45	4,933
Male	50.70	31,315	51.26	7,567	53.01	4,933
Firstborn child	40.24	31,315	44.68	7,567	36.12	4,933
Lives in urban area	53.34	30,730	50.76	7,478	46.08	4,884
Access to improved toilet	71.10	30,605	68.62	7,451	72.19	4,826
Episode of diarrhea in last 2 weeks before the interview	8.03	20,482	9.21	5,050	5.44	3,270
Episode of fever in last 2 weeks before the interview	26.31	20,485	31.38	5,051	23.05	3,271
Episode of coughing in last 2 weeks before the interview	40.09	20,486	45.22	5,051	37.11	3,271
Overlap of time in utero and Ramadan	82.50	31,315	81.79	7,567	81.80	4,933
Conceived during Ramadan	8.08		7.85		7.56	
Ramadan started in trimester 1	24.82		25.25		25.44	
Ramadan started in trimester 2	25.03		24.79		23.90	
Ramadan started in trimester 3	16.51		15.59		17.21	
Born during Ramadan	8.07		8.30		7.68	
Conceived shortly after Ramadan	5.69		5.76		6.35	
Certainly no overlap of time in utero and Ramadan	11.80		12.45		11.86	

Descriptive statistics of the sample of observations on 2-18 years-old children (pooled sample of IFLS waves 1-5). Access to an improved toilet is defined as household access to non-shared sanitary facilities.

SD: Standard deviation. N: Number of available observations on a variable.

Table 3-2. Associations between Ramadan during Pregnancy and Final Adult Height (in cm) among Muslims

Exposure Category	$\boldsymbol{\beta_1}$	**95% CI**
In utero during Ramadan	-0.026	(-0.266 ; 0.215)
Conceived shortly after Ramadan	-0.393**	(-0.776 ; -0.011)
Conceived during Ramadan	-0.441**	(-0.775 ; -0.011)
Ram. Start in Trimester 1	0.094	(-0.782 ; 0.363)
Ram. Start in Trimester 2	0.064	(-0.207 ; 0.335)
Ram. Start in Trimester 3	-0.113	(-0.415 ; 0.189)
Born during Ramadan	-0.019	(-0.364 ; 0.327)
Conceived shortly after Ramadan	-0.393**	(-0.775 ; -0.011)

Sample: Indonesian Muslims aged 19 and older, sampled in IFLS waves 1-5 (N= 30,024). Outcome: height in centimeters. Household fixed effects regressions on a pooled sample of all IFLS waves. Additional control variables: sex, age, age², month of birth, year of birth. This table shows the results of two separate regressions (upper panel: comparison of exposed and conceived shortly after Ramadan vs. not exposed; lower panel: differentiation of the exposure category into pregnancy phases of exposure). Standard errors are clustered at the household level. * P < 0.10 ** P < 0.05; ***P < 0.01.

Based on the model underlying Table 3-3, Figure 3-1 plots how the height-for-age z-scores develop over childhood by exposure category. The adjusted predictions consist of simulations where all covariates but the exposure categories are held at their mean. The depicted development of height-for-age z-scores is a prediction based on the simulation that all observations in the sample had been in a specific exposure group. While the growth curve of the non-exposed lies above the growth curve of both exposure categories (i.e. pregnancy overlapped with Ramadan, conceived shortly after a Ramadan) from the age of 5 onwards, significant differences only emerge in adolescence.

Table 3-3. Associations between Ramadan during Pregnancy and Height-for-Age Z-scores of 2-18 year-old Muslim Children in IFLS

	(1) 2 – 18 years	(2) Exp*2 – 4 years	(3) Exp*5 – 9 years	(4) Exp*10 – 14 years	(5) Exp* 15 – 18 years
Not in utero during Ramadan	*Reference*	*Reference*	*Reference*	*Reference*	*Reference*
In utero during Ramadan	-0.008 (-0.0592 ; 0.044)	0.033 (-0.068 ; 0.133)	0.016 (-0.050 ; 0.082)	-0.010 (-0.076 ; 0.056)	-0.092** (-0.163 ; -0.021)
Conceived shortly after Ramadan	-0.0378 (-0.122 ; 0.047)	0.090 (-0.057 ; 0.236)	-0.015 (-0.126 ; 0.096)	-0.083 (-0.197 ; 0.032)	-0.114* (-0.229 ; 0.000)
Conceived during Ramadan	-0.065* (-0.137 ; 0.008)	-0.040 (-0.186 ; 0.105)	-0.021 (-0.117 ; 0.075)	-0.030 (-0.125 ; 0.065)	-0.204*** (-0.302 ; -0.106)
Ram. Start in Trimester 1	0.008 (-0.050 ; 0.066)	0.047 (-0.066 ; 0.160)	0.065* (-0.008 ; 0.137)	-0.017 (-0.092 ; 0.058)	-0.088** (-0.169 ; -0.008)
Ram. Start in Trimester 2	0.005 (-0.055 ; 0.065)	0.031 (-0.086 ; 0.149)	0.015 (-0.061 ; 0.091)	0.025 (-0.051 ; 0.101)	-0.084** (-0.164 ; -0.004)
Ram. Start in Trimester 3	-0.019 (-0.082 ; 0.043)	0.025 (-0.097 ; 0.147)	-0.019 (-0.100 ; 0.062)	-0.015 (-0.094 ; 0.064)	-0.084* (-0.170 ; 0.002)
Born during Ramadan	-0.008 (-0.083 ; 0.067)	0.080 (-0.067 ; 0.227)	-0.018 (-0.115 ; 0.079)	-0.050 (-0.146 ; 0.046)	-0.008 (-0.109 ; 0.093)
Conceived shortly after Ramadan	-0.037 (-0.122 ; 0.047)	0.090 (-0.057 ; 0.236)	-0.014 (-0.125 ; 0.097)	-0.081 (-0.196 ; 0.033)	-0.115** (-0.230 ; -0.001)
N				31,315	
N of groups				7,629	

Sample of Indonesian 2-18 years-old Muslim children born to mothers that are more religious. Outcome: height-for-age z-score. Mother fixed effects regressions. Results are displayed with (confidence intervals). Pooled cross section of all IFLS waves (1-5). The upper panel shows the results of the comparison of exposed and conceived shortly after Ramadan vs. not exposed; the lower panel the results for a differentiation of the exposure category into pregnancy phases of exposure.

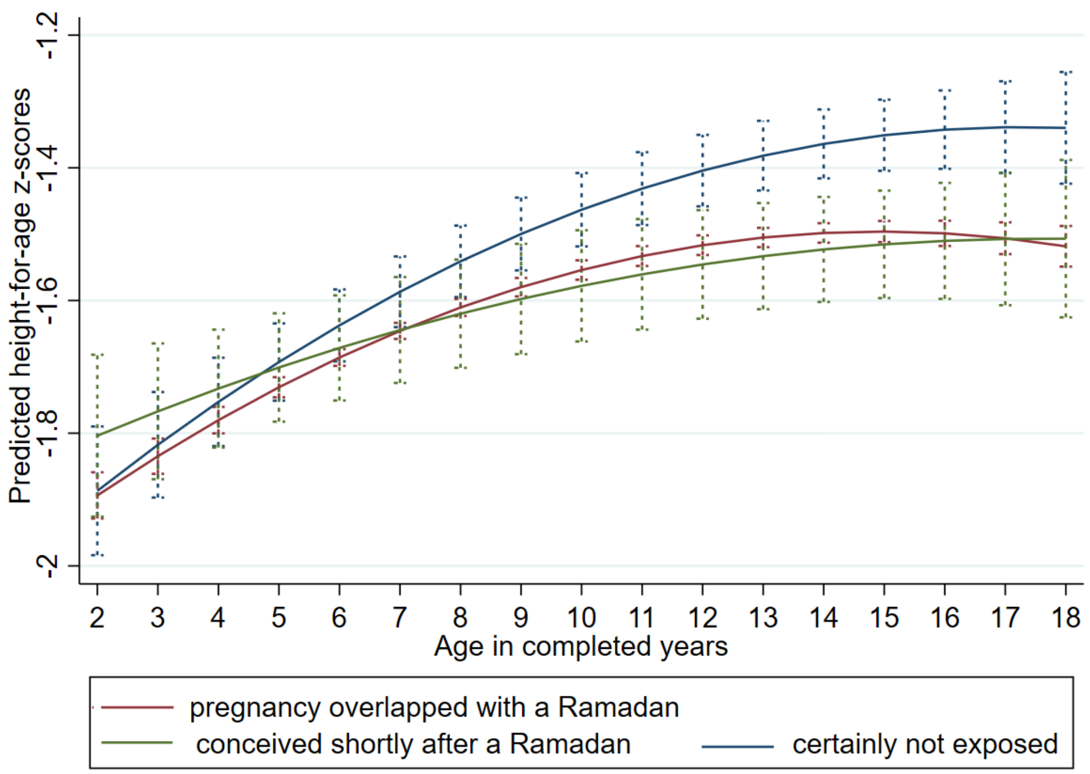
Column (1) displays the effect of Ramadan during pregnancy on the height-for-age z-scores of the entire sample of 2-18 years-old Muslim children, without differentiating by age group. Additional control variables: age, age², sex, month of birth, birth order, year of birth.

In columns (2), (3), (4) and (5), the coefficients refer to an interaction between the exposure category and the respective indicated age group. Additional control variables: age groups 2-4, 5-9, 10-14 and 15-18 (simple main effects), sex, month of birth, birth order, year of birth.

Standard errors are clustered at the mother level. * $P < 0.10$; ** $P < 0.05$, *** $P<0.01$

Similar to the associations between Ramadan during pregnancy and height-for-age z-scores, there are also indications that an overlap between Ramadan during conception is associated with a higher risk of being stunted, i.e. having a height-for-age z-score <-2 (OR 1.279, p-value < 0.01) (Appendix Table 3-7). Note that inference is limited due to fewer observations in these analyses (N=18,951)[18]. When interacting Ramadan during pregnancy with age groups (similar to columns 2-5 of Table 3-3), it appears that the association between Ramadan during pregnancy and an increased risk of being stunted is concentrated among 15-18 year-olds, and in particular those for whom an overlap with Ramadan occurred during conception. However, the power of these interaction analyses is limited due to the reduced sample size in the analyses on dichotomous outcomes. Consequently, these results are to be interpreted with caution and should be considered to be exploratory (available upon request).

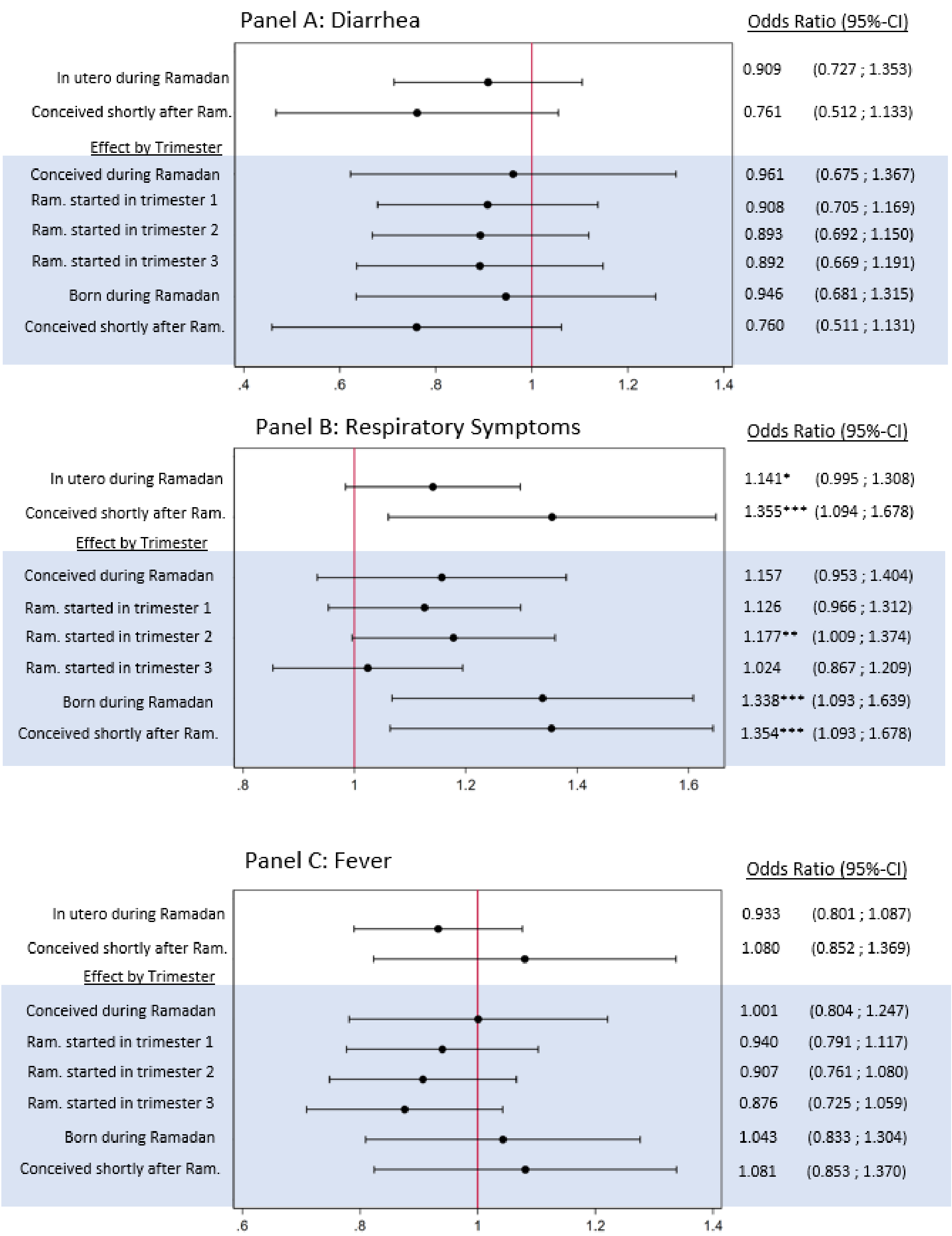
Figure 3-1. Adjusted Predictions of Height-for-Age Z-Scores of 2-18 year-old Muslim Children throughout Childhood and Adolescence by Category of Overlap between Time in Utero and Ramadan.



The figure displays adjusted predictions of height-for-age z-scores of 2-18 year-old offspring to more religious Muslim mothers at each age in completed years from 2 to 18 (Source: IFLS waves 1-5). Dotted lines represent the corresponding 95% confidence intervals. The underlying regression corresponds to the upper panel of column (1) in Table 3-3. Separate sets of adjusted predictions are estimated for each exposure category (i.e. pregnancy overlapped with Ramadan, conceived shortly after a Ramadan, certainly not exposed). Control variables in the underlying mother fixed effects regression: age, age^2, sex, month of birth, birth order, year of birth.

[18] Since inference is limited to observations of siblings with different outcomes on the binary outcome variable (stunted/not stunted). Observations whose siblings were all (not) stunted were thus dropped in these analyses (N=12,364).

Figure 3-2. Ramadan during Pregnancy and Infectious Disease Occurrence in the Last Four Weeks before an IFLS Interview among 2-18 year-old Children to More Religious Muslim Mothers.



Sample of Indonesian 2-18 years-old children born to more religious Muslim mothers. Outcome: self-reported occurrence of diarrhea, respiratory symptoms and fever in the last four weeks before an interview. Mother fixed effects logistic regressions. Results are displayed as Odds Ratios with (95% confidence intervals). The upper two lines of each panel show the results of the comparison of in utero during Ramadan and conceived shortly after Ramadan vs. not exposed; the lower panel the results for a differentiation of the in utero during Ramadan category into pregnancy phases of exposure. Additional control variables: age, age², sex, season of interview, month of birth, year of birth. Standard errors are clustered at the mother level. * P < 0.10; ** P < 0.05, *** P<0.01

3.4.3. Infectious disease susceptibility

I find indications for an association between Ramadan during pregnancy and the risk to experience respiratory symptoms, both among those who were in utero during a Ramadan (OR: 1.145, p-value < 0.10) and among those conceived shortly after a Ramadan (OR: 1.361, p-value < 0.01). There are no associations with the occurrence of diarrhea and fever (Figure 3-2). The increased risk to experience respiratory symptoms spreads across age groups and pregnancy trimesters of exposure (Appendix Table 3-8), while there are no associations between Ramadan during pregnancy and the risk for occurrence of diarrhea and fever in subgroups. The effects on respiratory disease occurrence are concentrated among male offspring (results available upon request).

Household access to improved toilets is associated with a decreased risk of low height-for-age z-scores among children since it prevents the transmission of infectious diseases. Unimproved sanitary standards as such are associated with lower height-for-age z-scores among offspring to all groups, as indicated by the main effect of unimproved sanitation (more religious Muslims: -0.268 SD, p-value < 0.01 / less-religious Muslims: -0.194 SD, p-value < 0.05 / Non-Muslims: -0.552 SD, p-value < 0.01). Note that postnatal exposure to unimproved sanitation does not vary with status of prenatal overlap with a Ramadan. While 28.70% of the observations on children with prenatal overlap with a Ramadan were exposed to unimproved sanitation postnatally, this applies to 28.94% of those without a prenatal overlap with a Ramadan (in the main sample of children born to more religious Muslim mothers). This difference was tested using a $\chi 2$ test of independence and it was not significant ($\chi 2$ = 0.1202, P = 0.729).

In order to assess a potential mediating role of postnatal sanitary standards for the materialization of height-for-age effects among 15-18 year-olds (where effects on height-for-age had previously been detected), prenatal overlap with a Ramadan is interacted with postnatal sanitary standards. The results suggest that the effects on height-for-age z-scores are concentrated among those 15-18 year-olds who were conceived during or shortly after a Ramadan and who grew up in a household that was not equipped with improved sanitation (Table 3-4)[19]. Performing this analysis on the entire sample of 2-18 year-olds, and further differentiating by age categories (i.e. including a three-way-interaction between exposure, age groups and postnatal sanitation quality), the association between Ramadan during pregnancy and height-for-age z-scores does not appear to be substantially moderated by postnatal access to improved sanitation (Appendix Table 3-10). Only among 5-9 year-old Muslim children conceived shortly after a Ramadan, there are indications that improved postnatal sanitary standards

[19] Note that among the entire sample of 2-18 year-olds, effects are concentrated only among those conceived shortly after a Ramadan and growing up with unimproved sanitary standards (Appendix Table 3-9).

Table 3-4. Influence of Postnatal Sanitary Standards on the Association between Ramadan during Pregnancy and Height-for-Age Z-Scores among 15-18 year-old Indonesian Muslim Adolescents

Exposure Category	**Improved postnatal sanitary standards**		**Unimproved postnatal sanitary standards**	
	β	**95% CI**	***β***	**95% CI**
In utero during Ramadan	-0.005	-0.090 ; 0.080	-0.033	-0.090 ; 0.080
Conceived shortly after a Ram.	-0.088	-0.155 ; 0.090	-0.213*	-0.437 ; 0.011
Conceived during Ramadan	-0.053	-0.174 ; 0.067	-0.238**	-0.426 ; -0.049
Ram. started in trimester 1	0.012	-0.084 ; 0.107	-0.042	-0.189 ; 0.105
Ram. started in trimester 2	0.003	-0.093 ; 0.098	0.055	-0.088 ; 0.198
Ram. started in trimester 3	0.014	-0.091 ; 0.116	0.002	-0.149 ; 0.153
Born during Ramadan	-0.030	-0.150 ; 0.089	-0.081	-0.266 ; 0.105
Conceived shortly after a Ram.	-0.089	-0.214 ; 0.037	-0.217*	-0.441 ; 0.008

Pooled OLS on the sample of 15-18 year-old children to more religious Muslim mothers observed in IFLS waves 1-5. The displayed coefficients show the results of an interaction between the respective exposure categories and postnatal sanitary standards. The upper panel shows the results of the comparison of in utero during Ramadan and conceived shortly after Ramadan vs. no overlap between pregnancy and a Ramadan; the lower panel the results for a differentiation of the in utero during Ramadan category into pregnancy phases of exposure. Additional control variables: age, age², sex, month of birth, year of birth, urban residency, birth order. Standard errors are clustered at the mother level.

might offset the negative effects of Ramadan during pregnancy on height-for-age z-scores, i.e. they appear to be mediated by postnatal access to improved sanitation (cf. Appendix Table 3-10: -0.199* + 0.260** > 0, a loss of the negative effects of Ramadan during pregnancy). appear to be mediated by postnatal access to improved sanitation (cf. Appendix Table 3-10: -0.199* + 0.260** > 0, a loss of the negative effects of Ramadan during pregnancy).

3.4.4. Effects on reproductive capacity

My results show that ever-married women with prenatal exposure to a Ramadan are younger when they give birth to their first child, in particular when exposure occurs in the first or second pregnancy trimester (Table 3-5). The effect size amounts to 197 days (p-value < 0.05) and 182 days (p-value < 0.05) respectively, indicating that those exposed in the first or second pregnancy trimester tend to have their first child approximately half a year earlier than their non-exposed peers. In utero exposure to Ramadan is not associated with age at menarche, neither as continuous outcome (Table *3-6*) nor as binary outcome, i.e. menarche before age 12 (Appendix Table 3-11). This result was robust to setting the cutoff for early menarche to 11 or 13 years.

Table 3-5. Associations between Ramadan during Pregnancy and Age at First Childbirth among Ever-Married Indonesian Muslim Women in IFLS

Exposure Category	β_1	**95% CI**
Not in utero during Ramadan	*Reference*	*Reference*
In utero during Ramadan	-123.459*	(-258.090 ; 11.171)
Conceived shortly after a Ramadan	-92.422	(-313.868 ; 129.025)
Conceived during Ramadan	-38.427	(-227.879 ; 151.024)
Ram. Start in Trimester 1	-197.150**	(-349.396 ; -44.904)
Ram. Start in Trimester 2	-182.016**	(-335.363 ; -28.670)
Ram. Start in Trimester 3	-13.181	(-176.491 ; 150.130)
Born during Ramadan	-62.166	(-257.112 ; 132.782)
Conceived shortly after a Ramadan	-94.004	(-315.967 ; 127.958)

Linear regression (OLS) based on a pooled cross section of ever-married Muslim women for whom information on birth history is available in IFLS (N=9,251). Effects of Ramadan during pregnancy on age at birth of first child is displayed in days. Only live births are taken into consideration. The table shows the results of two separate regressions: The upper panel displays the results of the comparison of in utero during Ramadan and conceived shortly after Ramadan vs. not exposed; the lower panel the results for a differentiation of the in utero during Ramadan category into pregnancy phases of exposure. Additional control variables: year of birth, month of birth, urban residency (at first observation in IFLS). Robust standard errors are clustered at the household level.
* P < 0.10; ** P < 0.05, *** P<0.01

Table 3-6. Associations between Ramadan during Pregnancy and Age at Menarche among Ever-Married Indonesian Muslim Women in IFLS

Exposure Category	β_1	**95% CI**
Not in utero during Ramadan	*Reference*	
In utero during Ramadan	0.025	(-0.066 ; 0.116)
Conceived shortly after a Ramadan	0.023	(-0.124 ; 0.170)
Conceived during Ramadan	0.069	(-0.060 ; 0.198)
Ram. Start in Trimester 1	0.020	(-0.084 ; 0.124)
Ram. Start in Trimester 2	0.016	(-0.088 ; 0.119)
Ram. Start in Trimester 3	0.031	(-0.081 ; 0.143)
Born during Ramadan	0.006	(-0.125 ; 0.137)
Conceived shortly after a Ramadan	0.023	(-0.124 ; 0.171)

Linear regression based on a pooled cross section of ever-married Muslim women for whom information on age at menarche is reported in IFLS (N=12,786). Age at menarche is self-reported in full years. The table shows the results of two separate regressions: The upper panel displays the results of the comparison of in utero during Ramadan and conceived shortly after Ramadan vs. not exposed; the lower panel the results for a differentiation of the in utero during Ramadan category into pregnancy phases of exposure. Additional control variables: month of birth, year of birth and urban/rural residency (at first observation in IFLS). Robust standard errors are clustered at the household level.
* P < 0.10; ** P < 0.05, *** P<0.01

3.4.5. Stability and robustness of results

The results of my analyses are stable to different model specifications (exemplarily shown for the analysis on height-for-age z-scores shown in Appendix Table 3-12). Neither taking those conceived shortly after a Ramadan out of the exposure category and thus no longer interacting this category with age groups nor removing those conceived shortly after Ramadan entirely from the sample changed the patterns of results. The results were also stable to removing birth order from the control variables, to additionally controlling for age in days and age in days^2 as well as to controlling for IFLS wave of observation instead of year of birth. None of the outcomes was associated with Ramadan during pregnancy among non-Muslims (exemplarily see Appendix Table 3-13, Appendix Table 3-14, Appendix Table 3-15. Further results available upon request). Since non-Muslims naturally do not adhere to the practice of Ramadan, not finding effects among this group implies that my results are most likely not attributable to other exposures that coincide with Ramadan and experienced by non-Muslims as well. In contrast to non-Muslims, less religious Muslims might practice Ramadan, however they are less likely to do so. My results show that the effect patterns among the offspring to less-religious Muslim mothers are less clear than among the offspring to more religious Muslims with respect to height-for-age z-scores and infectious disease outcomes (Appendix Table 3-16, Appendix Table 3-17). Note that in the analyses on reproductive maturation, a differentiation by mother's religiosity was not feasible, since adult ever-married women could not be linked to their mothers.

The patterns of results among the offspring to more religious Muslims (i.e. the analyses based on the children sample) is furthermore robust to using pooled OLS/logistic regressions instead of mother fixed effects (see Appendix Table 3-18 for the effects on respiratory symptoms occurrence). With respect to height-for-age z-scores the effects are somewhat less pronounced than in the mother-fixed effects setting, yet the pattern of results stays the same (Appendix Table 3-19). The results without mother fixed effect are robust to additionally controlling for mothers' height.

The results on infectious disease occurrence were stable to including month of interview fixed effects instead of season of interview fixed effects. Results were also robust to including an interaction between urban/rural residency and season of interview, as well as to including an interaction between province of residency and season of interview. These robustness checks were performed to make sure that results are not driven by seasonality in infectious disease occurrence, which might vary across Indonesian provinces[20]. The results were also stable to controlling for birth order. The rationale for this robustness check is that some studies suggest that there may be a birth order gradient with respect to

[20] Note that the evidence on the variability of infectious disease occurrences by season and Indonesian province is scarce, with surveillance infrastructure still being in the set-up phase in many regions (Ear, 2012; Kosasih et al., 2013)

infectious disease occurrence among young children. However, the evidence on the role of birth order has remained limited and inconsistent, moreover most studies focus on infants (Jourdan-Da Silva et al., 2004; Kikkawa et al., 2018).

Since age at menarche is self-reported, the results are tested for stability by controlling for the number of years between interview and reported age at menarche (i.e. age at interview minus reported age at menarche, to proxy for recall bias). The results remain stable. Moreover, restricting the sample to women for whom the recall period is short – i.e. who are maximum 15 years older than their reported age at menarche at the time of the interview – did not change the results.

3.4.6. Data quality

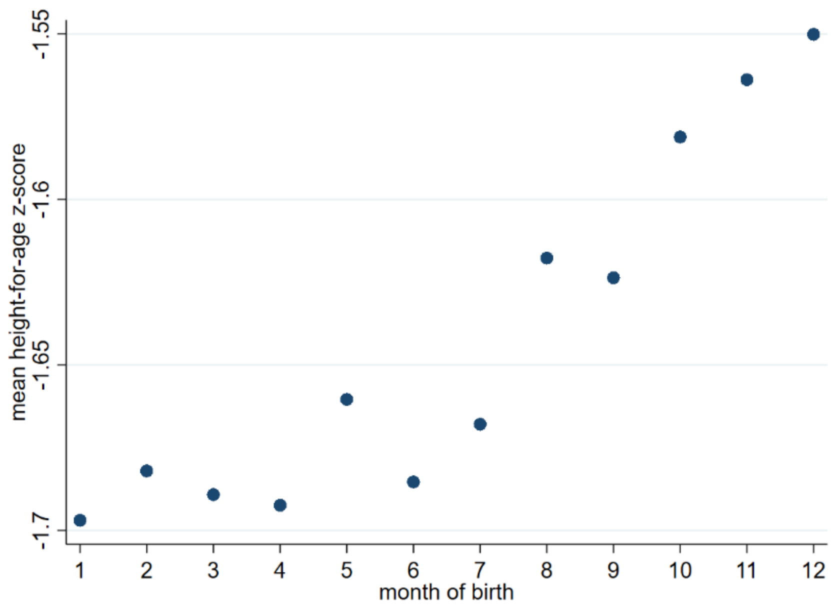
In the original children sample (i.e. before exclusion of observations with implausible as described in 3.3.1), 1.4% of observations have a height-for-age z-score below -6 or above +6. According to WHO classification, this is to be considered as “doubtful” data quality (World Health Organization, 1995). Consequently, the role of age misreporting is further inspecting using the approach by Larsen et al. (2019). When looking at the mean height-for-age z-score per month of birth in the children sample, a trend (Figure 3-3) emerges: the mean z-score increases over the birth months. This pattern hints at underlying date of birth misreporting (as explained in section 3.3.8). When restricting the sample to those observations whose parents provided a birth certificate in IFLS wave 5 (Figure 3-4) the upward trend disappears.

To the best of my knowledge, this is the first time that this data structure is reported for IFLS. Note that in all analyses, month of birth dummies were included to separate the effects of Ramadan during pregnancy from season of birth effects. These dummies also capture effects stemming from month of birth misreporting. It is thus essential to control for month of birth, but interpretations of month of birth effects need to be undertaken with caution. It is reasonable to expect that month of birth misreporting is independent of whether the prenatal period of a child overlapped with a Ramadan, since no systematic differences between parents whose offspring’s time in utero overlapped with a Ramadan and parents to offspring without such an overlap were detected by earlier research (see 3.3.5). Since classification into exposure and control categories is based on date of birth in my identification strategy, date of birth misreporting can thus be assumed to introduce noise in both exposure and control groups and may lead to a dilution of the effects, which may bias results towards zero.

3.5. Discussion

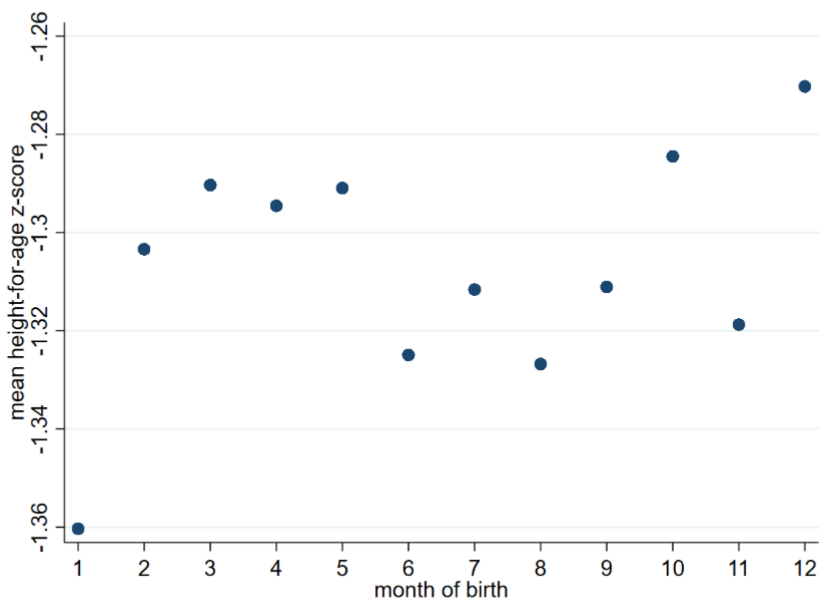
This study investigated the pathways from Ramadan during pregnancy to impaired linear growth. I find that both adult Muslims as well as Muslim adolescent offspring to more religious Muslim mothers

Figure 3-3. Mean height-for-age z-score per month of birth – all 2-18 year-olds



Source: observations on 2-18 year-old children, IFLS waves 1 – 5 (N= 43,815). The figure plots the mean height-for-age z-score per indicated month of birth. Date of birth in IFLS is self-reported.

Figure 3-4. Mean height-for-age z-score per month of birth – 2-18 year-olds with birth certificate



Source: observations on 2-18 year-old children whose parents provided a birth certificate in IFLS wave 5 (N=13,404). The figure plots the mean height-for-age z-score per indicated month of birth. Date of birth in IFLS is self-reported and provision of a birth certificate is voluntary.

whose time in utero overlapped with a Ramadan are smaller than their non-exposed peers. The effects are concentrated among males. My results indicate that Ramadan during pregnancy is associated with an increased risk of experiencing episodes of respiratory symptoms among children, which are predictors of impaired linear growth. The negative effects on height-for-age z-scores seem to be concentrated among Muslim adolescents who postnatally grew up with unimproved sanitary standards and thus have a higher probability to incur infectious diseases (Humphrey, 2009). Results further showed that there may be some trade-off between linear growth and the development of sexual maturation in response to Ramadan during pregnancy. Female Muslims who experienced a Ramadan in utero start reproducing at a younger age. However, Ramadan during pregnancy is not found to be associated with an earlier onset of menarche.

Many topical discussions of the fetal programming theory were addressed, including the role of the periconceptional period and potential interactions between prenatal and postnatal environments in shaping human health. In the following, I relate my results to the literature and discuss them in light of the research questions. Strengths and limitations of this research are highlighted and recommendations for future research given.

3.5.1. Manifestation of effects in adolescence

Several previous studies found linear growth to be affected by in utero shocks, including Ramadan during pregnancy. While my analyses are based on an extended dataset (IFLS waves 1 to 5 instead of only IFLS wave 3), the detected effect patterns for adult height are similar to the findings of Van Ewijk et al. (2013). Those conceived during a Ramadan are found to be shorter than those who were not prenatally exposed. While Van Ewijk et al. (2013) exclude those conceived shortly after a Ramadan from the sample, I include them as a separate exposure category and find that periconceptional exposure to a Ramadan is also associated with a smaller stature in adulthood. All effects are concentrated among male adults.

My results on the effects of Ramadan during pregnancy on children height-for-age z-scores corroborate the findings of a large part of the previous work on growth patterns throughout childhood. Similar to Kunto & Mandemakers (2019) and Karimi et al. (2020), the effects on height-for-age z-scores become manifest from adolescence onwards. This effect pattern is also found in a study on the association between childhood height-for-age and seasonal food scarcity, another comparatively mild prenatal shock (Miller, 2017). This is in accordance with fetal programming theory, which stipulates that in the absence of effects at birth or in infancy, in utero shocks may still have long-term health and human capital effects that remain latent for a long period of time. This also implies that the absence of effects during infancy does not preclude that health effects could manifest themselves at a later point in time (Jaacks et al., 2019). It thus seems to be in accordance with fetal programming theory that I find linear growth effects among adolescents and adults, even though research looking at newborns did not find effects on length at birth (chapter 5 of this dissertation; Savitri et al., 2020). This has implications for the interpretation of other research on linear growth, such as the association between prenatal exposure to air pollution and children's growth trajectories, where studies on long-term outcomes are still scarce, while the evidence on newborns is accumulating (Sinharoy et al., 2020).

In accordance with earlier research on Ramadan during pregnancy, I furthermore find the effects on height-for-age to be driven by male offspring and concentrated among offspring to more religious Muslim mothers. Similar to the analyses on adult final height, previous studies on child linear growth omitted those conceived shortly after a Ramadan from the sample. This study includes them in a separate exposure category, in response to recent research on the importance of the periconceptional period. I find strong effects in this exposure group among adolescents, which confirms my findings from the adult sample.

It should be noted that other studies did find effects of Ramadan during pregnancy on linear growth among under 5-year-old Muslim children (Karimi & Basu, 2018; Chaudhry & Mir, 2021). These studies do not cover growth patterns beyond age 5 so that effect patterns among adolescents remain unknown. Nevertheless, it is important to acknowledge that the linear growth effects of Ramadan during pregnancy might vary by country and Muslim populations, since traditions including nutrition during Ramadan can differ substantially between and within countries, with improved dietary diversity in some settings and caloric deficits in others (Seiermann et al., 2021). In order to understand why associations between Ramadan during pregnancy and linear growth among young children appear in other settings, country-specific analyses would be informative. However, in many cases, surveys such as the Demographic and Health Survey Programme (DHS) do not cover a sufficient amount of birth years to differentiate between the effects of Ramadan during pregnancy and seasonal effects when restricting the sample to a specific country (Karimi & Basu, 2018). Karimi & Basu (2018) combine data from different countries to circumvent this problem. It thus remains difficult to assess why these studies did find effects among young children, since the combination of data of Muslims stemming from different countries and different Muslim-traditions may have biased the results.

3.5.2. Susceptibility to infectious diseases as potential effect mechanism

The finding that only linear growth patterns of adolescents seem to be affected by Ramadan during pregnancy indicates that the associations might be side effects of other pathological perturbations such as episodes of infectious diseases that become manifest in adolescence. My results show that Muslim children who were prenatally exposed to a Ramadan are at an increased risk of experiencing episodes of respiratory diseases, which in turn have been shown to be predictors of linear growth impairments (Hedges et al., 2017). This finding is consistent with earlier findings on adults, which show that Ramadan during pregnancy is associated with wheezing and other breathing difficulties in later life (chapter 2 of this dissertation).

In my children sample, the effects on respiratory symptoms occurrence are spread across all age categories, yet it is plausible that the linear growth effects in adolescence are co-driven by the increased susceptibility to infectious diseases at earlier ages. While my analyses are based on snapshots of the children included in IFLS, it seems reasonable to assume that children with an increased risk of having experienced an episode of an infectious disease in the last few weeks before an IFLS interview also have a higher chance to experience recurrent infections. The consequences of the internal reallocation of energy to securing metabolic responses adequate to defy infections for linear growth may gradually become visible. It is somewhat surprising that episodes of diarrhea and fever were not associated with Ramadan during pregnancy, while the occurrence of respiratory symptoms was. Since this is the first study on Ramadan during pregnancy and infectious diseases among children, future studies are necessary to investigate if this is a general pattern and if so, why.

In accordance with the literature, I find that worse sanitary conditions have a negative effect on linear growth (for Indonesia cf. Rah et al. (2020)). The results of my analyses suggest that adverse linear growth effects of Ramadan during pregnancy might be concentrated among those adolescents who postnatally grow up with unimproved sanitary conditions. This is in line with our previous finding that the associations between in utero exposure to Ramadan and breathing difficulties are most pronounced for smokers (chapter 2 of this dissertation). The manifestation of effects in response to prenatal shocks seems to co-depend on postnatal circumstances, with adverse living conditions increasing the chances for the effects to materialize. An explanation for the concentration of the effects among those without access to improved sanitation could be that the immune systems of prenatally exposed children are less well prepared for mitigating postnatal harmful influences. This finding underlines that environmental factors related to children’s linear growth cannot be regarded in isolation, but that their potentials for interaction and synergy should be considered (Cumming et al., 2019). It seems like the linear growth trajectories of populations who are already at risk due to poor sanitary environments are particularly affected by the exposure to a prenatal shock. This combination of findings provides some support for the conceptual premise that the effects of Ramadan during pregnancy on linear growth may at least in part be attributable to the infectious disease channel.

3.5.3. Emergence of a fertile phenotype

Linear growth might also be traded off against the securing of other body functions such as reproduction as suggested by life history theory. The emergence of such a ‘fertile phenotype’ has been documented in response to prenatal exposure to the Dutch famine (Painter, Westendorp, et al., 2008). This is the first study to investigate if such a higher investment in fertility, with the risk of poorer health outcomes in other domains, also occurs in response to Ramadan during pregnancy as a milder in utero shock. Similar to Painter, Westendorp, et al. (2008), I find that Ramadan during pregnancy is associated with a younger age at first childbirth. However, Ramadan during pregnancy is not associated with age at menarche among the ever-married women sample of IFLS.

It is important to acknowledge that in contrast to age at menarche, age at first childbirth reflects the start of reproduction, which is not purely biological. One the one hand, from a biological perspective, Ramadan during pregnancy might program the offspring to reproduce early in order to ensure reproduction in a predicted adverse postnatal environment. This programming towards a potentially shorter life span might be co-shaped by an increased mortality pressure in response to Ramadan during pregnancy. While no evidence on Ramadan during pregnancy and mortality risks throughout the life course exist, Schoeps et al. (2018) find an increased mortality risk among children younger than five years. In accordance with life history evolution theory, linear growth could thus (in part) be traded off against reproductive success. At second glance, the picture becomes more complex, since age at first childbirth is socially-shaped and may itself be a side effect of other health and human capital effects of Ramadan during pregnancy. Earlier studies revealed an association between Ramadan during pregnancy and success at school and on the labor market (Almond & Mazumder, 2011; Almond et al., 2015; Majid, 2015; Majid et al., 2019). Since higher educational outcomes are considered to be associated with a later age at first reproduction (Fagbamigbe & Idemudia, 2016), it remains unclear if Ramadan during pregnancy is directly associated with compromised growth via the early maturation channel.

Not finding effects on age of menarche further speaks against the growth reproduction tradeoff hypothesis. This finding suggests that the biological onset of reproductive capacity is not affected by Ramadan during pregnancy. I consider this result to be preliminary since data quality was limited. Age at menarche was only reported in full years and only a small share (≈4%) of the sample experienced menarche before age 12, which reduced the power in this analysis. Future studies on prenatal shocks and reproductive trajectories, including genetic markers of the onset of puberty, will help to improve our understanding in this domain. While biological markers of the onset of puberty in males were not available for this study, it would be highly informative to investigate the effects of adverse prenatal conditions on male reproductive trajectories as well, also against the background of the height-for-age effects being concentrated among male offspring.

3.5.4. Epigenetic programming in response to Ramadan during pregnancy

In accordance with knowledge from the medical sciences and in particular epigenetics, the large majority of studies on Ramadan during pregnancy and long-term health effects found effects to be concentrated among those who were exposed in early pregnancy, usually defined as conception and the first pregnancy trimester. This is the first study on Ramadan during pregnancy and linear growth that also considers the periconceptional phase as potential exposure period. I find most health effects of Ramadan during pregnancy to be concentrated among those exposed in the earliest phases of pregnancy, i.e. periconceptionally, at conception and during the first pregnancy trimester. This suggests that those conceived shortly after a Ramadan should not be omitted from future analyses on Ramadan during pregnancy and at the same time, counselling of women in childbearing age should ideally start before conception.

Survey-based investigations of Ramadan during pregnancy revealed a higher adherence to fasting during early pregnancy, in particular among women who did not yet know that they were pregnant (chapter 5 of this dissertation). Consequently, the concentration of the effects among those exposed in earlier pregnancy phases could also be attributable to a higher maternal adherence to fasting. Furthermore, even if the effects detected among those exposed periconceptionally are biologically plausible, there are limitations to the investigation of the periconceptional phase based on Ramadan during pregnancy. First, those calculated to be conceived shortly after a Ramadan may partially have been exposed during the first pregnancy trimester in case of a postmature pregnancy. Second, the end of Ramadan is shaped by traditional celebrations as well as travels to the home villages. It cannot be precluded that those conceiving during this special time of the Islamic calendar differ systematically from those conceiving during other times of the year, even though previous evidence does not support the hypothesis that parents plan pregnancies as to avoid or promote an overlap with Ramadan. The exposure category 'conceived shortly after a Ramadan' might thus capture more than periconceptional issues. Still, future research is encouraged to further investigate the role of the periconceptional period.

3.5.5. Strengths and limitations

This paper constitutes a comprehensive analysis of potential background mechanisms linking Ramadan during pregnancy to linear growth impairment. It provides first evidence on both Ramadan during pregnancy and infectious disease occurrence among children as well as fertility and reproduction outcomes among women. The analyses rely on a natural experiment approach, which allows the identification of causal associations between Ramadan during pregnancy and offspring health outcomes, even if randomized controlled trials on Ramadan during pregnancy are both unfeasible and highly unethical. All results were rigorously tested for stability and robustness.

By focusing on the effects among offspring to more religious Muslim mothers, outcomes in the children sample could be tested against two control samples, namely offspring to non-Muslims as well as less less-religious Muslims. I find effects among non-Muslims for none of the outcome measures, which shows that it is unlikely that occurrences during Ramadan that are independent of religion (such as increasing food prices) are driving the effects. This allows to plausibly trace the detected effects to Ramadan during pregnancy. The associations were also less clearly pronounced among offspring to less religious Muslims, which suggests that adherence to the Ramadan traditions drives the health effects in the offspring to more religious Muslim mothers. Concerns about potential residual confounding by seasonality were addressed by controlling for month of birth effects in all regressions.

A general limitation of the natural experiment approach used in this paper is that the true association between Ramadan during pregnancy and the outcome measures is likely to be underestimated. All individuals calculated to have had an overlap with a Ramadan and an individual's own time in utero were classified as exposed, even though it is improbable that all religious Muslim mothers adhered to the practice of Ramadan during pregnancy. Moreover, the results of intention-to-treat analyses need to be interpreted with some caution: the effects should be interpreted as the effects of Ramadan during pregnancy, and not necessarily the effects of fasting (Seiermann & Gabrysch, 2020). Beyond the abstinence from food and drink, the observance of the Ramadan fast is associated with further lifestyle changes such as adjusted sleep rhythms and dietary patterns. The sleeping rhythm of Muslims changes since nutritional intake is shifted to nighttime hours (BaHammam, 2005; BaHammam et al., 2013). Moreover, the breaking of the fast each day after sunset is traditionally celebrated with fatty and sweet food and drinks which implies changes to the types of food consumed (Ibrahim et al., 2008; Trepanowski & Bloomer, 2010). These changes beyond the fasting decision may in in themselves have an impact on fetal development, initiate predictive adaptive responses, or affect the relationship between maternal fasting and offspring health outcomes.

With comparatively high infant mortality rates in Indonesia, it should also be taken into account that scarring and selection effects might play a role. It has been shown that in utero exposure to Ramadan is associated with an increased under-5 mortality (Schoeps et al., 2018). To the extent that the exposed who are either lost at conception or in utero and those who pass away at a later postnatal stage can be expected to have had worse health outcomes than their non-exposed peers who survive until an older age, the true effect of exposure is further biased towards zero.

A further limitation is related to data quality. Many outcome measures are self-reported (infectious disease occurrence, age at menarche, age at first childbirth). While infectious disease occurrence only covered the last four weeks before an interview, recall bias might be an issue for age at menarche and age at first childbirth. There are also issues with the reported date of birth, as demonstrated by the linear pattern of height-for-age z-scores increasing by reported month of birth (Figure 3-3). Since the overlap between a Ramadan and a pregnancy ('exposure') is calculated based on reported date of birth, this finding implies that there is more noise in the classification of in utero exposure to Ramadan in IFLS-based papers than previously thought. Assuming that date of birth misreporting is independent of status of prenatal overlap with Ramadan, this introduces a classical measurement error in an independent variable, which further biases the estimates towards zero. Finally, the results on the potential mitigating role of sanitary conditions – in particular when stratified by age groups in the three-way-interaction setting – are to be interpreted with caution and should be replicated by further studies. Since only very few coefficients are significantly different from zero, it remains to be further elucidated to which extent the results are driven by sampling variation.

3.5.6. External validity

This study is based on data from Indonesia, a country with high incidence rates of low height-for-age z-scores and stunting among children. The implications of causal associations detected in this specific setting depend on the exact circumstances of the study. At the same time, similar findings on the association between more subtle in utero shocks and height-for-age trajectories throughout childhood have been made in different contexts. In conjunction with earlier research, my findings underpin the general perception that maternal nutritional status, before and during pregnancy, is associated with offspring long-term health (Gluckman et al., 2007; Fleming et al., 2018).

The practice of Ramadan is highly context-specific, with considerable across- and within-country variations. While a study in a hospital in Jakarta, Indonesia, revealed lower total energy, protein and vitamin A intakes among pregnant women during Ramadan as compared to nutritional intakes outside of Ramadan, an increased dietary diversity was detected in Bangladesh and in Ghana (Ali & Abizari, 2018; Savitri et al., 2018; Seiermann et al., 2021). It might thus be that despite the universal traditional practice of intermittent fasting during Ramadan, the findings on Ramadan during pregnancy and children's height-for-age z-scores and other outcomes are equally context-specific, to the extent that effect materialization can be explained by nutritional intake during Ramadan[21].

My findings on the role of sanitation are similarly more specific to the Global South context where the access to adequate sanitation is not universal. Since my findings provide suggestive evidence for the effects of Ramadan during pregnancy on height-for-age z-scores to be concentrated among those postnatally exposed to unimproved sanitary standards, the materialization of effects might be more limited in the Global North due to lower postnatal risks. Yet, there might be other risk factors in the Global North that have not been studied yet. This might also apply to the emergence of a fertile phenotype in response to Ramadan during pregnancy, since the mortality pressure is on average higher in the Global South. Consequently, future research on both the role of sanitation and other postnatal risk factors as well as the associations between milder in utero shocks during pregnancy and

[21] This context-specificity may also apply to other Ramadan-related behaviors such as sleep patterns, to the extent that a different practice of Ramadan is associated with different Ramadan-related behaviors. However, those have not yet been studied among pregnant Muslims during Ramadan in detail in many different contexts.

reproductive success will be necessary. The results of this study should not be directly transferred to other settings.

3.5.7. Directions for future research

When discussing the findings of this paper in light of fetal programming theory, as well as earlier research on the effects of in utero events on child linear growth, several new questions and hypotheses emerged. Due to the high variation in how Ramadan is practiced across and within countries, all outcomes studied in this paper should further be investigated in other settings. In particular studies on (milder) prenatal shocks and infectious disease occurrence and fertility outcomes are recommended, since this paper provided first evidence on this association. Since reproduction outcomes are also socially-shaped, making it difficult to disentangle direct effects of in utero shocks from indirect effects via inter alia the education channel, a focus on genetic markers and other biological markers of sexual maturation might be beneficial. Reproductive trajectories of men should equally be investigated to gain further insights into the growth reproduction tradeoff hypothesis.

A further avenue for future research could be the closer investigation of programming effects induced by pre- and periconceptional exposure to adverse in utero conditions. Future research is encouraged not to neglect the preconception period, but further inspect its role for developmental plasticity, including epigenetic changes as well as characteristics of the emerging phenotypes. It might be that adaptations to adverse in utero conditions are transferred to future generations via epigenetic changes. Amongst many health outcomes, there is also a well-documented intergenerational dimension to linear growth (de Onis & Branca, 2016). Future research could thus not only study the health outcomes of those exposed to Ramadan in utero, or other prenatal shocks, themselves but also the health of their offspring (i.e. in the grandchildren generation).

This is also one of the first studies to investigate potential interaction effects between prenatal shocks and postnatal circumstances. Since the materialization of the effects of in utero exposure to Ramadan on linear growth seems to co-depend on postnatal living circumstances, future research is encouraged to include postnatal risk factors in analyses on the health and human capital effects of early life adverse events.

3.6. Conclusion

The findings of this paper corroborate that more subtle prenatal shocks are associated with long-lasting health and human capital effects. I find that Ramadan during pregnancy is associated with negative effects on height-for-age z-scores among Muslim adolescents, while no effects were detected among younger age groups. This finding is in line with the previous literature. It also implies that the absence of height-for-age effects of Ramadan during pregnancy among newborns does not preclude that effects may appear at later ages. This underlines that if a prenatal shock is not associated with health or human capital effects in a specific age group, this does not eliminate the possibility that effects materialize at a later point in time.

Beyond the documentation of these associations, the present paper sought to identify mechanisms linking Ramadan during pregnancy to impaired linear growth. While the hypothesis that Ramadan during pregnancy might be associated with a weakened immune system is not new (Schoeps et al., 2018), this is the first paper to demonstrate an association between Ramadan during pregnancy and respiratory symptoms occurrence among children. Since (recurrent) infections are associated with an increased risk for impaired growth, infectious disease susceptibility is indeed a likely pathway from Ramadan during pregnancy to smaller final stature. The first evidence that the negative effects on linear growth are concentrated among those adolescents who grow up without access to improved sanitary conditions further supports this hypothesis.

My analyses on the association between Ramadan during pregnancy and reproductive success do not suggest that Ramadan during pregnancy has effects on the age at menarche. Even though prenatally exposed Muslims are found to be younger at their first live birth, this might also be due to effects of Ramadan during pregnancy on education and labor market outcomes and associated fertility decisions. Additional research on reproductive trajectories will be necessary to further assess the growth reproduction tradeoff hypothesis. Since there is to date very few empirical evidence on prenatal shocks and reproductive success, and even less so on milder in utero shocks, the findings here should be regarded as starting point for further analyses.

Taken together, the findings of this paper demonstrate that the study of the manifestation of the health effects of prenatal adverse conditions is a highly complex undertaking, of which direct programming effects might be only one part. In the case of linear growth, programming effects and defects in the fetus may also lead to conditions that favor linear growth impairment via other pathological perturbations, such as weakened immune responses. This complexity also allows the identification of many potential opportunities for policy and public health interventions. Associations between the periconceptional environment and later-life health outcomes imply that the target group of many health policies should be women of childbearing age, instead of women who already are pregnant. The potential for interaction effects between prenatal and postnatal circumstances in the manifestation of the effects of prenatal shocks suggests that policies should not be constrained to behavioral recommendations for pregnant women and women of childbearing age. Policies aiming at improving the living conditions of children, such as securing the access to improved sanitation, may have so far undervalued positive externalities, since they may help to avoid the effects of prenatal shocks to materialize. Future research will shed more light on this.

Early childhood development, including its earliest stages in utero, has not only been endorsed in the 2030 Sustainable Development Goals, but growing evidence has established links between the intrauterine environment and various health and human capital outcomes. This study has enriched the accumulating empirical evidence on the health and human capital effects of Ramadan during pregnancy and several ongoing discussions in the DOHaD literature. Almost a quarter of the world population is Muslim, with 75% of Muslim pregnancies overlapping with a Ramadan. Since the practice of Ramadan is highly context-specific, further evidence from other settings will be pivotal to develop guidelines for healthcare practitioners and to promote a healthy start to life for all children.

Appendix Chapter 3. Further descriptives and analyses

Appendix Table 3-1. Characteristics of the Adult Sample

	Muslims (N=30,024) %	**Non-Muslims** (N=3,726) %
Age in years (Mean (SD))	35.96 (14.22)	37.22 (15.09)
Height in cm (Mean (SD))	156.59 (8.52)	157.83 (8.66)
Male	48.97	48.90
Lives in urban area	57.03	57.22
In utero during Ramadan	82.93	81.96
Conceived during Ramadan	8.79	7.51
Ramadan started in trimester 1	24.99	24.75
Ramadan started in trimester 2	24.62	24.48
Ramadan started in trimester 3	16.20	16.56
Born during Ramadan	8.34	8.67
Conceived shortly after Ramadan	5.62	6.28
Certainly no overlap of time in utero and Ramadan	11.45	11.76

Descriptive statistics of the sample of observations on adult Muslims (pooled sample of IFLS waves 1-5, all observations on ≥19 year-olds). SD: Standard deviation.

Appendix Table 3-2. Characteristics of the Sample of Ever-Married Women with Information on Age at Menarche

	Muslims (N=12,786) %	**Non-Muslims** (N=3,726) %
Age in years (Mean (SD))	31.26 (12.16)	32.51 (12.20)
Age at menarche in years (Mean (SD))	13.90 (1.70)	14.23 (1.63)
Menarche before age 12	4.47	2.29
Lives in urban area	51.84	54.43
In utero during Ramadan	82.26	82.32
Conceived during Ramadan	8.81	7.94
Ramadan started in trimester 1	25.72	24.96
Ramadan started in trimester 2	25.20	25.11
Ramadan started in trimester 3	15.85	16.95
Born during Ramadan	8.03	8.37
Conceived shortly after Ramadan	5.60	5.58
Certainly no overlap of time in utero and Ramadan	10.79	11.09

Descriptive statistics of the sample of observations on ever-married women who self-reported age at menarche in years (pooled cross section of IFLS waves 1-5, with each observed ever-married woman appearing once). SD: Standard deviation.

Appendix Table 3-3. Characteristics of the Sample of Ever-Married Women with Information on Age at First Childbirth

	Muslims (N=9,251) %	Non-Muslims (N=1,129) %
Age in years (Mean (SD))	32.63 (12.81)	35.20 (13.16)
Age at first live birth in years (Mean (SD))	23.43 (5.58)	24.14 (5.08)
Lives in urban area	51.35	54.65
In utero during Ramadan	83.70	83.53
Conceived during Ramadan	8.81	8.33
Ramadan started in trimester 1	25.44	24.36
Ramadan started in trimester 2	25.25	25.78
Ramadan started in trimester 3	16.38	16.83
Born during Ramadan	7.83	8.24
Conceived shortly after Ramadan	5.42	5.05
Certainly no overlap of time in utero and Ramadan	10.89	11.43

Descriptive statistics of the sample of observations on ever-married women with available childbirth history (pooled cross section of IFLS waves 1-5, with each observed ever-married woman appearing once). Only live births are recorded. SD: Standard deviation.

Appendix Table 3-4. Ramadan during Pregnancy and Final Attained Height among Indonesian Adult Muslims, by Sex

	Men (N=14,703)		Women (N=15,321)	
Exposure Category	β_1	**95% CI**	β_1	**95% CI**
Not in utero during Ramadan	*0.00*	*Reference*	*0.00*	*Reference*
In utero during Ramadan	-0.192	(-0.623 ; 0.239)	0.184	(-0.208 ; 0.576)
Conceived shortly after Ramadan	-0.608*	(-1.297 ; 0.080)	0.122	(-0.504 ; 0.748)
Conceived during Ramadan	-0.590*	(-1.216 ; 0.037)	-0.134	(-0.668 ; 0.400)
Ram. Start in Trimester 1	0.047	(-0.457 ; 0.550)	0.210	(-0.227 ; 0.646)
Ram. Start in Trimester 2	-0.175	(-0.679 ; 0.328)	0.133	(-0.309 ; 0.575)
Ram. Start in Trimester 3	-0.321	(-0.865 ; 0.223)	0.327	(-0.163 ; 0.816)
Born during Ramadan	-0.247	(-0.861 ; 0.380)	0.271	(-0.255 ; 0.797)
Conceived shortly after Ramadan	-0.606*	(-1.296 ; 0.083)	0.116	(-0.510 ; 0.741)

Sample: Indonesian Non-Muslims aged 19 and older. Outcome: height in centimeters. Household fixed effects regressions on a pooled sample of observations of adults in all IFLS waves. The sample was split by sex (i.e. left column: results for the male sample, right column: results for the female sample). For both samples (i.e. in both columns), this table shows the results of two separate regressions (upper panel: comparison of exposed and conceived shortly after Ramadan vs. not exposed; lower panel: differentiation of the exposure category into pregnancy phases of exposure). Additional control variables: sex, age, age^2, month of birth, living in an urban area. Standard errors are clustered at the household level.
* P < 0.10 ** P < 0.05; ***P < 0.01.

Appendix Table 3-5. Associations between Ramadan during Pregnancy and Height-for-Age Z-Scores of 2-18 year-old Male Muslim Children

	(1)	(2)	(3)	(4)	(5)
	2 – 18 years	**Exp*2 – 4 years**	**Exp*5 – 9 years**	**Exp*10 – 14 years**	**Exp* 15 – 18 years**
Exp. categories					
Not in utero during Ram.	*Reference*	*Reference*	*Reference*	*Reference*	*Reference*
In utero during Ramadan	-0.047	-0.052	0.020	-0.013	-0.199***
	(-0.139 ; 0.045)	(-0.213 ; 0.109)	(-0.087 ; 0.126)	(-0.123 ; 0.097)	(-0.307 ; -0.090)
Conceived shortly after	-0.149**	0.020	-0.061	-0.229**	-0.294***
Ramadan	(-0.290 ; -0.007)	(-0.210 ; 0.249)	(-0.235 ; 0.113)	(-0.417 ; -0.041)	(-0.472 ; -0.117)
Conceived during	-0.093	-0.109	-0.021	-0.025	-0.290***
Ramadan	(-0.226 ; 0.040)	(-0.347 ; 0.128)	(-0.173 ; 0.130)	(-0.187 ; 0.137)	(-0.451 ; -0.130)
Ram. Start in Trimester 1	-0.031	-0.016	0.076	-0.045	-0.197***
	(-0.134 ; 0.072)	(-0.195 ; 0.164)	(-0.042 ; 0.194)	(-0.169 ; 0.080)	(-0.323 ; -0.070)
Ram. Start in Trimester 2	-0.073	-0.136	-0.014	-0.012	-0.212***
	(-0.179 ; 0.034)	(-0.322 ; 0.051)	(-0.136 ; 0.108)	(-0.137 ; 0.113)	(-0.336 ; -0.088)
Ram. Start in Trimester 3	0.022	0.049	0.055	0.083	-0.141**
	(-0.091 ; 0.135)	(-0.146 ; 0.245)	(-0.076 ; 0.186)	(-0.053 ; 0.219)	(-0.276 ; -0.005)
Born during Ramadan	-0.094	-0.045	-0.065	-0.092	-0.165*
	(-0.226 ; 0.039)	(-0.277 ; 0.186)	(-0.225 ; 0.094)	(-0.249 ; 0.065)	(-0.331 ; 0.001)
Conceived shortly after	-0.148**	0.018	-0.060	-0.228**	-0.294***
Ramadan	(-0.289 ; -0.006)	(-0.212 ; 0.247)	(-0.234 ; 0.114)	(-0.416 ; -0.041)	(-0.472 ; -0.117)
N				15,876	
N of groups				5,407	

Sample of Indonesian 2-18 years-old male Muslim children born to mothers that are more religious. Outcome: height-for-age z-score. Mother fixed effects regressions. Results are displayed with (confidence intervals). Pooled cross section of all IFLS waves (1-5). The upper panel shows the results of the comparison of exposed and conceived shortly after Ramadan vs. not exposed; the lower panel the results for a differentiation of the exposure category into pregnancy phases of exposure.
Column (1) displays the effect of Ramadan during pregnancy on the height-for-age z-scores of the entire sample of 2-18 years-old male Muslim children, without differentiating by age group. Additional control variables: age, age², month of birth, birth order, year of birth.
In columns (2), (3), (4) and (5), the coefficients refer to an interaction between the exposure category and the respective indicated age group. Additional control variables: age groups 2-4, 5-9, 10-14 and 15-18 (simple main effects), month of birth, birth order, year of birth. Standard errors are clustered at the mother level. * $P < 0.10$; ** $P < 0.05$, *** $P<0.01$

Appendix Table 3-6. Associations between Ramadan during Pregnancy and Height-for-Age Z-Scores of 2-18 year-old Female Muslim Children

	(1)	(2)	(3)	(4)	(5)
Exp. categories	**2 – 18 years**	**Exp*2 – 4 years**	**Exp*5 – 9 years**	**Exp*10 – 14 years**	**Exp* 15 – 18 years**
Not in utero during Ramadan	*Reference*	*Reference*	*Reference*	*Reference*	*Reference*
In utero during Ramadan	0.003 (-0.090 ; 0.095)	0.022 (-0.137 ; 0.180)	-0.024 (-0.133 ; 0.084)	0.008 (-0.102 ; 0.118)	0.005 (-0.114 ; 0.123)
Conceived shortly after Ramadan	0.100 (-0.045 ; 0.246)	0.092 (-0.143 ; 0.327)	0.081 (-0.104 ; 0.266)	0.100 (-0.070 ; 0.270)	0.164* (-0.015 ; 0.344)
Conceived during Ramadan	-0.040 (-0.168 ; 0.087)	-0.066 (-0.296 ; 0.164)	-0.017 (-0.172 ; 0.139)	-0.016 (-0.168 ; 0.136)	-0.103 (-0.261 ; 0.055)
Ram. Start in Trimester 1	-0.019 (-0.124 ; 0.086)	0.007 (-0.173 ; 0.187)	-0.021 (-0.144 ; 0.102)	-0.017 (-0.142 ; 0.108)	-0.038 (-0.174 ; 0.099)
Ram. Start in Trimester 2	0.057 (-0.049 ; 0.163)	0.093 (-0.089 ; 0.276)	0.014 (-0.111 ; 0.139)	0.076 (-0.051 ; 0.203)	0.046 (-0.088 ; 0.179)
Ram. Start in Trimester 3	-0.011 (-0.123 ; 0.100)	-0.012 (-0.204 ; 0.181)	-0.064 (-0.200 ; 0.073)	-0.010 (-0.138 ; 0.118)	0.038 (-0.102 ; 0.178)
Born during Ramadan	-0.005 (-0.142 ; 0.133)	0.020 (-0.207 ; 0.247)	-0.039 (-0.197 ; 0.120)	-0.041 (-0.209 ; 0.127)	0.078 (-0.083 ; 0.239)
Conceived shortly after Ramadan	0.103 (-0.043 ; 0.248)	0.094 (-0.141 ; 0.328)	0.083 (-0.102 ; 0.268)	0.102 (-0.068 ; 0.272)	0.163* (-0.017 ; 0.344)
N				15,439	
N of groups				5,349	

Sample of Indonesian 2-18 years-old female Muslim children born to mothers that are more religious. Outcome: height-for-age z-score. Mother fixed effects regressions. Results are displayed with (confidence intervals). Pooled cross section of all IFLS waves (1-5). The upper panel shows the results of the comparison of exposed and conceived shortly after Ramadan vs. not exposed; the lower panel the results for a differentiation of the exposure category into pregnancy phases of exposure.

Column (1) displays the effect of Ramadan during pregnancy on the height-for-age z-scores of the entire sample of 2-18 years-old female Muslim children, without differentiating by age group. Additional control variables: age, age², month of birth, birth order, year of birth.

In columns (2), (3), (4) and (5), the coefficients refer to an interaction between the exposure category and the respective indicated age group. Additional control variables: age groups 2-4, 5-9, 10-14 and 15-18 (simple main effects, reference: 2-4 years), month of birth, birth order, year of birth. Standard errors are clustered at the mother level.

* P < 0.10; ** P < 0.05, *** P<0.01

Appendix Table 3-7. Association between Ramadan during Pregnancy and Risk for being Stunted among 2-18 year-old Indonesian Muslim Children

Exposure Category	β_1	**95% CI**
In utero during Ramadan	1.055	(0.934 ; 1.191)
Conceived shortly after Ramadan	0.899	(0.737 ; 1.095)
Conceived during Ramadan	1.270***	(1.062 ; 1.519)
Ram. Start in Trimester 1	0.980	(0.854 ; 1.125)
Ram. Start in Trimester 2	1.027	(0.893 ; 1.180)
Ram. Start in Trimester 3	1.140*	(0.982 ; 1.322)
Born during Ramadan	1.017	(0.851 ; 1.215)
Conceived shortly after Ramadan	0.897	(0.735 ; 1.093)

Sample: Indonesian 2-18 years-old Muslim offspring to more religious Muslim mothers, sampled in IFLS waves 1-5 (N= 18,951). Outcome: being stunted, i.e. having a height-for-age z-score < -2 (dummy). Mother fixed effects logistic regressions with 3,038 clusters. Additional control variables: sex, age, age², month of birth, birth year, birth order. This table shows the results of two separate regressions (upper panel: comparison of exposed and conceived shortly after Ramadan vs. not exposed; lower panel: differentiation of the exposure category into pregnancy phases of exposure). Standard errors are clustered at the mother level. The reference group in all analyses are observations of children without prenatal overlap with a Ramadan.
* P < 0.10 ** P < 0.05; ***P < 0.01.

Appendix Table 3-8. Associations between Ramadan during Pregnancy and the Risk for Respiratory Symptoms Occurrence across Age Groups and Pregnancy Trimesters of Overlap with a Ramadan among Indonesian Muslim Children

	(2)	(3)	(4)	(5)
	Exp*2 – 4 years	**Exp*5 – 9 Years**	**Exp*10 – 14 years**	**Exp* 15 – 18 years**
Conceived during Ramadan	0.828	1.456**	0.953	1.259
	(0.540 ; 1.269)	(1.040 ; 2.039)	(0.679 ; 1.338)	(0.903 ; 1.756)
Ram. Start in Trimester 1	1.011	1.146	1.148	1.168
	(0.721 ; 1.419)	(0.877 ; 1.498)	(0.879 ; 1.499)	(0.893 ; 1.530)
Ram. Start in Trimester 2	1.469**	1.144	1.125	1.253
	(1.036 ; 2.082)	(0.852 ; 1.455)	(0.865 ; 1.465)	(0.954 ; 1.648)
Ram. Start in Trimester 3	0.950	1.227	0.906	1.023
	(0.657 ; 1.375)	(0.917 ; 1.641)	(0.681 ; 1.204)	(0.763 ; 1.372)
Born during Ramadan	1.400	1.378*	1.253	1.411**
	(0.865 ; 2.265)	(0.972 ; 1.952)	(0.888 ; 1.768)	(1.002 ; 1.987)
Conceived shortly after	1.454	1.238	1.281	1.468**
Ramadan	(0.906 ; 2.334)	(0.842 ; 1.818)	(0.879 ; 1.866)	(1.011 ; 2.132)
N	12,747			
N of groups	3,147			

Sample of Indonesian children born to more religious Muslim mothers. Outcome: Experienced respiratory symptoms in the last four weeks before the interview. Mother fixed effects logistic regressions. Results are displayed as odds ratios. The coefficients (with confidence intervals) refer to an interaction between the respective exposure category and the respective indicated age group. Additional control variables: age groups (simple main effects, reference: 2-4 years), sex, season of interview, month of birth, year of birth. Standard errors are clustered at the mother level.
* P < 0.10; ** P < 0.05, *** P<0.01

Appendix Table 3-9. Influence of Postnatal Sanitary Standards on the Association between Ramadan during Pregnancy and Height-for-Age Z-Scores among 2-18 year-old Indonesian Muslim Children

Exposure Category	**Improved postnatal sanitary standards**		**Unimproved postnatal sanitary standards**	
	β	95% CI	β	95% CI
In utero during Ramadan	0.023	-0.029 ; 0.075	0.032	-0.039 ; 0.102
Conceived shortly after a Ram.	-0.012	-0.093 ; 0.070	-0.144**	-0.267 ; -0.021
Conceived during Ramadan	0.026	-0.053 ; 0.106	-0.041	-0.146 ; 0.064
Ram. started in trimester 1	0.027	-0.032 ; 0.087	0.044	-0.037 ; 0.125
Ram. started in trimester 2	0.032	-0.029 ; 0.093	0.046	-0.038 ; 0.130
Ram. started in trimester 3	0.014	-0.051 ; 0.079	0.042	-0.044 ; 0.129
Born during Ramadan	-0.002	-0.082 ; 0.007	0.006	-0.098 ; 0.110
Conceived shortly after a Ram.	-0.012	-0.093 ; 0.070	-0.144**	-0.267 ; -0.021

Pooled OLS on the children sample of (2-18 years-old Muslim children from IFLS waves 1-5). The displayed coefficients show the results of an interaction between the respective exposure categories and postnatal sanitary standards. The upper panel shows the results of the comparison of in utero during Ramadan and conceived shortly after Ramadan vs. not exposed; the lower panel the results for a differentiation of the in utero during Ramadan category into pregnancy phases of exposure. Additional control variables: age, age², sex, month of birth, year of birth, urban residency, birth order. Standard errors are clustered at the mother level.

Appendix Table 3-10. Differential Impact of Ramadan during Pregnancy on Height-for-Age Z-Scores among Indonesian Muslim children across Age Groups and by Postnatal Sanitary Standards (Three-Way-Interaction)

Age Group	**Exposure Category**	**Age Group * Exposure Cat.**		**Age Group * Exposure Cat. * Postnatal Improved Sanitation**	
		β_1	95% CI	β_2	95% CI
2-4 years	In utero during Ramadan	0.021	(-0.152 ; 0.193)	0.020	(-0.185 ; 0.226)
	Conceived shortly after a Ram.	-0.024	(-0.264 ; 0.217)	0.180	(-0.113 ; 0.474)
5-9 years	In utero during Ramadan	-0.039	(-0.147 ; 0.069)	0.076	(-0.049 ; 0.200)
	Conceived shortly after a Ram.	-0.199*	(-0.400 ; 0.002)	0.260**	(0.033 ; 0.487)
10-14 years	In utero during Ramadan	-0.028	(-0.141 ; 0.084)	0.022	(-0.110 ; 0.153)
	Conceived shortly after a Ram.	0.002	(-0.202 ; 0.205)	-0.110	(-0.343 ; 0.124)
15-19 years	In utero during Ramadan	-0.092	(-0.237 ; 0.053)	-0.006	(-0.169 ; 0.157)
	Conceived shortly after a Ram.	-0.145	(-0.397 ; 0.108)	0.058	(-0.221 ; 0.336)
N			30,605		
N of groups			7,568		

Sample of Indonesian children born to more religious Muslim mothers. Mother fixed effects regressions. Outcome: height-for-age z-scores. The table displays how the association between Ramadan during pregnancy and height-for-age z-scores varies by age group and postnatal sanitary standards based on a regression including a three-way-interaction between age group, exposure category and postnatal sanitary standards. While the coefficients in the left panel refer to the effects among exposed children growing up under unimproved sanitary standards, the coefficients in the right panel describe how improved sanitation moderates the effects shown in panel B (i.e. $\beta_1 + \beta_2$). Additional control variables: Good sanitary standards (simple main effect), age groups (simple main effects), sex, month of birth, year of birth, birth order. The reference group are 2-4 years-old non-exposed children. Standard errors are clustered at the mother level.
* P < 0.10; ** P < 0.05, *** P<0.01

Appendix Table 3-11. Associations between Ramadan during Pregnancy and Menarche before Age 12 among Ever-Married Indonesian Muslim Women

Exposure Category	OR	95% CI
In utero during Ramadan	1.030	(0.782 ; 1.356)
Conceived shortly after a Ramadan	1.148	(0.752 ; 1.754)
Conceived during Ramadan	0.921	(0.615 ; 1.353)
Ram. Start in Trimester 1	1.014	(0.746 ; 1.378)
Ram. Start in Trimester 2	1.045	(0.766 ; 1.424)
Ram. Start in Trimester 3	1.037	(0.742 ; 1.451)
Born during Ramadan	1.144	(0.780 ; 1.680)
Conceived shortly after a Ramadan	1.147	(0.751 ; 1.752)

Sample: Ever-married Muslim women for whom information on age at menarche is reported (N=3,444). Effects of in utero exposure to Ramadan on early menarche (=1 if menarche before age 12) are displayed as odds ratios. Logistic regressions on a pooled sample of ever-married women interviewed in all IFLS waves that additionally control for month of birth, year of birth and urban/rural residency (at first observation in IFLS). The table shows the results of two separate regressions (upper panel: comparison of exposed vs. not exposed; lower panel: differentiation of the exposed category into pregnancy phases). Robust standard errors are clustered at the household level. * P < 0.10; ** P < 0.05, *** P<0.01

Appendix Table 3-12. Testing the Results of Table 3-3 for Stability to Different Model Specifications

	(1) Main (Table 3-3)	(2)	(3)	(4)	(5)	(6)	(7)
Exp * 2-4 years	0.033	-0.007	0.043	0.030	0.026	0.030	0.023
	(-0.068 ; 0.133)	(-0.095 ; 0.081)	(-0.058 ; 0.143)	(-0.070 ; 0.130)	(-0.074 ; 0.126)	(-0.070 ; 0.130)	(-0.078 ; 0.123)
Exp * 5-9 years	0.016	0.009	0.012	0.015	0.015	0.020	0.021
	(-0.050 ; 0.082)	(-0.053 ; 0.072)	(-0.055 ; 0.079)	(-0.051 ; 0.081)	(-0.051 ; 0.081)	(-0.046 ; 0.086)	(-0.045 ; 0.088)
Exp * 10-14 years	-0.010	0.008	-0.015	-0.012	-0.012	-0.011	-0.006
	(-0.076 ; 0.056)	(-0.054 ; 0.070)	(-0.083 ; 0.052)	(-0.078 ; 0.054)	(-0.078 ; 0.054)	(-0.077 ; 0.055)	(-0.073 ; 0.060)
Exp * 15-19 years	-0.092**	-0.063*	-0.089**	-0.095***	-0.094***	-0.091**	-0.085**
	(-0.163 ; -0.021)	(-0.129 ; 0.003)	(-0.161 ; -0.017)	(-0.166 ; -0.024)	(-0.165 ; -0.023)	(-0.161 ; -0.020)	(-0.156 ; -0.015)
Conceived shortly after Ramadan * 2-4 years	0.090	/	/	0.079	0.071	0.075	0.079
	(-0.057 ; 0.236)			(-0.067 ; 0.225)	(-0.074 ; 0.217)	(-0.071 ; 0.221)	(-0.068 ; 0.227)
Conceived shortly after Ramadan * 5-9 years	-0.015	/	/	-0.017	-0.017	-0.010	-0.004
	(-0.126 ; 0.096)			(-0.128 ; 0.094)	(-0.128 ; 0.094)	(-0.120 ; 0.101)	(-0.116 ; 0.107)
Conceived shortly after Ramadan * 10-14 years	-0.083	/	/	-0.082	-0.083	-0.077	-0.072
	(-0.197 ; 0.032)			(-0.197 ; 0.032)	(-0.198 ; 0.031)	(-0.192 ; 0.038)	(-0.188 ; 0.043)
Conceived shortly after Ramadan * 15-19 years	-0.114*	/	/	-0.115**	-0.116**	-0.117**	-0.115*
	(-0.229 ; 0.000)			(-0.230 ; -0.000)	(-0.230 ; -0.001)	(-0.231 ; -0.002)	(-0.231 ; 0.000)
Control variables/sample							
Age in years	X	x	x			x	x
Age in years²	X	x	x			x	x
Year of birth	X	x	x	x	x	x	
Month of birth	X	x	x	x	x	x	x
Sex	X	x	x	x	x	x	x
Conceived shortly after Ramadan in sample	X	x		x	x	x	x
Conceived shortly after Ramadan interacted with age groups	X			x	x	x	x
Age in days				x			
Age in days²				x			
Birth order	X	x	x	x	x		x
IFLS wave					x		x
N	31,315	31,315	29,532	31,315	31,315	31,315	31,315
N of groups	7,629	7,629	7,459	7,629	7,629	7,629	7,629

Sample of Indonesian Muslim children born to more religious Muslim mothers. Outcome: height-for-age z-scores. Changes undertaken to the main model (1) are indicated in the middle panel. Standard errors are clustered at the mother level in all specifications. * P < 0.10; ** P < 0.05, *** P<0.01

Appendix Table 3-13. Ramadan during Pregnancy and Final Attained Height among Indonesian Non-Muslims

Exposure Category	$\boldsymbol{\beta_1}$	**95% CI**
In utero during Ramadan	-0.058	(-0.722 ; 0.606)
Conceived shortly after Ramadan	-0.093	(-1.120 ; 0.935)
Conceived during Ramadan	-0.327	(-1.230 ; 0.576)
Ram. Start in Trimester 1	-0.105	(-0.832 ; 0.622)
Ram. Start in Trimester 2	-0.164	(-0.916 ; 0.588)
Ram. Start in Trimester 3	0.152	(-0.726 ; 1.030)
Born during Ramadan	0.131	(-0.856 ; 1.118)
Conceived shortly after Ramadan	-0.100	(-1.128 ; 0.927)

Sample: Indonesian Non-Muslims aged 19 and older (N= 3,726). Outcome: height in centimeters. Household fixed effects regressions on a pooled sample of observations of adults in all IFLS waves. Additional control variables: sex, age, age², month of birth, living in an urban area. This table shows the results of two separate regressions (upper panel: comparison of exposed and conceived shortly after Ramadan vs. not exposed; lower panel: differentiation of the exposure category into pregnancy phases of exposure). Standard errors are clustered at the household level.
* P < 0.10 ** P < 0.05; ***P < 0.01.

Appendix Table 3-14. Associations between Ramadan during Pregnancy and Height-for-Age Z-Scores of 2-18 year-old Indonesian Non-Muslim Children

	(1)	(2)	(3)	(4)	(5)	(6)
	2 – 18 years	**Exp*2 – 4 Years**	**Exp*5 – 9 Years**	**Exp*10 – 14 years**	**Exp* 15 – 18 years**	**2 – 18 years (mother fixed effects)**
Not in utero during Ramadan	*Reference*	*Reference*	*Reference*	*Reference*	*Reference*	*Reference*
In utero during Ramadan	-0.015 (-0.156 ; 0.126)	-0.073 (-0.302 ; 0.155)	-0.019 (-0.212 ; 0.174)	0.041 (-0.154 ; 0.237)	-0.025 (-0.283 ; 0.233)	-0.002 (-0.116 ; 0.111)
Conceived shortly after Ramadan	0.015 (-0.203 ; 0.232)	0.033 (-0.386 ; 0.451)	0.014 (-0.278 ; 0.305)	0.066 (-0.210 ; 0.342)	-0.064 (-0.443 ; 0.315)	-0.013 (-0.195 ; 0.168)
Conceived during Ramadan	-0.090 (-0.298 ; 0.117)	-0.207 (-0.556 ; 0.142)	-0.198 (-0.460 ; 0.064)	0.033 (-0.287 ; 0.352)	0.070 (-0.270 ; 0.410)	0.049 (-0.124 ; 0.223)
Ram. Start in Trimester 1	0.039 (-0.118 ; 0.196)	0.007 (-0.266 ; 0.281)	0.074 (-0.146 ; 0.294)	0.052 (-0.162 ; 0.266)	-0.018 (-0.298 ; 0.261)	0.011 (-0.121 ; 0.144)
Ram. Start in Trimester 2	-0.041 (-0.199 ; 0.118)	-0.071 (-0.337 ; 0.196)	-0.088 (-0.300 ; 0.124)	0.057 (-0.169 ; 0.282)	-0.069 (-0.353 ; 0.215)	0.019 (-0.115 ; 0.152)
Ram. Start in Trimester 3	-0.016 (-0.184 ; 0.153)	-0.144 (-0.423 ; 0.136)	-0.042 (-0.275 ; 0.190)	0.073 (-0.170 ; 0.315)	0.020 (-0.270 ; 0.310)	-0.050 (-0.189 ; 0.089)
Born during Ramadan	-0.034 (-0.233 ; 0.166)	-0.070 (-0.401 ; 0.260)	0.098 (-0.169 ; 0.365)	-0.116 (-0.412 ; 0.179)	-0.065 (-0.420 ; 0.291)	-0.045 (-0.206 ; 0.116)
Conceived shortly after Ramadan	0.015 (-0.203 ; 0.233)	0.031 (-0.388 ; 0.450)	0.013 (-0.279 ; 0.306)	0.067 (-0.209 ; 0.344)	-0.058 (-0.437 ; 0.321)	-0.018 (-0.201 ; 0.165)
N				4,844		4,933
N of groups						1,104

Sample of Indonesian children born to Non-Muslim Mothers. Outcome: height-for-age z-scores. Results are shown with (confidence intervals). The upper panel shows the results of the comparison of exposed and conceived shortly after Ramadan vs. not exposed; the lower panel the results for a differentiation of the exposure category into pregnancy phases of exposure.
Columns (1) to (5): Pooled OLS on a pooled sample from all IFLS waves. Column (1) shows the effect of Ramadan during pregnancy on the entire sample of children aged 2 to 18 years, without differentiating by age group. Additional control variables: age, age², sex, month of birth, birth order, year of birth, living in an urban area. In columns (2), (3), (4) and (5), the coefficients refer to an interaction between the exposure category and the respective indicated age group. Additional control variables: age groups 2-4, 5-9, 10-14 and 15-18 (simple main effects, reference: 2-4 years), month of birth, birth order, year of birth, living in an urban area. Standard errors are clustered at the mother level.
Column (6): Mother fixed effects regressions. Additional control variables: age, age², sex, month of birth, birth order, year of birth. Column (6) shows the effect of Ramadan during pregnancy on the entire sample of children aged 2 to 18 years, without differentiating by age group.
* P < 0.10; ** P < 0.05, *** P<0.01

Appendix Table 3-15. Associations between Ramadan during Pregnancy and Age at First Childbirth among Ever-Married Indonesian Non-Muslim Women

Exposure Category	$\boldsymbol{\beta_1}$	**95% CI**
In utero during Ramadan	81.902	(-235.749 ; 399.554)
Conceived shortly after a Ramadan	-279.042	(-876.034 ; 317.950)
Conceived during Ramadan	-262.924	(-754.886 ; 229.008)
Ram. Start in Trimester 1	-160.733	(-537.835 ; 216.369)
Ram. Start in Trimester 2	101.154	(-270.453 ; 472.760)
Ram. Start in Trimester 3	377.643*	(-30.942 ; 786.229)
Born during Ramadan	339.069	(-129.923 ; 808.061)
Conceived shortly after a Ramadan	-297.725	(-902.249 ; 306.799)

Linear regression based on a pooled cross section of ever-married Non-Muslim women for whom information on birth history is available in IFLS (N=1,129). Effects of Ramadan during pregnancy on age at birth of first child is displayed in days. Only live births are taken into consideration. The table shows the results of two separate regressions: The upper panel displays the results of the comparison of in utero during Ramadan and conceived shortly after Ramadan vs. not exposed; the lower panel the results for a differentiation of the in utero during Ramadan category into pregnancy phases of exposure. Additional control variables: year of birth, month of birth, urban residency (at first observation in IFLS). Robust standard errors are clustered at the household level.
* P < 0.10; ** P < 0.05, *** P<0.01

Appendix Table 3-16. Associations between Ramadan during Pregnancy and Height-for-Age Z-Scores in Indonesian Muslim children with Less-Religious Muslim Mothers

	(1) **2 – 18 years**	(2) **Exp*2 – 4 years**	(3) **Exp*5 – 9 years**	(4) **Exp*10 – 14 years**	(5) **Exp* 15 – 18 years**
Not in utero during Ramadan	*Reference*	*Reference*	*Reference*	*Reference*	*Reference*
In utero during Ramadan	0.015 (-0.081 ; 0.111)	0.031 (-0.122 ; 0.183)	0.031 (-0.104 ; 0.166)	0.039 (-0.125 ; 0.203)	-0.064 (-0.234 ; 0.107)
Conceived shortly after Ramadan	-0.132* (-0.282 ; 0.017)	0.007 (-0.256 ; 0.270)	-0.220** (-0.435 ; -0.004)	-0.107 (-0.355 ; 0.140)	-0.151 (-0.418 ; 0.117)
Conceived during Ramadan	-0.051 (-0.197 ; 0.094)	0.106 (-0.133 ; 0.346)	-0.065 (-0.273 ; 0.144)	-0.011 (-0.245 ; 0.222)	-0.208* (-0.443 ; 0.028)
Ram. Start in Trimester 1	0.000 (-0.113 ; 0.114)	0.046 (-0.140 ; 0.233)	0.039 (-0.119 ; 0.196)	-0.024 (-0.209 ; 0.162)	-0.070 (-0.267 ; 0.128)
Ram. Start in Trimester 2	0.094* (-0.018 ; 0.206)	0.046 (-0.139 ; 0.231)	0.100 (-0.053 ; 0.253)	0.184* (-0.004 ; 0.372)	-0.033 (-0.226 ; 0.160)
Ram. Start in Trimester 3	-0.047 (-0.165 ; 0.070)	-0.113 (-0.322 ; 0.095)	-0.023 (-0.189 ; 0.143)	-0.071 (-0.262 ; 0.120)	0.024 (-0.194 ; 0.242)
Born during Ramadan	0.031 (-0.106 ; 0.168)	0.212* (-0.037 ; 0.460)	-0.023 (-0.209 ; 0.163)	0.041 (-0.169 ; 0.252)	-0.090 (-0.336 ; 0.156)
Conceived shortly after Ramadan	-0.131* (-0.280 ; 0.019)	0.011 (-0.253 ; 0.274)	-0.221** (-0.436 ; -0.006)	-0.102 (-0.349 ; 0.145)	-0.147 (-0.415 ; 0.122)
N				7,438	

Sample of Indonesian Muslim children born to less-religious Muslim Mothers. Outcome: height-for-age z-score. Pooled OLS. Results are shown with (confidence intervals). Pooled sample of all IFLS waves. The table shows the results of two separate regressions (upper panel: comparison of exposed vs. not exposed; lower panel: differentiation of the exposed category into pregnancy phases). Robust standard errors are clustered at the mother level. Column (1) shows the effects of Ramadan during pregnancy on the entire sample of children aged 2 to 18 years, without differentiating by age group. Additional control variables: age, age², sex, month of birth, birth order, year of birth, living in an urban area.

Columns (2), (3), (4) and (5) represent the interaction between the exposure category and the respective indicated age group. Additional control variables: age groups (simple main effects, reference: 2-4 years), sex, month of birth, birth order, year of birth, living in an urban area.

* P < 0.10; ** P < 0.05, *** P<0.01

Appendix Table 3-17. Associations between Ramadan during Pregnancy and Risk of Respiratory Symptoms Occurrence among 2-18 year-old Indonesian Offspring to Less-Religious Muslim Mothers

	(1) **2 – 18 years**	(2) **Exp*2 – 4 Years**	(3) **Exp*5 – 9 Years**	(4) **Exp*10 – 14 years**	(5) **Exp* 15 – 18 years**	(6) **2 – 18 years (mother fixed effects)**
Not in utero during Ramadan	*Reference*	*Reference*	*Reference*	*Reference*	*Reference*	*Reference*
In utero during Ramadan	1.062 (0.891 ; 1.265)	0.972 (0.722 ; 1.309)	1.489** (1.075 ; 2.064)	0.634 (0.550 ; 1.137)	0.920 (0.593 ; 1.429)	1.004 (0.773 ; 1.304)
Conceived shortly after Ramadan	0.925 (0.675 ; 1.269)	0.563* (0.305 ; 1.039)	1.494 (0.884 ; 2.524)	0.636 (0.340 ; 1.190)	1.051 (0.550 ; 2.011)	1.102 (0.699 ; 1.738)
Conceived during Ramadan	0.940 (0.718 ; 1.231)	1.060 (0.618 ; 1.818)	1.237 (0.773 ; 1.978)	0.748 (0.416 ; 1.343)	0.687 (0.375 ; 1.259)	0.755 (0.497 ; 1.148)
Ram. Start in Trimester 1	1.114 (0.913 ; 1.359)	0.851 (0.596 ; 1.214)	1.573** (1.086 ; 2.271)	0.917 (0.607 ; 1.386)	1.005 (0.611 ; 1.652)	1.113 (0.821 ; 1.509)
Ram. Start in Trimester 2	1.079 (0.884 ; 1.318)	0.882 (0.601 ; 1.294)	1.593** (1.113 ; 2.281)	0.741 (0.494 ; 1.111)	1.076 (0.648 ; 1.785)	0.993 (0.736 ; 1.340)
Ram. Start in Trimester 3	1.069 (0.853 ; 1.341)	1.140 (0.732 ; 1.776)	1.266 (0.837 ; 1.916)	0.849 (0.535 ; 1.347)	0.964 (0.556 ; 1.673)	1.015 (0.735 ; 1.401)
Born during Ramadan	0.979 (0.754 ; 1.271)	1.494 (0.849 ; 2.632)	1.348 (0.856 ; 2.122)	0.640* (0.378 ; 1.085)	0.645 (0.339 ; 1.228)	0.982 (0.667 ; 1.447)
Conceived shortly after Ramadan	0.926 (0.675 ; 1.269)	0.560* (0.303 ; 1.035)	1.486 (0.879 ; 2.512)	0.647 (0.346 ; 1.211)	1.051 (0.548 ; 2.015)	1.100 (0.697 ; 1.737)
N				4,980		2,809
N of groups						746

Sample of Indonesian children born to less-religious Muslim Mothers. Outcome: respiratory symptoms in the last four weeks before the interview. Results are displayed as odds ratios and shown with (confidence intervals). The upper panel shows the results of the comparison of exposed and conceived shortly after Ramadan vs. not exposed; the lower panel the results for a differentiation of the exposure category into pregnancy phases of exposure. Columns (1) to (5): Logistic regression on a pooled sample from all IFLS waves. Column (1) shows the effect of Ramadan during pregnancy on the entire sample of children aged 2 to 18 years, without differentiating by age group. Additional control variables: age, age², sex, month of birth, year of birth, living in an urban area. In columns (2), (3), (4) and (5), the coefficients refer to an interaction between the exposure category and the respective indicated age group. Additional control variables: age groups (simple main effects, reference: 2-4 years), month of birth, year of birth, living in an urban area. Standard errors are clustered at the mother level.

Column (6): Mother fixed effects logistic regression. Column (6) shows the effect of Ramadan during pregnancy on the entire sample of children aged 2 to 18 years, without differentiating by age group. Additional control variables: age, age², sex, month of birth, year of birth. Note that 2,242 observations were dropped from the sample due to all positive or all negative outcomes among children to the same mother.

* P < 0.10; ** P < 0.05, *** P<0.01

Appendix Table 3-18. Associations between Ramadan during Pregnancy and Risk of Respiratory Symptoms Occurrence among 2-18 year-old Indonesian Offspring to More-Religious Muslim Mothers (logistic regression without mother fixed effects)

	(1) **2 – 18 years**	(2) **Exp*2 – 4 Years**	(3) **Exp*5 – 9 Years**	(4) **Exp*10 – 14 years**	(5) **Exp* 15 – 18 years**
Not in utero during Ramadan	*Reference*	*Reference*	*Reference*	*Reference*	*Reference*
In utero during Ramadan	1.117**	1.095	1.052	1.123	1.175
	(1.019 ; 1.224)	(0.919 ; 1.304)	(0.888 ; 1.247)	(0.935 ; 1.349)	(0.969 ; 1.426)
Conceived shortly after Ramadan	1.199**	1.254	0.968	1.373**	1.203
	(1.034 ; 1.392)	(0.912 ; 1.722)	(0.736 ; 1.273)	(1.036 ; 1.822)	(0.883 ; 1.638)
Conceived during Ramadan	1.145**	0.986	1.282**	1.019	1.211
	(1.004 ; 1.307)	(0.742 ; 1.311)	(1.000 ; 1.642)	(0.780 ; 1.330)	(0.928 ; 1.580)
Ram. Start in Trimester 1	1.122**	0.990	1.043	1.214*	1.193
	(1.012 ; 1.244)	(0.804 ; 1.218)	(0.861 ; 1.264)	(0.989 ; 1.482)	(0.960 ; 1.482)
Ram. Start in Trimester 2	1.134**	1.269**	0.980	1.168	1.219*
	(1.024 ; 1.258)	(1.026 ; 1.569)	(0.811 ; 1.185)	(0.953 ; 1.431)	(0.979 ; 1.518)
Ram. Start in Trimester 3	1.037	0.996	1.104	0.950	1.067
	(0.925 ; 1.163)	(0.780 ; 1.273)	(0.896 ; 1.361)	(0.760 ; 1.189)	(0.842 ; 1.351)
Born during Ramadan	1.183**	1.285	1.118	1.174	1.165
	(1.035 ; 1.352)	(0.939 ; 1.758)	(0.875 ; 1.430)	(0.908 ; 1.520)	(0.887 ; 1.530)
Conceived shortly after Ramadan	1.199**	1.263	0.977	1.357**	1.206
	(1.034 ; 1.392)	(0.919 ; 1.735)	(0.743 ; 1.285)	(1.023 ; 1.800)	(0.885 ; 1.642)
N				19,973	

Sample of Indonesian children born to more religious Muslim mothers. Outcome: Experienced respiratory symptoms in the last four weeks before the interview. Logistic regressions based on a pooled sample of observations of all IFLS waves. Results are displayed as odds ratios. Standard errors are clustered at the mother level. Column (1) shows the effect of Ramadan during pregnancy on the entire sample of children aged 2 to 18 years, without differentiating by age group. Additional control variables: age, age², sex, month of birth, year of birth, living in an urban area. In columns (2), (3), (4) and (5), the coefficients refer to an interaction between the exposure category and the respective indicated age group. Additional control variables: age groups (simple main effects, reference: 2-4 years), month of birth, year of birth, living in an urban area.

* P < 0.10; ** P < 0.05, *** P<0.01

Appendix Table 3-19. Associations between Ramadan during Pregnancy and Height-for-Age Z-Scores among Indonesian Muslim Children to More Religious Muslim Mothers (pooled OLS, i.e. without mother fixed effects)

	(1) 2 – 18 years	(2) Exp*2 – 4 years	(3) Exp*5 – 9 years	(4) Exp*10 – 14 years	(5) Exp* 15 – 18 years
Not in utero during Ramadan	*Reference*	*Reference*	*Reference*	*Reference*	*Reference*
In utero during Ramadan	0.029 (-0.019 ; 0.077)	0.094** (0.003 ; 0.186)	0.013 (-0.055 ; 0.081)	0.024 (-0.046 ; 0.094)	-0.015 (-0.092 ; 0.061)
Conceived shortly after Ramadan	-0.029 (-0.107 ; 0.050)	0.071 (-0.071 ; 0.214)	-0.040 (-0.150 ; 0.071)	-0.023 (-0.142 ; 0.096)	-0.116 (-0.239 ; 0.007)
Conceived during Ramadan	0.012 (-0.060 ; 0.084)	0.072 (-0.069 ; 0.213)	0.007 (-0.096 ; 0.110)	0.048 (-0.056 ; 0.153)	-0.101* (-0.214 ; 0.012)
Ram. Start in Trimester 1	0.042 (-0.112 ; 0.096)	0.083 (-0.022 ; 0.188)	0.063 (-0.124 ; 0.139)	0.023 (-0.057 ; 0.103)	-0.013 (-0.099 ; 0.074)
Ram. Start in Trimester 2	0.024 (-0.032 ; 0.080)	0.087 (-0.022 ; 0.197)	-0.009 (-0.087 ; 0.068)	0.026 (-0.056 ; 0.107)	-0.005 (-0.092 ; 0.081)
Ram. Start in Trimester 3	0.043 (-0.016 ; 0.102)	0.115* (-0.003 ; 0.234)	0.002 (-0.081 ; 0.234)	0.051 (-0.034 ; 0.135)	0.008 (-0.085 ; 0.102)
Born during Ramadan	-0.005 (-0.770 ; 0.067)	0.138* (-0.005 ; 0.280)	-0.051 (-0.151 ; 0.049)	-0.046 (-0.152 ; 0.060)	0.005 (-0.105 ; 0.114)
Conceived shortly after Ramadan	-0.029 (-0.107 ; 0.050)	0.072 (-0.071 ; 0.214)	-0.040 (-0.150 ; 0.071)	-0.023 (-0.142 ; 0.097)	-0.116* (-0.238 ; 0.007)
N				30,730	

Sample of Indonesian Muslim children born to more-religious Muslim Mothers. Outcome: height-for-age z-score. Pooled OLS on a pooled sample of observations of all IFLS waves. Results are shown with (confidence intervals). The table shows the results of two separate regressions (upper panel: comparison of exposed vs. not exposed; lower panel: differentiation of the exposed category into pregnancy phases). Robust standard errors are clustered at the mother level.

Column (1) shows the effects of Ramadan during pregnancy on the entire sample of children aged 2 to 18 years, without differentiating by age group. Additional control variables: age, age², sex, month of birth, birth order, year of birth, living in an urban area.

Columns (2), (3), (4) and (5) represent the interaction between the exposure category and the respective indicated age group. Additional control variables: age groups (simple main effects, reference: 2-4 years), sex, month of birth, birth order, year of birth, living in an urban area.

* P < 0.10; ** P < 0.05, *** P<0.01

Chapter 4
Ramadan Observance during Pregnancy in Germany: a Challenge for Prenatal Care

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This chapter has been published in Geburtshilfe und Frauenheilkunde:

English version: Leimer, B., Pradella, F., Fruth, A., Queißer, A., & van Ewijk, R. (2018). Ramadan observance during pregnancy in Germany: A challenge for prenatal care. Geburtshilfe und Frauenheilkunde, 78(7), 684-689.

German version: Leimer, B., Pradella, F., Fruth, A., Queißer, A., & van Ewijk, R. (2018). Ramadan während der Schwangerschaft in Deutschland: eine Herausforderung für die Schwangerschaftsvorsorge. Geburtshilfe und Frauenheilkunde, 78(7), 684-689.

This research was funded by the German Research Foundation (DFG grant 260639091).

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4.1. Introduction

Prenatal exposure to Ramadan has been shown to have negative effects on the offspring's physical and cognitive health. Increased risks for symptoms indicative of type 2 diabetes and coronary heart disease (Van Ewijk, 2011) as well as lower BMI in adulthood (Van Ewijk et al., 2013) have been reported. Negative effects on cognitive health outcomes such as lower performance in schools (Almond & Mazumder, 2011; Almond et al., 2015; Majid, 2015) and negative effects on labor market participation (Majid, 2015) have also been identified. Due to these negative health effects on the offspring, it is important that medical personnel who interact with pregnant Muslim women are sensitized to the customs and behavior during Ramadan. As the number of Muslims in Germany has increased to over 5% of the total population and is expected to increase further in the future (Stichs, 2016) , this is becoming an increasing concern for medical professionals in Germany.

The negative health effects of prenatal Ramadan exposure are generally attributed to maternal fasting during pregnancy. Ramadan lasts 29 – 30 days and requires the abstinence from food and drink during daylight hours. Among pregnant women who adhere to this diurnal fasting, low serum levels of glucose and alanine as well as elevated levels of free fatty acids have been found (Prentice et al., 1983; Arab, 2004). Pregnant women skipping meals quickly reach states similar to those of starvation ('accelerated starvation') (Metzger et al., 1982; Meis et al., 1984). Due to the lack of metabolic fuel and the accompanying changes to hormone levels in the blood, negative health effects are expected in the offspring. This can be placed into a broader literature of fetal programming, which has shown that impaired in utero growth due to malnutrition increases the risk of chronic diseases in adulthood (Godfrey & Barker, 2001; Barker, 2004a).

Whether or not pregnant women should fast during Ramadan depends on the interpretation of the Quran, though studies in various countries generally find that a considerable percentage of women fast. Different studies have found that the proportion of pregnant women who fast for at least one day during Ramadan varies from 87% in southeast Michigan, USA (Robinson & Raisler, 2005) and in Singapore (Joosoph et al., 2004), to 54% in the Netherlands (Savitri et al., 2014) and 43% in Bradford, UK (Petherick et al., 2014). As immigrant and Muslim populations differ across European countries, studies on Ramadan fasting practices during pregnancy in some countries do not allow inference to be made about other countries. No data exists to date for Ramadan adherence and behavior in Germany.

To fill this gap, the Mainz Study of Ramadan and Pregnancy was conducted in the obstetric wards in Mainz (Germany) to collect data on the fasting behavior of pregnant Muslim women. The study offers insights about which women in Germany decide to fast and why. We also investigated behavioral changes, such as changes in the types of foods women consumed even on those days when they did not fast. Our goal is to contribute to the development of patient information services related to Ramadan fasting during pregnancy for Muslims living in Germany.

4.2. Materials and methods

4.2.1. Data acquisition

A survey was conducted among pregnant Muslims and new Muslim mothers in both obstetric wards in Mainz between October 2016 and January 2017. In Germany, almost all women give birth in hospital (98.6% of live births in 2014, 98.8% of live births in 2015), so our study is representative for almost all births in Mainz (Statistical Office Rhineland-Palatinate, 2018) . As women in Germany usually stay in hospital for 2 – 3 days after giving birth (Gesundheitsberichterstattung des Bundes, 2017), the interviews were held on three days per week in order to approach most of the relevant population. All Muslim women were asked to participate, whether or not they fasted during Ramadan. Relevant women were identified by either having indicated 'Muslim' as their religion on the clinic’s patient registration form or by their name.

In addition to asking women about their fasting decision and the number of days they fasted, the questionnaire included questions on nutritional changes during Ramadan, even on those days on which women did not fast. We also inquired about the reasons why women decided to fast or not to fast. Lastly, personal details were collected, including the country of origin and the amount of time spent in Germany. This last question is of particular interest to identify recent refugees, who might differ from Muslims born or raised in Germany in terms of their religious traditions and beliefs.

Surveys were conducted in the participant’s mother tongue as often as possible. For this purpose, two research assistants, who spoke Arabic and Turkish in addition to German, were hired and trained to conduct the interviews. Most interviews were conducted in German (46%), followed by Arabic (34%), Turkish (19%) and English (1%). Before the interview, all participants were asked to sign an informed consent and after the interview, all data were pseudonymized. The study was approved by the Ethics Committee of the Rhineland-Palatinate State Chamber of Medicine (Ethikkommission der Landesärztekammer Rheinland-Pfalz).

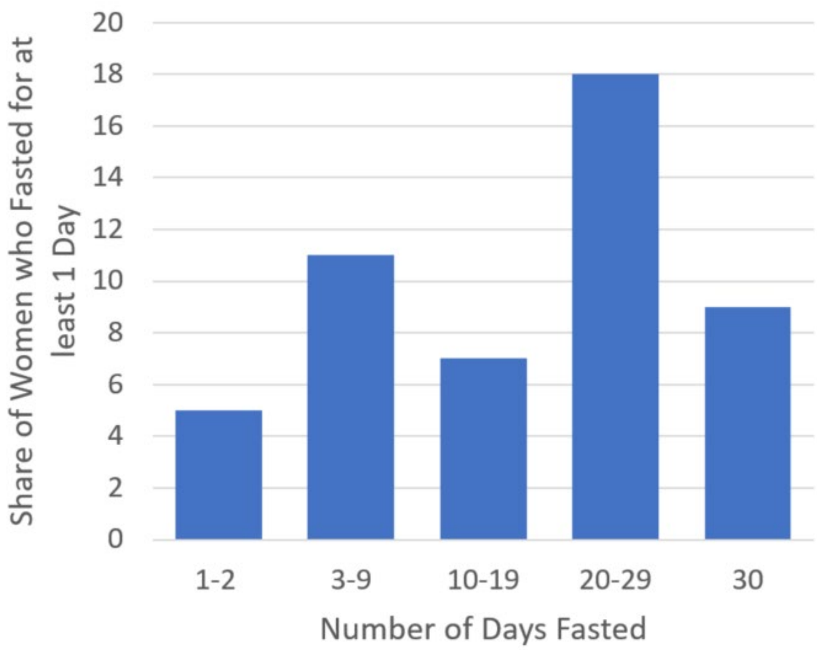
4.2.2. Statistical analysis

Statistical analysis was used to investigate whether there are differences between women who fasted and women who did not fast during Ramadan. T-test and Mann-Whitney test (for ordinal variables such as education) and χ^2-test (for categorical variables such as employment status) were used to identify differences in mean values between groups. The significance level was set at $p < 0.05$. Stata 15 was used for all statistical analyses.

4.3. Results

Of the women approached to participate in the study, 71% participated in the study (n = 116). Overall, we were able to approach 51% of the relevant population and ask them to participate. The main reasons for not being able to approach all of the women were language barriers and if women had already been discharged. Other reasons included the presence of visitors or if women were asleep or not in the room.

Figure 4-1: Distribution of Number of Days Fasted



Distribution of number of days fasted (among the women who fasted for at least 1 day). The figure shows the percentage of pregnant women who fasted for at least one day during Ramadan (n = 50) and how many days they fasted. The classification is based on a personal survey of the pregnant women, who were asked to categorize the number of days they fasted by choosing one of the following options: on a few days (1 – 2), on some days (3 – 9), on about half of the days (10 – 19), on most days (20 – 29), and on all days (30). Many women reported the exact number of days they fasted, and the classification into categories was then done by the project team.

4.3.1. Fasting behavior

Of the interviewed women, 43% stated that they had fasted for at least one day during their pregnancy. Of these women, the majority (54%) fasted between 20 and 30 days (Figure 4-1). Table 4-1 shows that there were some differences between the groups of fasting and non-fasting women.

Women who fasted during pregnancy were significantly younger, less educated and more likely to wear a veil during the interview.

Women were asked about the reasons (multiple answers were possible) they fasted during Ramadan. Religious reasons and religious obligation were referenced by 64% of the women. Almost one quarter of the women (24%) said that they fasted because they wanted to try fasting while pregnant. Women who stopped fasting after a few days explained that they had wanted to fast but were not able to continue because they felt too sick and weak[27]. Women who decided not to fast indicated that they did not fast because of their pregnancy or because they were worried about their baby's health. Five women (4%) indicated that they did not fast during their pregnancy because they never fast.

4.3.2. Nutrition during Ramadan

Half of the women who fasted stated that they had adapted their Ramadan eating habits to being pregnant (e.g. "healthier", "regular food intake throughout the night", "drinking more"). On the days they did not fast, 43% of all women changed their diet because of religious traditions such as breaking their fast at night with sweet food.

4.3.3. Living environment

Fasting women were more likely to live with household members who fasted. Irrespective of the woman's decision about fasting, very few partners of pregnant Muslims believed that pregnant women should fast. Of the women who fasted at least one day during their pregnancy, 6% of the partners were reported to believe that pregnant women should fast. The partners of the other women either believed that pregnant women should not fast (48%), had no opinion (16%) or thought it was up to the woman to decide, depending on her health (30%).

4.3.4. Country of origin

Most of the participants (77%) had immigrated to Germany themselves and were thus first-generation immigrants. The majority of first-generation immigrant women were born in Morocco (26%), Syria (24%) or Turkey (21%). The parents of women who were born in Germany (23%, second-generation immigrants) had mainly emigrated from Turkey (ca. 60%) and Morocco (ca. 20%). No participating woman had parents who were both born in Germany. There was no significant difference in terms of country of origin between those women who fasted and those who did not (see Table 4-1).

[27] The women reported that they had experienced nausea, circulatory problems, dizziness and headaches.

Table 4-1. Characteristics of fasting and non-fasting pregnant Muslims

	Did not fast	Fasted	p-value
N	66	50	
Age	31.9	29.2	0.014 [1)]
Education			
Did not complete secondary education	2%	7%	0.007 [2)]
Completed secondary education	41%	65%	
Vocational training	26%	12%	
University degree	31%	16%	
Birth country			
Born in Germany	26%	20%	0.375 [3)]
Lived in Germany <2 years (not born in Germany)	24%	36%	
Lived in Germany ≥2 years (not born in Germany)	50%	44%	
Opinions			
Fasting has negative effects on child	67%	20%	< 0.001 [3)]
Fasting has negative effects on mother	59%	26%	< 0.001 [3)]
My partner thinks pregnant women should fast	8%	6%	0.740 [3)]
Living environment			
Other household members fasted	80%	97%	0.019 [3)]
Advice sought from gynecologist/midwife	38%	49%	0.221 [3)]
First pregnancy	42%	32%	0.252 [3)]
Veiled/wore a headscarf during the interview	23%	41%	0.049 [3)]

1) t-test
2) Mann-Whitney-test
3) χ^2-test

Note: The table summarizes the characteristics of fasting and non-fasting pregnant women. The investigation into the expected effect of fasting on mother or child asked respondents about the effect fasting had on the health of the child or mother, giving them the option of no effect, positive effect, negative effect. The beliefs of the woman's partner were elicited by asking whether the respondent's partner thought pregnant women should not fast, should fast, or had no opinion.

4.3.5. Advice of gynecologists and midwives

Less than half of the women who fasted (49%) and even fewer of the women who did not fast (38%) discussed their behavior during Ramadan with medical professionals. Only two women (2%) indicated that their doctor had proactively addressed the issue. Of the consulted medical professionals, 73% had advised the pregnant woman not to fast. Some gynecologists left the decision to the woman (e.g. "if you want to, you can try", "it is up to you, although I would not do it") while others stated that fasting during pregnancy was not risky (e.g. "there are no negative effects as you are in early pregnancy", "if you can manage to fast, it is no problem").

4.4. Discussion

The Mainz Study of Ramadan and Pregnancy is the first study to collect data on the behavior of pregnant Muslims during Ramadan in Germany. We asked 116 pregnant Muslims and new Muslim mothers whether they observed Ramadan and how they behaved during Ramadan while pregnant. Their responses revealed that Ramadan fasting during pregnancy is a relevant topic in Germany, as 43% of the respondents fasted for at least one day. Due to the various negative long-term health consequences of prenatal exposure to fasting for Ramadan, Ramadan fasting during pregnancy should be addressed during prenatal care in Germany.

Our study shows that younger women and women with lower levels of education had a higher tendency to fast in Germany. Consequently, health workers should focus especially on these women when discussing Ramadan behavior during pregnancy. Among the gynecologists and midwives who were asked for advice by our participants, 73% discouraged the women from fasting; nevertheless, a considerable percentage of women (27%) reported that they were not made aware of the potential negative effects. The fact that most women did not ask their doctor or midwife for advice both highlights the sensitivity of this religious issue and the importance of health workers proactively addressing Ramadan behavior during pregnancy with their patients.

The challenge for all attempts to offer counseling is that Ramadan fasting during pregnancy is a highly sensitive religious topic. (Perceived) expectations among the religious community may also play a role in a woman's decision whether or not to fast. Otherwise, it is hard to explain why many women who fasted during pregnancy observed Ramadan even though they believed that fasting could harm their child's health (18% of the fasting women) or their own health (22% of the fasting women)[28]. In contrast, the partners of the pregnant women in our sample were largely opposed to fasting during pregnancy or left the decision to the woman. Only 6% of partners of fasting women were reported to believe that pregnant women should fast (8% of the partners of non-fasting women). It is worth noting that 48% of the fasting women decided to fast, even though their partner indicated that pregnant women should not fast.

The results of the Mainz Study of Ramadan and Pregnancy add to our understanding of the behavior of pregnant Muslim women in Europe. The generalization of the study results to other years and countries should, however, be done with caution, as Ramadan shifts over the years in the Gregorian calendar and the number of daylight hours during which fasting is mandated thus varies. Moreover, immigrant populations differ across European countries. So far, data on Ramadan fasting during pregnancy in Europe are available for the United Kingdom and the Netherlands. In the United Kingdom, 43% of 310 interviewed pregnant Muslim women of Asian or Asian British ethnicity reported fasting during Ramadan 2010 (Petherick et al., 2014). In 2010, Ramadan took place from

[28] See Appendix Figure 4-1 and Appendix Figure 4-2 for an overview of opinions on the effects of Ramadan fasting during pregnancy among fasting and non-fasting survey participants.

the middle of August to the middle of September, fasting hours were thus shorter than in 2016. Similar to our results, better educated women and older women were less likely to fast. In the Netherlands, Savitri et al. (2014) conducted a study on Ramadan 2010. Of the 130 interviewed women, 54% fasted at least one day during their pregnancy. In contrast to our results and the study in the United Kingdom, Savitri et al. (2014) did not find differences with respect to age or level of education between fasting and non-fasting pregnant Muslims.

It is known that fetal development can be impaired by prenatal malnutrition. Since fasting is a central aspect of Ramadan, previous research has mostly focused on the effects of fasting itself. However, it is possible that other behaviors during Ramadan, in addition to the decision to fast, may negatively affect the offspring. We therefore examined the changes in nutrition during Ramadan, including on those days on which women did not fast. We found that Ramadan also impacted the nutrition of non-fasting pregnant women, as they often lived in households where other members were fasting and participated in religious traditions such as the breaking of the fast after sunset, which is traditionally celebrated with sweet foods and drinks. Consequently, counseling on Ramadan during pregnancy should target both women who fast and women who do not. Moreover, due to a shift in daily routines (e.g., the preparation of breakfast before dawn, dinner after sunset), sleep patterns during Ramadan may also be altered significantly in both fasting and non-fasting individuals (Roky et al., 2001; BaHammam, 2005; BaHammam et al., 2013). Previous research has shown that sleep deprivation during pregnancy affects maternal health and fetal birth outcomes (Chang et al., 2010; Reutrakul et al., 2018). Therefore, in a follow-up study, we will be exploring the changes in sleep patterns during Ramadan.

The main strength of this study was that we did not rely on registry data but conducted a survey in which we asked the women themselves for detailed information about their religious observance and behavior during Ramadan. For the first time, it was possible to investigate the eating behavior of pregnant women during Ramadan beyond the binary decision to fast. It should also be noted that it is very likely that the percentage of fasting pregnant women will vary, depending on when Ramadan occurs in the Gregorian calendar. Lower fasting rates should be expected during the summer months, as occurred in Ramadan 2016 when fasting times were very long and temperatures were high.

Even though the present study is limited by its sample size, we were able to approach a large percentage of affected women in the two obstetric wards in Mainz and had a high response rate. Our results are therefore unlikely to suffer from a large selection bias. However, the survey mainly interviewed women who delivered between October 2016 and January 2017[29]. The overlap between Ramadan 2016 (from the beginning of June until the beginning of July) and pregnancy therefore mainly occurred during the second trimester of pregnancy. In a follow-up study, we intend to study fasting rates across all trimesters of pregnancy.

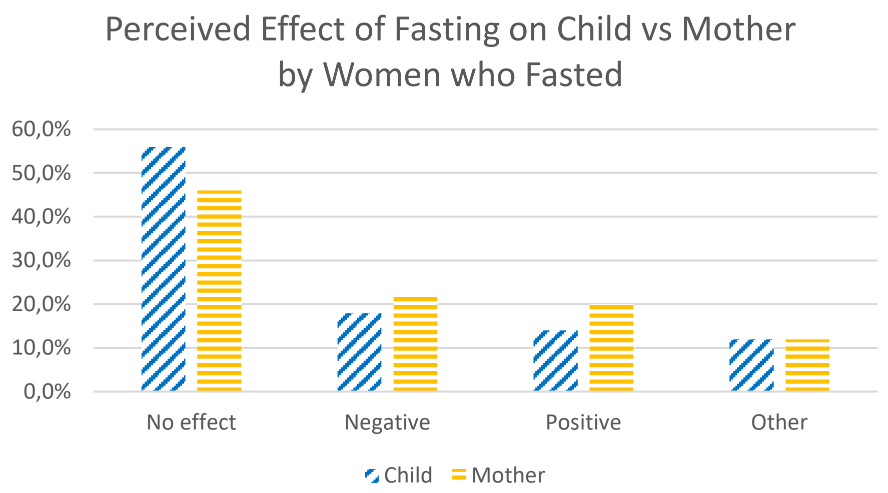
4.5. Conclusion

Ramadan fasting during pregnancy is a very relevant topic for Germany, especially in light of the growing Muslim population. Of the interviewed women, 43% fasted at least 1 day during their pregnancy. The majority of women who decided to fast fasted for more than 20 days. These women decided to fast during pregnancy, even though a large percentage of the women and their partners did not believe it was obligatory to fast. Our findings show that younger and less educated women and pregnant Muslims who wore a headscarf during the interview were more likely to fast. Due to the various long-term negative health effects of in utero exposure to Ramadan fasting and the low percentage of pregnant Muslims who seek advice from medical professionals, gynecologists, midwives and other health workers need to be sensitized and trained to proactively address this sensitive religious topic with their patients. To ensure that women make an informed decision about whether or not to fast, it is important that women receive objective information from health workers about the potential effects of their decision.

[29] Our results refer only to inpatient deliveries, as we could not approach Muslim women who opted for a home birth or outpatient delivery. However, inpatient deliveries with hospital stays for 2–3 days are standard in Germany, and very few women choose other options (Statistical Office Rhineland-Palatinate, 2018).

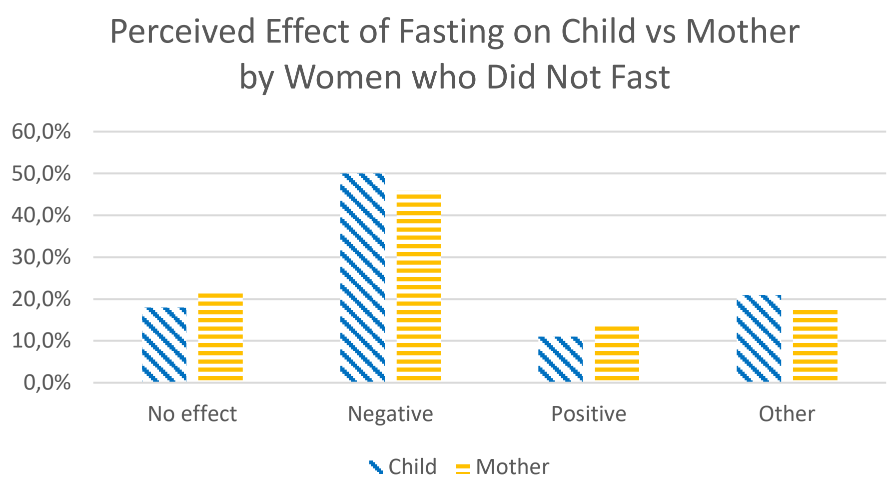
Appendix Chapter 4. Further descriptives

Appendix Figure 4-1. Perceived Effect of Fasting on the Health of the Child and the Mother, Women who Fasted at Least One Day



The figure displays the perceived effect of fasting during pregnancy on the health of the child and the mother among women who fasted at least one day during their pregnancy (Survey question: What effect do you think fasting during Ramadan has on the health of the unborn child? No effect / Negative effect / Positive effect / Other opinion). Several women in the category 'other' indicated that they think that the health effects depend on the health status of the woman fasting during pregnancy.

Appendix Figure 4-2. Perceived Effect of Fasting on the Health of the Child and the Mother, Women who Did Not Fast



The figure displays the perceived effect of fasting during pregnancy on the health of the child and the mother among women who did not fast during their pregnancy (Survey question: What effect do you think fasting during Ramadan has on the health of the unborn child? No effect / Negative effect / Positive effect / Other opinion). Several women in the category 'other' indicated that they think that the health effects depend on the health status of the woman fasting during pregnancy.

Chapter 5
Beyond Fasting: Maternal Dietary and Sleep Changes during Ramadan and their Effects on Birth Outcomes

by Fabienne Pradella*[30] and Birgit Leimer*[31]

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This research was funded by the German Research Foundation (DFG grant 260639091).

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5.1. Introduction

Shocks experienced while in utero affect health throughout the entire life, which is particularly relevant from an economic perspective since health is an integral component of human capital (Heckman, 2007; Currie & Almond, 2011; Attanasio, 2015). While many studies focus on the effects after exposure to famines and other extreme events, the question has been posed whether milder forms of in utero experiences also have negative effects. To investigate if less severe changes to maternal nutrition affect the offspring, researchers have studied the health effects of Ramadan during pregnancy. Ramadan is the ninth month of the Islamic calendar, in which all able-bodied Muslim adults are required to abstain from food and drink during daylight hours for 29-30 days. They have shown that prenatal exposure to Ramadan increases the risks for symptoms of type 2 diabetes, coronary heart disease (Van Ewijk, 2011) and respiratory disease (chapter 2 of this dissertation) as well as small stature and thinness (Van Ewijk et al., 2013). It has also been linked to increases in child mortality (Schoeps et al., 2018) and an increased risk for mental and learning disabilities (Almond & Mazumder, 2011). Research on birth outcomes has been less clear, with some evidence showing lower birthweight among exposed children (Almond & Mazumder, 2011; Savitri et al., 2014), while others found no effect on birthweight (Petherick et al., 2014; Jürges, 2015; Savitri et al., 2018).

The identified effects in response to Ramadan during pregnancy have been attributed to the fasting decision of the mothers. While intermittent fasting during daylight hours is central to the observance of Ramadan, it is accompanied by other nutritional and behavioral changes. For example, Ramadan is marked by dietary adjustments, as the breaking of the fast is traditionally celebrated with foods of high sugar and fat content (Fedail et al., 1982; Ibrahim et al., 2008; Trepanowski & Bloomer, 2010). Furthermore, sleep behavior is adapted during Ramadan as food and drink intake as well as its preparation is shifted to night hours (Roky et al., 2001; BaHammam, 2005; BaHammam et al., 2013). It is unclear whether these dietary and behavioral adjustments themselves or in combination with fasting behavior may explain part of the previously found negative effects.

To gain a clearer understanding whether effects of maternal Ramadan behavior can be identified at birth as well as of the underlying channels through which Ramadan affects health, we conducted the *Mainz Survey Study on Ramadan and Pregnancy* in Mainz, Germany. We collected information on the fasting decision and fasting intensity of the Muslim women giving birth in Mainz. We are among the first survey studies to collect information on further adjustments to Ramadan, including changes to the types of food consumed as well as changes to the sleeping patterns during Ramadan.

We are also the first study to systematically collect information on an entire cohort of women exposed to a Ramadan, from the women giving birth on the first day of Ramadan 2017 to the women conceiving on the last day of Ramadan 2017. Through the systematic identification and approach of Muslim women in the hospitals in Mainz, we were able to gather information on all possible stages of pregnancy overlapping with Ramadan.

We find that fasting during pregnancy is common among Muslims in Mainz, Germany. The final sample includes 303 women, 38% of whom fasted for at least one day during Ramadan 2017. Out of the women who fasted, 50% reported fasting between 20 and 29 days. Fasting is most common if Ramadan falls into the first pregnancy trimester, where 52% of the women reported fasting for at least one day, driven by women conceiving during Ramadan, with a fasting rate of 86%. Fasting rates are also strongly dependent on the country of birth, with the highest fasting rates (between 63-75%) among women born in Morocco, Syria and other Arab countries.

We show that fasting has a negative effect on birthweight, while not affecting the 5-minute APGAR score and gestational age at birth. The timing of fasting as well as the fasting intensity influence the magnitude of the effect. Fasting during the first pregnancy trimester has a strong, negative effect on birthweight, while fasting during other pregnancy trimesters does not significantly affect birthweight. The effect of fasting increases with the number of days fasted. The effect of fasting depends on the types of food consumed and on the changes in sleeping patters. Eating more fatty foods during Ramadan counteracts the negative effect of fasting on birthweight. The negative effect on birthweight is stronger among fasting women who reported eating more fruits and vegetables during Ramadan, consuming less fluids or sleeping less during Ramadan. Since fasting interacts with other Ramadan-related adjustments, this may explain why previous research, especially on the effects on birth outcomes, has found inconclusive evidence.

The rest of this paper is structured as follows. Section 5.2 gives a brief insight into how human capital accumulation starts in the womb, before Section 5.3 provides information about Ramadan during pregnancy, including the practices and previously identified health effects. In Section 5.4, we explain the survey study set up, including the data collection process, before explaining the data in more detail in Section 5.5. This is followed by the methods in Section 5.6 and the presentation of the results in Section 5.7. Section 5.8 discusses our research in light of the existing literature before concluding.

5.2. Human capital accumulation starts in the womb

Next to other factors such as education and on the job training, health is a dimension of human capital. Recently, the early life years have received special attention, as it has been shown that childhood health – starting at its earliest stage in utero – has a major impact on adulthood health, educational level and economic status (Currie, 2009; Currie, 2020). This opens up new pathways for interventions to improve human capital accumulation via health promotion in early life.

5.2.1. In utero experiences and health outcomes

Research on the impacts of the in utero environment on health outcomes suggests that lifestyle-related risk factors alone are not sufficient to explain variations in outcomes such as coronary heart disease (Godfrey & Barker, 2001). The fetal origins hypothesis posits that chronic diseases are associated with adverse in utero experiences (Barker, 1990; Barker, 2004b; Gluckman & Hanson, 2004a; Almond & Currie, 2011). The mechanism through which in utero experiences may affect the occurrence of chronic diseases, such as type 2 diabetes and cardiovascular diseases, is called fetal programming. It describes a process in which the in utero exposure to adverse environmental circumstances, in particular during critical developmental phases, induces adaptations that result in permanent physiological changes (Langley-Evans, 2015). These programming mechanisms are not concerned with changes to the underlying DNA, but with gene expression. Fundamental to these epigenetic adaptations is the prediction that the in utero and postnatal environments will correspond to each other, so that adaptations to the in utero environment have the role to secure survival and fitness in the expected postnatal environment (Stevenson et al., 2020).

The early pregnancy phases are particularly sensitive to epigenetic adaptations (Langley-Evans, 2015; Stevenson et al., 2020). While adaptations to prenatal circumstances generally enable organisms to rapidly adapt to changing environments, harmful effects may emerge if there is a mismatch between prenatal and postnatal circumstances (Gluckman et al., 2005; Almond & Currie, 2011). The emerging phenotype is adapted to experiencing similar environmental circumstances in later life. However, if the postnatal environment differs from the one to which an organism was exposed prenatally, health problems can emerge. For example, children who faced a nutritionally deficient environment in utero, but are born into an environment without nutritional scarcity, quickly catch up growth. However, their system was prepared for a living environment where nutrition is scarce. Due to long-term structural, physiological and metabolic effects of the in utero experience, these children have an increased risk of obesity in adulthood (Hales & Barker, 1992; Godfrey & Barker, 2001; Hales & Barker, 2001). A distinctive feature of the fetal programming concept is its prediction that consequences of adverse in utero experiences may remain latent until adulthood and are not necessarily reflected in health outcomes at birth (Gluckman et al., 2005; Almond & Currie, 2011).

In epigenetics, the general concept describing how an organism adapts to prenatal environmental circumstances is referred to as 'Predictive Adaptive Responses'. Note that epigenetic adaptations are not restricted to particularly severe or adverse prenatal circumstances, by contrast adaptations are expected to any kind of prenatal circumstances encountered. Since epigenetic adaptations and DNA methylation processes determine the expression of the underlying DNA structure without changing it ('thrifty phenotype hypothesis'), predictive adaptive responses are deemed to have evolutionary advantages via a rapid adaptation to changing environmental circumstances (Gluckman et al., 2005; Bateson et al., 2014). However, as explained above, when the prenatal and postnatal circumstances do not match, the adaptation to the prenatal circumstances may have harmful consequences.

Beside epigenetic adaptations to prenatal circumstances, in utero shocks can also cause damage to the developing organs and body systems without involving predictive adaptive responses. A fetus is particularly vulnerable to suboptimal conditions during critical growth phases of organs. Prenatal shocks can lead to compromises in the organ development and cause persistent health effects. Direct damage to an organ is hypothesized to occur, for instance, when a fetus is exposed to a shock such a nutritional stress and devotes the remaining energy to brain development ('brain sparing'), while other organs receive less energy than necessary (Cohen et al., 2015; Giussani, 2016). Similarly, in utero exposure to toxic substances such as smoking has been linked to various short- and long-term adverse effects on offspring health, but is not hypothesized to improve survival in a postnatal environment with continued exposure to the substance (Hackshaw et al., 2011; Banderali et al., 2015). Similarly, in utero exposure to low-dosed radioactivity in Sweden and Norway was found to have negative effects on cognitive ability (Almond et al., 2009; Black et al., 2019). These negative effects are thought to be driven solely by direct damage during organ development and not by predictive adaptive responses. Other in utero experiences such as exposure to severe nutritional restrictions might include both channels, i.e. leading to direct damage as well as inducing fetal programming effects.

Most empirical research on the fetal origins of disease has focused on extreme in utero events. For instance, studies on the Dutch famine birth cohort confirmed the fetal origins hypothesis, finding negative effects of exposure on various health outcomes, ranging from glucose intolerance to obstructive airway diseases (Roseboom et al., 2006). The evidence of studies on extreme in utero experiences might not always be transferable to non-extreme settings, as the mismatch between in utero and ex utero environments is larger in extreme situations. However, more subtle in utero shocks such as common nutritional variations have also been shown to induce long-term effects.[32] Given that extreme shocks during pregnancy are less likely to occur in many contemporary societies, an improved understanding of the consequences of milder in utero shocks is of high relevance to policy makers. Moreover, it is often more feasible to plan and implement interventions for these milder shocks (Almond & Currie, 2011).

5.2.2. Childhood health and adulthood human capital

As a dimension of human capital, health is a determinant of the development of cognitive and noncognitive skills and capabilities, including health itself, of individuals over the lifecycle. Combining insights from epidemiology and health economics, Heckman (2007) introduces a life cycle approach to human capability formation. Central to his conceptualization are the self-productivity and dynamic complementarities that arise in human skill formation, based on which health early in life is ascribed a decisive role in human capital formation. Self-productivity refers to the association between the stock of a capability in previous periods and the stock of human capital in the present period, whereby higher stocks in previous periods increase the stock in present periods. For example, health in early childhood is associated with improved health outcomes over the life cycle. This self-reinforcing nature of capabilities is however not restricted to outcomes along the same capability dimension, but transcends to other dimensions, as capabilities are highly interrelated. For instance, better health outcomes are associated with improved learning and job market outcomes ('cross-fertilizing' nature of capabilities). The notion of dynamic complementarities describes that investments in earlier stages of life increase the productivity of investments at later stages. With respect to the role of early life, this implies that investments in the earliest stages of life may have high returns, since they also increase the productivity of later-life investments aimed at capability formation (Heckman, 2007; Heckman & Masterov, 2007).

This approach has also been translated to recommendations for policy design. Traditionally, interventions to improve human capital formation focused on school reforms and other educational measures. However, as in utero exposure to shocks such as famines, maternal stress, wars or infectious diseases has been shown to increase the risk for lower cognitive performance and worse labor market outcomes, besides impaired health, the cost efficiency of this traditional policy approach has been questioned. Instead, it has been proposed to start interventions very early in life, in order to make use of the self-reinforcing nature and dynamic complementarities

[32] For an overview of studies on milder prenatal shocks and fetal programming see Almond & Currie (2011); Currie & Almond (2011).

underlying skill formation (Heckman & Masterov, 2007). Investments during a woman's pregnancy and in early childhood have been suggested to be an effective policy tool to reduce inequality (Heckman, 2007) and improve human capital accumulation. The returns to this kind of investments are expected to be large (Currie & Almond, 2011; Aizer & Currie, 2014).

Most recently, Currie (2020) proposes to regard health in childhood as a specific form of human capital, in light of the accumulating evidence linking health in early life to later-life health and labor market outcomes, as well as the development of (non)cognitive skills. Besides investigating associations between prenatal experiences and later-life health outcomes, economics has enriched the literature on the fetal origins hypothesis by analyzing whether in utero experiences are related to outcomes reflecting further dimensions of human capital accumulation, such as educational measures and labor market outcomes (Currie & Almond, 2011). Research on interventions during the prenatal period and their effects on human capital outcomes remains scarce. Causal inference is difficult due to the correlation between family background and in utero conditions. An exemption is Lavy et al. (2016), who exploited a sudden quasi-random immigration wave of Ethiopian Jews to Israel and demonstrated that improved provision of micronutrients during early pregnancy is related to better educational outcomes. Beyond the in utero period, it has been shown that the first 1000 days of life (i.e. until the second birthday) are a highly sensitive period of human development. Bharadwaj et al. (2013) found that investments in the postnatal period, such as intensive care for babies born below the very low birthweight cutoff, are related to later educational success. Similarly, Black et al. (2019) demonstrated that the availability of free healthcare checkups during the first year of a child's life is related to an increased probability to achieve a higher education and being part of the labor market. It was thus shown that early childhood experiences are not only related to adult health, but also to various other dimensions of human capital accumulation (Almond & Currie, 2011; Currie & Almond, 2011; Currie, 2020). Coming back to the terminology of Heckman (2007), improved health in early life might lead to a higher probability to invest in capabilities formation over the life course ('self-productivity') as well as a higher productivity of later investments in capabilities formation ('dynamic complementarities'). This suggests that there is a direct path from investments in health in early life to human capital outcomes over the life cycle.

5.3. Ramadan during pregnancy

As elaborated in the preceding section, in utero experiences are important determinants of health throughout the entire life course. In this paper, we focus on the effects of in utero exposure to intermittent maternal fasting during Ramadan. We also investigate whether Ramadan is purely a nutritional shock or if further adaptations to Ramadan, such as changes in food composition and sleep behavior, influence the effects on birth outcomes.

5.3.1. Traditions and observance

Ramadan is the Muslim holy month. For 29-30 days, all able-bodied adult Muslims are required to fast during daylight hours. Fasting implies the complete abstention from food and drink (including water), medication, smoking and sexual intercourse. Ramadan is determined by the lunar Islamic calendar and therefore the timing shifts by 10-12 days each year in the Gregorian calendar. The daily length of the fast depends on the location and the time of the year during which Ramadan takes place. Adherence to the Ramadan fast implies that any nutritional intake is shifted to the night hours: after sunset and before sunrise. Food as well as fluid intake is unrestricted during night hours. Among healthy non-pregnant subjects, Ramadan fasting is associated with similar beneficial metabolic effects as many other forms of intermittent fasting (Abdeen & Elinav, 2021; Su et al., 2021). The travelling, the sick, women breastfeeding and women experiencing their menstruation are exempted from fasting, but are required to make up for the non-fasted days at a later time. Alternatively, they can make up for the non-fasted days by an expiatory payment to feed the poor.

Most interpretations of the Quran allow pregnant women to refrain from fasting if their own health or the health of the unborn child is believed to be endangered by fasting – provided that they later compensate for the non-fasted days. Nevertheless, research in countries with large Muslim populations has shown that a majority of pregnant women decide to fast, with fasting rates (i.e. the share of pregnant women who fasted at least 1 day during a Ramadan that overlapped with their pregnancy) ranging from 65% (Iran), over 80% (Indonesia), 87% (Pakistan, Singapore) to 99% (Bangladesh) (Joosoph et al., 2004; Ziaee et al., 2010; Mubeen et al., 2012; van Bilsen et al., 2016; Seiermann et al., 2021). Despite a growing Muslim population, research on Ramadan observance among pregnant Muslims in Europe remains scarce. In chapter 4 of this dissertation, we found that 43% of pregnant Muslim women in Germany fasted at least one day during Ramadan 2016. A fasting rate of 54% was detected during Ramadan 2010 in the Netherlands (Savitri et al., 2014), while 43% of pregnant Muslim women of Asian or Asian British ethnicity reported fasting during Ramadan 2010 in the United Kingdom (Petherick et al., 2014).

While intermittent fasting is central to the observance of Ramadan, it is accompanied by other behavioral and dietary changes which may influence health outcomes. The timing of food intake is changed and the food composition is altered due to an increased consumption of sweet and fatty foods and drinks during the breaking of the fast (Fedail et al., 1982; Ibrahim et al., 2008; Trepanowski & Bloomer, 2010). Non-fasting Muslims are also potentially exposed to these changes, if they participate in the nightly celebrations with other household members who fast (chapter 4 of this dissertation; Savitri et al., 2018). While the evidence of Ramadan fasting on caloric intake is inconclusive for the general population, caloric deficiencies were found in pregnant fasting women in Iran (Arab, 2004). Using dietary recalls, Savitri et al. (2018) detected that the total energy, macronutrient as well as water intake were low among fasting pregnant women in Indonesia. By contrast, pregnant Muslims' dietary diversity was found to have increased during Ramadan in Bangladesh, in particular on days during which pregnant women fasted (Seiermann et al., 2021). Women in general were also found to be lighter and have lower BMIs during Ramadan (Al-Hourani & Atoum, 2007). The daily routines are changed considerably during Ramadan, as breakfast is prepared before dawn and the breaking of the fast is celebrated after sunset. Consequently, since many pregnant Muslims reside in households with fasting members, the sleep behavior of pregnant Muslims is potentially adapted irrespective of their decision to fast or not (chapter 4 of this dissertation; Roky et al., 2001; BaHammam, 2005; BaHammam et al., 2013; Faris et al., 2020).

5.3.2. Health effects of Ramadan during pregnancy

As Ramadan only lasts for 29-30 days and fasting is intermittent, in utero exposure to Ramadan is a comparatively mild prenatal shock. It is often treated as a natural experiment, since its overlap with pregnancy is considered to be exogenous. If a certain type of woman timed her pregnancy to overlap (or not to overlap) with Ramadan – leading to selective fertility – the occurrence of a Ramadan during pregnancy would be endogenous. However, there has been no evidence in support of selective fertility (Van Ewijk, 2011; Majid, 2015). This allows researchers to compare outcomes of individuals whose own time in utero overlapped with a Ramadan to outcomes of those without such a prenatal overlap with a Ramadan. This approach is known as an intention to treat analysis. These studies determine the overlap between a pregnancy and a Ramadan by using a person's date of birth in combination with an average gestational length of 266 days. While it is known which individuals are potentially treated, i.e. potentially experienced changes in maternal behavior during Ramadan, no information on actual maternal behavior is known. As a result, intention to treat analyses will lead to a lower bound result, as not all individuals actually experienced the treatment (since not all pregnant Muslims decide to fast and/or adapt other behaviors to Ramadan).

In adults, the strongest effects have been detected among Muslims whose own time in utero overlapped with a Ramadan once they reached post-reproductive age (45+) and among individuals for whom the overlap between their own time in utero and a Ramadan occurred in early pregnancy(chapter 2 of this dissertation; Almond & Mazumder, 2011; Van Ewijk, 2011). The identified effects include increased risk for symptoms of type 2 diabetes, coronary heart disease (Van Ewijk, 2011) and respiratory disease (chapter 2 of this dissertation) as well as small stature and thinness in adulthood (Van Ewijk et al., 2013). Effects have also been found among younger age groups. Ramadan during pregnancy is related to increases in child mortality (Schoeps et al., 2018) and to negative effects on cognitive performance, such as increased risks for mental and learning disabilities (Almond & Mazumder, 2011). Children for whom a Ramadan occurred during their own time in utero also performed worse in school (Almond et al., 2015; Majid, 2015).

The evidence on the effects on health outcomes at birth, and in particular on birthweight, is less consistent. Studies using birth outcomes either look at the effect of Ramadan during pregnancy, as the long-term studies have done, or gather information on fasting behavior and measure the effect of fasting. The first strand analyses the effect of **Ramadan during pregnancy** using an intention to treat approach. Using natality data from Michigan (1989-2006), Almond & Mazumder (2011) detected a small negative effect (-18g; 95% CI: [-33,-2]) of Ramadan during pregnancy on birthweight. When differentiating between pregnancy trimesters of overlap with a Ramadan, the negative effect was higher when exposure occurred during the first or second trimester (-20g to -25g; 95% CIs: [-39, 0] and [-45, -6]), while the effect during the third trimester was both smaller and insignificant. Jürges (2015) used register data from Germany (1996-2010) with more than 1 million births to Muslim mothers. He found that Ramadan exposure in Germany did not have an effect on birthweight.

The main advantage of these studies is that they are based on large datasets spanning a large time period that can abstract from confounding variables and seasonal variations. The occurrence of a Ramadan during a pregnancy, other than the fasting decision, is considered to be random and should therefore not be confounded with maternal characteristics. A disadvantage to these studies is that the datasets lack information on important variables. For example, Jürges (2015) does not have information on the country of origin of the mother. As we will show, different cultural backgrounds influence the decision to fast and differences in birth outcomes exist between women of different backgrounds [33]. Both studies also lack information on the exact date of conception/gestational age at birth and might thus misclassify general exposure as well as the exposed trimester. Misclassification of the overlap between a pregnancy and a Ramadan occurs if a pregnancy lasts more or less than the 266 days used to calculate the day of conception (as calculated backwards from the date of birth). Women with shorter pregnancy duration may be assigned to having overlapped with Ramadan even if they had no overlap, while women who conceived during Ramadan with longer gestational durations will not be considered to have

[33] Birthweight differences between women of different ethnic background have been documented in Migone et al. (1991); David & Collins (1997); Guendelman et al. (1999); Troe et al. (2007).

overlapped with Ramadan. Majid (2015) controls for the latter misclassification by controlling for having been conceived within three weeks after the end of a Ramadan. As it is not possible to determine preterm births based on registry data, some children of women with shorter pregnancy duration will be classified as having had an overlap with a Ramadan while in utero, even though they had not. Consequently, the general effect of Ramadan during pregnancy on health outcomes is biased downwards. Jürges (2015) does not address this issue and only differentiates between those calculated to have had an overlap with a Ramadan while in utero and those calculated not to have had such an overlap. Unknown fasting rates in study populations, such as in Jürges (2015), can also decrease the probability to identify an effect of Ramadan during pregnancy in the intention to treat analysis, especially when fasting rates are low.

The second strand of literature has sought to compare the offspring of **fasting** vs. **non-fasting** women and collected data on fasting behavior among pregnant Muslims. Petherick et al. (2014) investigated the fasting behavior of Asian and Asian British Muslim women in Bradford, UK (N=300). Women who reported being of Asian or Asian British ethnicity and who indicated being Muslim were asked if and for how many days they had fasted. No effects on birthweight were found. Savitri et al. (2014) studied birth outcomes of Muslims in Amsterdam and Zaanstad, the Netherlands. Study subjects were women whose pregnancy overlapped with Ramadan and for whom birthweight information was available (N=130). Fasting led to lower birthweight when it occurred during the first trimester (-272g; 95% CI: [-547,3]), while no effects were found for fasting during later stages of pregnancy. Based on a survey study among pregnant Muslims in Jakarta, Indonesia (N=139), Savitri et al. (2018) did not find effects on birthweight. These studies have several disadvantages. While they are able to collect more information about the respondents, including fasting behavior, they only include a small number of women leading to a lack of statistical power. Women for whose pregnancy overlapped with a Ramadan in the first pregnancy trimester are often underrepresented in studies that approach women via antenatal care visits (Petherick et al., 2014; Savitri et al., 2014). Furthermore, the fasting decision is endogenous. While the occurrence of a Ramadan as such during a pregnancy is considered exogenous, actual behavioral and dietary changes during Ramadan are correlated with maternal characteristics. In order to identify the causal effect of fasting on birth outcomes, it is necessary to control for all potential factors that influence both fasting behavior and birth outcomes. Existing research has only been able to control for a small number of potential confounders, which could bias their results.

Different biological mechanisms are seen as drivers of potential health effects. As previously discussed, the mismatch between the in utero environment (intermittent fasting, lack of sleep and other behavioral changes) during Ramadan and the ex utero environment (no fasting, normal sleeping patterns and other behaviors) after Ramadan may elicit predictive adaptive responses. As a result, the fetus prepares its organs to survive in a Ramadan-like setting ex utero and is thus improperly prepared for a setting without scarcities. The nutritional changes and potential increases in stress levels due to a lack of sleep could also lead to direct organ damage during critical growth phases of the respective organs (and body systems). It is stipulated that first trimester effects are driven by changes in food composition (in particular in relation to the availability of micronutrients), a reduced caloric intake and increased stress hormones (Larijani et al., 2003; Arab, 2004). Moreover, tissues are most sensitive to environmental influences and epigenetic adaptations in early pregnancy (Langley-Evans, 2015). Lastly, intermitted fasting during the second and third pregnancy trimester has been shown to induce accelerated starvation. A pregnant woman's blood levels of metabolic fuels and hormones approach levels that are normally found in women exposed to famines. Its occurrence is explained by the increased energy demand to supply a sufficient amount of nutrients to the fetus and the placenta. Pregnant women can already experience accelerated starvation after skipping single meals (Arab, 2004; Prentice et al., 1983; Malhotra et al., 1989). This suggests that intermittent fasting during pregnancy might lead to health effects in the offspring due to the long fasting hours, independent of dietary intake outside of the fasting hours.

Previous research largely operated under the belief that Ramadan can influence the health of the exposed child through the fasting behavior. Studies looking at the effects of Ramadan during pregnancy attributed any negative effect of Ramadan mainly to a woman's decision to fast, while those studies collecting information on Ramadan focused on gathering data on the fasting decision. This research neglected other potential channels through which Ramadan exposure could affect the health of the unborn child, such as food composition and sleep patterns. Potentially, other behavioral changes could either exacerbate or mitigate the effect of fasting. One study did collect dietary recalls. However, this nutritional information was not available for all women and could therefore not be included in the birthweight analysis (Savitri et al., 2018). More recently, the potential role of adjustments to Ramadan beyond the fasting decision are discussed; yet so far they have not been integrated in the analyses on health outcomes (Seiermann & Gabrysch, 2020; Seiermann et al., 2021).

Research on other health outcomes in newborns in response to Ramadan (fasting) during pregnancy remains scarce. Several studies found a sex ratio that was skewed in favor of girls (Almond & Mazumder, 2011; Van Ewijk, 2011), while Jürges (2015) did not find such effects. Effects on the APGAR score and gestational age at delivery (Hızlı et al., 2012) have so far not been detected in the limited literature available.

5.3.3. Contribution

The *Mainz Survey Study on Ramadan and Pregnancy* makes several important contributions to the understanding of the health effects of early life shocks, and in particular Ramadan during pregnancy, on birth outcomes. We add to the understanding of Ramadan behavior of pregnant Muslims in Europe by systematically collecting data on fasting behavior, Ramadan-related dietary and sleep adjustments along with demographic data for the cohort of women whose pregnancy overlapped with Ramadan 2017 in Mainz, Germany. By collecting detailed information about the respondents, such as country of birth and length of time in Germany, we will be able to assess in how far our results can be generalized to Muslim populations in Europe.

Our sampling procedure included approaching all Muslims giving birth in the two obstetric wards in Mainz. The relevant population to be interviewed included all Muslim women whose pregnancy overlapped with Ramadan 2017 – from delivery to conception during Ramadan. Since we have access to medical data from the obstetric wards in Mainz, general and trimester overlap with Ramadan is not misclassified as the date of conception is known. This allows us to describe the behavior of pregnant Muslims during Ramadan more thoroughly than previous research has done. We can use our detailed data on fasting decisions to identify the effect of fasting on birth outcomes instead of relying on an intention to treat analysis, which can only measure the effect of Ramadan during pregnancy by comparing individuals who were in utero during a Ramadan to those who were not. Furthermore, we do not only take the binary fasting decision into consideration, we also consider the timing and intensity of fasting decisions as well as sleeping behavior and a changed composition of the diet. While those behaviors have been mentioned as potential further channels for the health effects of Ramadan during pregnancy, previous literature did not have data on these behavioral changes.

5.4. Survey study design

5.4.1. General set-up

The *Mainz Survey Study on Ramadan and Pregnancy* was conducted in Mainz, Germany, from May 27, 2017 through April 15, 2018.[34] The study population is comprised of pregnant Muslims and new Muslim mothers whose pregnancy overlapped with Ramadan 2017 (May 26 - June 24, 2017) and who either delivered their newborn or preregistered for delivery with one of the two obstetric wards in Mainz. Interviews were conducted on three days per week (Monday, Wednesday, and Friday) in the obstetric wards. This was sufficient to approach most of the relevant population. As it is very uncommon to have a home birth or outpatient delivery in Rhineland-Palatinate (Statistisches Bundesamt, 2018), most of the Muslim women living in and close to Mainz give birth in one of the two obstetric wards in Mainz and stay hospitalized for two to three days on average. As neighboring cities such as Wiesbaden, Worms or Bad Kreuznach have their own obstetric wards, only very few women who do not live in Mainz deliver in Mainz.

The interviews were conducted using a structured questionnaire, consisting of questions on pregnancy history, behavior during Ramadan 2017, personal beliefs on Ramadan during pregnancy as well as personal background information. The questionnaire is an expansion and development of the questionnaire used by Savitri et al. (2014). Certified translators translated the questionnaires into Arabic and Turkish and research assistants who spoke Arabic or Turkish, in addition to German and English, were hired and trained to conduct the interviews.

Before the main study was conducted, a pilot study with 116 participants was carried out from October 2016 to January 2017. The procedures to identify and approach the relevant population as well as the survey questionnaire were tested and subsequently revised (for an overview of the results of this study see chapter 4 of this dissertation).

5.4.2. Data collection

Our survey study systematically collected data for the entire cohort of pregnant Muslims whose pregnancy overlapped with Ramadan 2017 (May 26 - June 24, 2017) in Mainz, from the women who gave birth on the first day of Ramadan to the women who conceived on the last day of Ramadan. The aim was to include all women whose pregnancy overlapped with Ramadan 2017 for at least one day. Interviews were held until mid-April 2018, in order to capture women who

[34] The Rhineland-Palatinate State Chamber of Medicine (Ethikkommission der Landesärztekammer Rheinland-Pfalz) approved this survey study.

conceived during Ramadan and who may have had a longer gestational period than 266 days.[35] Our dataset is therefore comprised of all Muslim women in Mainz for whom Ramadan 2017 occurred during their pregnancy and who were willing and able to participate in our survey study[36]. Relevant women were identified by either having indicated “Muslim/Islam” as their religion on the hospitals’ patient registration form or by their name, as not all women reported their religion on the hospital registration form.[37]

Our trained interviewers approached the identified women in their hospital room and asked whether they were willing to participate in the survey study. It was made clear that women who fasted as well as those who did not fast were relevant for the study. If an interview on site was not possible, but a woman was still willing to participate, a phone or written online interview was offered and scheduled. A second approach to identifying relevant women was through the preregistration process of the hospitals. Midwives in each hospital were asked to hand out information leaflets and contact cards to Muslim women who preregistered for delivery. Interested women were asked to fill out the contact cards, so that an interviewer could contact them by e-mail or phone.

A written questionnaire (see Appendix 5.A) was used during the personal interviews to ensure that all interviews were conducted in the same manner. The questions were retrospective, requiring women to recall their behavior during the past Ramadan. However, as the interviews took place a maximum of 9-10 months after Ramadan, the recall period was quite short. Before the interview was conducted, each woman had to sign an informed consent form (see Appendix 5.B), agreeing to participate in the survey study. Additionally, we asked each participant to consent to connecting her survey data with medical data on pregnancy and birth outcomes provided by the hospitals. Interviewers explained that data would be pseudonymized and that the published data analysis would not allow conclusions to be drawn about single individuals (see the information leaflet in Appendix 5.C). If the consent was given, medical data about the pregnancy and birth were collected and connected with the survey data. Women who wanted to

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[35] A woman who conceived her child on the last day of Ramadan (June 24, 2017) will have an expected day of birth of March 17, 2018. Since it is possible to give birth at gestational ages past 266 days, we extended our interview period until mid-April.

[36] Note that women were able to participate if they spoke German, Turkish, Arabic or English well enough to fill out our questionnaire, as explained in section 5.4.3.

[37] Women whose first and/or last name indicated a potential Muslim heritage were approached by the interviewers and asked if they were Muslim.

participate in the survey but did not give their consent to connecting their medical data, were interviewed but later excluded from the analysis on birth outcomes.

5.4.3. Sample selection

As illustrated in Figure 5-1, we were able to identify a total of 785 Muslim women[38] who were registered to give birth, were about to give birth or already gave birth in the obstetric wards in Mainz.[39] The true number of Muslim women giving birth in Mainz may be slightly higher if some women slipped through our identification process. One main reason for not identifying a woman is if she came and left the hospital after our interviewers left the hospitals on Friday and before they returned on Monday. However, as women cannot influence the beginning of their contractions and on which day of the week the delivery takes place, it is unlikely that these women are systematically different from women who give birth on other days of the week[40]. Those women who gave birth over the weekend and were discharged by Monday were usually still written on the boards in the obstetric wards and were therefore identified by the interviewers and noted down as already discharged[41]. A second reason for not identifying a woman is if she opted for an outpatient birth (leaving immediately after delivery) or if she decided to deliver the child outside of the hospital. However, around 98% of all births in Germany occur in hospitals (QUAG, 2018) and outpatient births are very rare. If either case were more common, it could bias our results, as these women are most likely healthier and have healthier babies than the rest.

A number of the identified women (N=49) had to be excluded since their date of conception was after Ramadan 2017. These women did not have a single day of pregnancy overlap with Ramadan 2017. This sample of women is not representative of women whose pregnancy did not overlap with Ramadan, since it is biased towards women who were in the hospital due to pregnancy complications, delivering pre-term and towards those conceiving right after Ramadan and giving

[38] This number is in line with estimations by the former Mainz birth registry, which estimated that around 20% of all births in Mainz are to Muslim parents. A back of the envelope calculation shows that around 376 births took place each month in Mainz, assuming that the number of births is evenly distributed over the year (4 510 births took place in Mainz in 2017). Therefore, around 3 760 births occurred in the 10-month interview period. Our identified sample of 782 Muslim women makes up 21% of total births. These numbers are also roughly in line with births outside of Mainz (Statistisches Bundesamt, 2018).

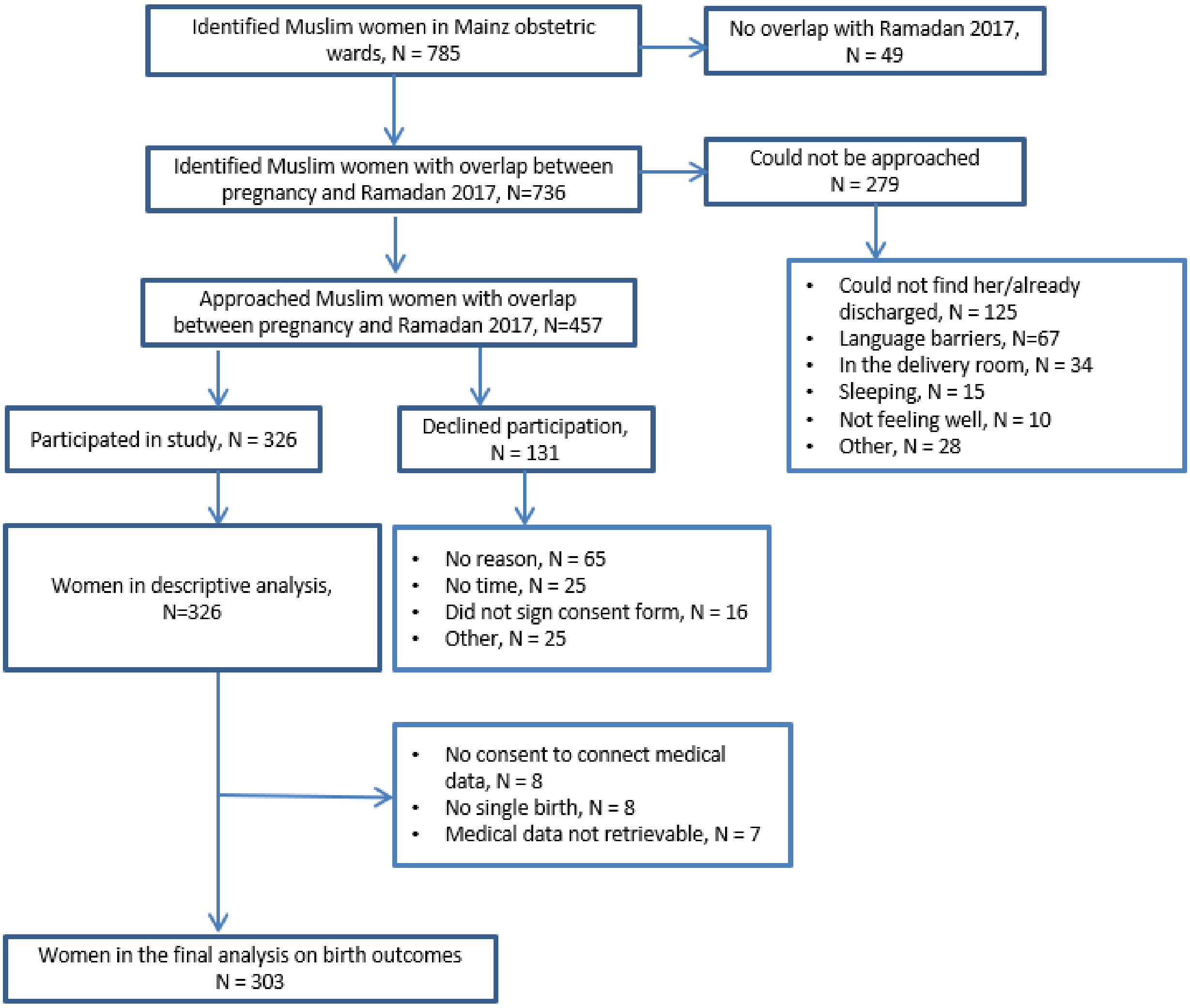
[39] Another 106 women whose name indicated they could be Muslim were approached, were not Muslim and were therefore not interviewed.

[40] Note that while women can influence when their delivery takes place in case of planned c-sections, those rarely take place during weekends in Germany (Kolip et al., 2009). Moreover, the birth outcomes of women with a migration background delivering in Germany do not seem to differ with respect to whether the delivery took place during the weekend (David et al., 2020). Women who could not be approached due to a weekend delivery are included in the count of identified women (‘already discharged’).

[41] It is possible that some of the women noted down as already discharged after weekends actually were not Muslim, even though their names suggested so. We thus provide a conservative estimate of the reach and response rates.

birth during the end of the interview period. We were able to identify 736 Muslim women whose pregnancy overlapped with Ramadan 2017. The main reason for not approaching some of the identified women was that they were not in their room, either because they were in the visitors' room, at a doctor's appointment, already discharged, currently in the delivery room or sleeping. While we cannot check for selection, it is unlikely this introduced selection bias into our sample, as these women should not be systematically different from the rest.

Figure 5-1. Overview of the Study Population



We could not conduct interviews with 9% (N=67) of the identified women due to a language barrier. These women mainly spoke Somali (N=22) and Dari/Farsi/Pashto/Persian[42] (N=19).[43] It was not financially feasible to hire further student assistants to conduct interviews in these languages. The interviews of the 326 women who participated in the study were digitalized and the medical data provided by the hospitals was connected (upon consent by the interviewee).

A source of potential bias is selection through non-participation. Low participation rates are problematic, as it is likely that only certain types of women decide to participate. However, out of the 457 women we asked to participate in our survey, 71% (N=326) agreed to participate. Out of those who declined participation, 50% (N=65) did not give a reason for non-participation, while 19% (N=25) did not have time either due to having too many visitors or having a doctor's appointment or being in the process of being discharged. Another 12% (N=16) did not want to sign the consent form. Women who declined participation because they never fast (N=4, included in the 'other' category in Figure 5-1) or those who did not want to sign the consent form could potentially introduce sample selection bias into our analysis, as these women may be different from the women in our sample. However, the number of women who gave these reasons is very small and therefore unlikely to introduce a large bias. Due to high reach and participation rates, we believe our sample to be representative of Muslim women living in and around Mainz, speaking German, Arabic, Turkish or English well enough to participate in the survey study.

5.5. Data

This section will explain the variables in the dataset necessary to identify the effect of behavior during Ramadan on birth outcomes. First, we will describe which birth outcomes will be considered. Second, we will describe in detail how fasting during Ramadan is defined, before explaining the variables that capture further behavioral and dietary changes.

5.5.1. Outcome variables

Our outcome variables to analyze the effect of Ramadan behavior on health at birth include birthweight (in grams), 5-minute APGAR score and gestational age at birth (in completed weeks). Birthweight is a common birth outcome variable used in economic studies. It has been shown to

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[42] For some women, the exact language was reported. However, for many it was just reported that they were from Afghanistan, so it is unclear which of the languages the women spoke and therefore the different languages are grouped together.

[43] The other languages were Albanian (N=1), Arabic (N=4), Berber (N=1), English (N=1), French (N=1), Italian (N=2), Kurdish (N=3), Macedonian (N=2), Serbian (N=2), Spanish (N=2), Tigrinya (N=1), Turkish (N=1) and for five women the language was unknown. Due to sickness and vacation days, Turkish, Arabic and English could not be covered by the interview team on all days.

have predictive value for short- and long-term health, education and labor market outcomes (Almond et al., 2005; Black et al., 2007; Oreopoulos et al., 2008; Conley & Strully, 2012; Saldarriaga, 2015; Helgertz & Nilsson, 2019). The APGAR score is used to asses a newborn's health at 1, 5 and 10 minutes after birth and considers the **a**ppearance, **p**ulse, **g**rimace, **a**ctivity and **r**espiration of the newborn (a newborn is given 0-2 points per category which is summed up, so that the score ranges from 0 to 10 per measurement; a higher score indicates better health).

Lower APGAR scores are associated with higher mortality in the first year of life (Chong & Karlberg, 2004) as well as a higher prevalence of neurologic disability and lower cognitive function in early adulthood (Oreopoulos et al., 2008; Ehrenstein et al., 2009). We use the 5-minute measurement in our analysis as it has the greatest predictive power (Ehrenstein et al., 2009). The third outcome variable is the gestational age at birth. Prematurity has been shown to be the main cause of death among newborns and the second leading cause of death among children up to 5 years. Long-term health effects such as hearing complications and cognitive disabilities have also been linked to prematurity (Volpe, 2009; Jarjour, 2015).

Some sample restrictions are necessary for our analysis on birth outcomes. 2% of the survey participants (N=8) gave birth to twins or triplets and 2% (N=8) did not give consent to connect their survey data to the medical data and therefore had to be excluded in the analysis on birth outcomes. Lastly, 2% (N=7) of the observations had to be excluded in the analysis on birth outcomes as we were not able to retrieve the medical data from the hospital. The final sample size for the analysis on birth outcomes is 303 (see Figure 5-1).

5.5.2. Exposure to fasting

We use four different fasting definitions in our analysis. First, we use a binary variable equal to 1 if a woman reported having fasted for at least one day during Ramadan 2017. Second, we split the fasting behavior by trimester, thus including three binary variables for having fasted at least one day during the first, second or third trimester. To determine which trimester overlapped with Ramadan, we calculate the day of conception using the expected day of birth and a gestational period of 266 days. The 266 days are split into three equal trimesters. If the expected day of birth is unknown, we use the day of birth in combination with gestational age to calculate trimester exposure. If exposure falls within two trimesters, we assign the woman to the trimester where the number of days of overlap is larger (for example, if 10 days overlapped with the first trimester and 19 days with the second trimester, the pregnancy is considered to overlap with the second trimester). As some women only fast for a very short time (1 or 2 days), we also want to consider the fasting intensity, which is reflected in the third and fourth fasting definitions[44]. In the third definition, we separate fasting into three intensities by including indicator variables for high (fasting 20-29 days), middle (10 and 19 days) and low (1-9 days) fasting intensity. Lastly, we use a continuous variable for the number of days fasted. Women who did not indicate the exact number of days fasted are assigned the median number of days in the category they reported.[45]

5.5.3. Exposure to sleep deprivation and nutritional changes

As discussed previously, there may be further channels, such as changes to the sleep behavior or to the types or amount of food consumed, which may also explain why Ramadan exposure has negative effects. We capture the changes in sleeping patterns among all women by asking whether the respondent got up earlier or went to bed later during the month of Ramadan, compared to the month before. We also asked whether the respondent slept more during the day, to make up for potential loss of sleep at night. Using these three questions, we create a binary variable indicating sleep loss that is equal to 1 if a woman reported either going to bed later or getting up earlier (or both), while not napping more.

The first dietary change captures how women, independent of their fasting decision, changed their consumption of sweet foods during Ramadan. We create indicator variables for women reporting to have consumed more, less or the same amount of sweet foods during Ramadan, in comparison to the month before Ramadan. Further nutritional behavioral changes were collected only among fasting women[46]. For fasting women, we create indicator variables for consuming more, less or the same amount of fatty foods, compared to the month prior to Ramadan.[47] Similarly, we have indicator variables for consuming more, less or the same amount of fruits and vegetables. Furthermore, we create binary variables for eating healthier, less healthy or similarly during Ramadan, according to conventional guidelines. The indicator for eating healthier is equal to 1, if a fasting woman reported eating less sweets and fatty foods during Ramadan, while eating more fruits and vegetables. The indicator for eating less healthy is equal to 1 if a woman reported eating

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[44] The majority of women who only fasted 1 or 2 days indicated that they wanted to try fasting during pregnancy but then realized that fasting was too difficult for them during pregnancy.

[45] Women who fasted were asked whether they fasted on all days (29 days), on most days (20-28), on about half of the days (10-19), on some days (3-9) or on few days (1-2). This means that those who chose the category 20-28 days are assigned 24 days, those who chose 10-19 are assigned 14.5 days, those who chose 3-9 are assigned 6 days and those who chose 1-2 are assigned 1.5 days. Out of the 116 women who fasted included in the analysis, 22 women did not report the actual number of days fasted. Of these women, 8 women fasted 20-28 days, 3 women 10-19 days, 3 women 3-9 days and 8 women 1-2 days.

[46] This choice was based on our experiences in the pilot study, in order to avoid overburdening our interviewees by keeping interview length for new mothers/women in the last stages of pregnancy as short as possible.

[47] Women who fasted were asked if they had consumed more, less or the same amount of fatty foods during Ramadan compared to the month prior to Ramadan.

more sweets and/or more fatty foods. The other women who fasted, whose diet was neither healthier nor unhealthier, are considered to have the same type of diet. Lastly, we create indicator variables for consuming more, less or the same amount of fluids. These variables take on the value 0 for those women who did not fast.

5.6. Methods

5.6.1. Model on fasting

In our first set of analyses, we will use the information on fasting decisions to investigate the effect of fasting on birth outcomes by estimating the following linear regression by ordinary least squares (OLS):

(1) $Y_i = \alpha + \beta\, fast_i + \gamma X_i + \varepsilon_i$

where Y_i is the birth outcome of individual i, $fast_i$ is a variable capturing the fasting behavior of the woman (using the definitions discussed in the previous section) and X_i is a vector of control variables (see below).

The above regression will lead to biased results if we do not control for other variables, as the decision to fast is not exogenous. Women who decide to fast are different from women who do not (see Table 5-2 in section 5.7.1 for more details), therefore β will also capture the effect of omitted variables. In order to minimize this bias, we control for gender of the child, age, age squared and age cubed of the mother at birth, employment status (indicator variable equal to 1 if a woman reported being employed or partially employed prior to entering parental leave), educational attainment (indicator variable equal to 1 if a woman reported having completed a technical or university degree), country of birth indicators[48], nulliparity (indicator variable equal to 1 if not given birth before) and being new in Germany (indicator variable equal to 1 if a person has immigrated to Germany less than three years before the interview). This last variable allows us to differentiate between those women who arrived in Germany before and after the so-called refugee crisis.[49]

Other personal characteristics could both influence the decision to fast and birth outcomes. Women who are more health conscious may decide against fasting, while also having generally

[48] We use country dummies for Syria, Turkey, Morocco and Somalia. Due to the small number of women from other countries, we group them into regional dummies as follows: South Asia (Afghanistan, Pakistan, Bangladesh), other Arab countries (Algeria, Egypt, Iraq, Lebanon, Palestine, Tunisia) and Other (Azerbaijan, Bosnia-Herzegovina, Bulgaria, Kosovo, Macedonia, Serbia, Spain, Iran, Guinea-Bissau, Moldova, Poland, Togo, Tadzhikistan, Gambia, Austria, Ghana). The reference group is women born in Germany.

[49] The European refugee crisis took place in 2015. Interviews were conducted between May 2017 and April 2018, so women who had arrived within the last three years arrived during the crisis period.

better birth outcomes. To proxy for general health consciousness, we control for pre-pregnancy BMI. Furthermore, women who are more religious are more likely to fast and simultaneously have a different lifestyle that may affect birth outcomes. We proxy for the degree of religiosity by a dummy variable that is equal to 1 if a woman reports wearing a veiling on a daily basis and usually fasting during Ramadan when she is not pregnant. We also control for risky behavior that is known to affect birth outcomes, namely smoking, alcohol consumption, drug use during pregnancy as well as consanguinity. Due to the rarity of these events, we combine these four variables into one risky behavior variable equal to 1, if a woman reported drinking alcohol, smoking and/or taking drugs during her pregnancy and/or reported being married to a relative. To account for women acting differently whether or not they knew about their pregnancy during Ramadan, we include an indicator variable capturing whether a woman was aware of her pregnancy during Ramadan. Except in the specification where gestational age is the outcome variable, we control for the gestational age at birth (in full weeks) and gestational age at birth squared. We also control for trimester overlap by including indicator variables for Ramadan overlapping with the second or third trimester (reference category are women whose pregnancy overlapped with Ramadan during the first trimester).

These variables should reflect most factors that may influence both the behavior during Ramadan and the birth outcomes and thus capture a large part of the potential bias. With the inclusion of these controls, we go beyond what other studies have been able to do. However, we recognize that the observed controls can still be an incomplete proxy for potential confounders. One common approach to assess the potential confounding due to unobservables has been to analyze coefficient movements when adding covariates. If adding covariates does not greatly affect the coefficient of interest, it is argued that it is unlikely that the unobservable variables will have such an effect on the treatment effect as to undermine it. However, as Oster (2017) points out, this method would only be sufficient if the assumption held that the relationship between the treatment (fasting) and the unobservable variables can be fully recovered from the treatment and the observed covariates. As this assumption is unlikely to hold, the coefficient movements should be scaled by the change in R^2. Oster (2017) developed a test statistic, δ, to evaluate the degree of selection on unobservables in relation to observables that would be necessary to explain away the estimated coefficient. For example, $\delta = 2$ indicates that unobservables would have to be twice as important as observables. For the calculation of this test statistics, assumptions have to be made about the maximum R^2 (R_{max}) that could be reached in a model with all observables and unobservables. Oster (2017) suggests that $R_{max} = \min(1.3 * \widetilde{R}, 1)$, where $\widetilde{R}$ is the R^2 from regressing the outcome variable on the treatment and all observables.

Oster (2017) further allows for the calculation of a bias-adjusted treatment effect. She suggests calculating a set, ranging from $\tilde{\beta}$ to β^*, where $\tilde{\beta}$ is the treatment coefficient of the regression including all control variables and β^* is the calculated coefficient using R_{max} and $\delta = 1$. If the identified set includes zero, the treatment effect is not robust to controlling for unobservables. However, this is only applicable in cases where adding covariates moves the treatment effect towards zero. In the case where covariates move the treatment effect away from zero, an analysis can be done by comparing whether the identified set lies within +/- 2.8 standard errors from $\tilde{\beta}$, i.e. the 99.5% confidence interval of the treatment coefficient in the regression with all observable controls. This tests whether $\tilde{\beta}$ is similar to the bias-adjusted estimate. We will calculate both δ and β^* to ensure that selection on unobservables is not driving our results.[50]

5.6.2. Model on dietary and sleep changes

To capture whether other changes besides the fasting decision influence birth outcomes, we control for dietary and sleeping changes in a second set of analyses. We first control for changed sleeping behavior in the following regression:

(2) $Y_i = \theta + \beta\, fast_i + \mu\, sleepless_i + \vartheta X_i + \epsilon_i$

where $sleepless_i$ is equal to 1 if any woman (fasting and non-fasting) reported sleeping less during Ramadan (reference group: those who did not sleep less). This model investigates whether sleeping behavior, independent of the fasting decision, has effects on the birth outcome. In a next analysis, we interact sleeping behavior with fasting behavior, by including $sleepless_i * fast_i$ and $didnotsleepless_i * fast_i$, which splits the effect of fasting into those fasting women who reported sleeping less during Ramadan and those who did not sleep less during Ramadan.

(3) $Y_i = \theta + \mu_1\, sleepless_i + \mu_2\, sleepless_i * fast_i$
$+\mu_3\, didnotsleepless_i * fast_i + \vartheta X_i + \epsilon_i$

The reference group in this analysis are women who did not fast and who did not report sleeping less during Ramadan. The coefficient (μ_1) of the indicator variable for having slept less ($sleepless$) now captures the effect of sleeping less among women who did not fast. The effect of sleeping less for a woman who fasted is the sum of μ_1 and μ_2, while the effect of fasting among women who fasted but did not sleep less is captured by μ_3.

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[50] We will use the `psacalc` command for Stata (Oster, 2013) to calculate the necessary test statistic and bias-adjusted coefficient.

In a next analysis, we control for changes in the consumption of sweet foods, which was collected for all women, independent of their fasting behavior.

$$(4)\ Y_i = \theta + \beta\, fast_i + \mu_1 * lesssweets_i + \mu_2 * moreweets_i + \vartheta X_i + \epsilon_i$$

where $lesssweets_i$ and $moresweets_i$ capture whether women reported eating less or more sweet foods during Ramadan (eating the same amount of sweet foods is the reference category). In the next analysis we interact sweet consumption with fasting behavior.

$$(5)\ Y_i = \theta + \mu_1 lesssweets_i + \mu_2 moresweets_i + \mu_3\, lesssweets_i * fast_i + \mu_4\, sameamountsweets_i * fast_i + \mu_5\, moresweets_i * fast_i + \vartheta X_i + \epsilon_i$$

where $lesssweets_i * fast_i$, $sameamountsweets_i * fast_i$ and $moresweets_i * fast_i$, capture whether a woman who fasted reported having consumed more, less or the same amount of sweets during Ramadan. The reference group is women who did not fast and who ate the same amount of sweets during Ramadan.

Lastly, we differentiate the effect of fasting by the dietary behavior of women who fasted.

$$(6)\ Y_i = \theta + \mu_1 less_i * fast_i + \mu_2\, sameamount_i * fast_i + \mu_3\, more_i * fast_i + \vartheta X_i + \epsilon_i$$

The variable $less_i * fast_i$ captures if a woman who fasted reported consuming less of a food category (fatty foods, fruit and vegetables, healthy food, fluids), while $sameamount_i * fast_i$ captures if a fasting woman ate the same amount, and $more_i * fast_i$ captures if a fasting women reported eating more of a food category. This will allow us to analyze whether certain dietary behavior mitigates or exacerbates the effect of fasting.

In these specifications, we include the same controls as in the first set of analyses described in Section 5.5.2. We will also use the different fasting definitions (see section 5.5.2) in all analyses.

5.6.3. Heterogeneity

To investigate whether results differ for women who either gave birth or who conceived during Ramadan, we add indicators for having been conceived or born during Ramadan and interact these indicators with the fasting variables. Next, we investigate whether the effects may differ by the gender of the child, by including an interaction term of fasting and gender of the child. It may be that fasting, especially in the first trimester, has a greater effect on male offspring as male fetuses have been shown to be more vulnerable (Kraemer, 2000; DiPietro & Voegtline, 2017). However, if fasting reduces the likelihood to have a male offspring, the effect may be more negative for female offspring, due to a survival bias. Following the work by Lumey et al. (1995), we conduct a heterogeneity analysis by birth order. Lumey et al. (1995) found that in utero exposure to the Dutch hunger winter had different effects for first versus second born children. We interact the fasting variable with the nulliparous indicator, to check whether this differential effect is present.

Lastly, we interact the fasting variable with whether a woman has been in Germany for less or more than three years to investigate the differing effects among women who have been living in Germany since before the refugee crisis. This analysis is done to investigate whether a potential effect is only present among women recently immigrating to Germany. If an effect can only be identified for those recently immigrated women, it could indicate that we are missing important covariates (such as stress or social isolation which might be more prominent among the recently immigrated). It could also mean that living in Germany for a longer period of time will mitigate the potential effects of fasting and therefore Ramadan (fasting) during pregnancy will not be such a relevant topic for medical personnel in Germany.

5.6.4. Robustness checks

To check the robustness of our results, we run several robustness checks to ensure that our sample restrictions are not driving our results. Due to the data availability, the number of possible robustness checks is limited. To test the sensitivity of our results, we additionally run regressions in which fasting is defined as having fasted at least 3 days, while placing women fasting 1 or 2 days in a separate category. The reason for this sensitivity analysis is that many of the women who had fasted 1 or 2 days had indicated in an open question that they wanted to try fasting, but immediately gave up when realizing it was too difficult for them during pregnancy. It could be argued that these women cannot be considered regularly fasting. The definition of having fasted at least 3 days is also used to test the sensitivity of the analyses on sleep and dietary adjustments to Ramadan.

Moreover, we run a model controlling for the month of Ramadan overlap instead of controlling for the trimester overlap, to control for further differences that the timing of overlap may cause. We also run robustness checks with different data restrictions. First, we use only full-term births by excluding premature births, i.e. mothers who gave birth to children with gestational ages below 37 weeks. Second, we also exclude births with abnormally long gestational ages, i.e. longer than 42 weeks. We also run our analysis without those women whose children are deceased, to ensure that these extreme cases are not driving our results. Lastly, we run the analysis on birthweight without controlling for gestational age. If fasting leads to shorter gestational durations, the effect on birthweight may be partially driven through the exposed children being younger at birth.

5.7. Results

To gain insight into how pregnant women observed Ramadan 2017 in Mainz, we will first report descriptive statistics of our dataset before presenting and discussing the regression results on how fasting and other nutritional and behavioral changes during Ramadan affect birth outcomes.

5.7.1. Descriptives

Out of the 303 interviews included in our analysis, 95% were personal interviews in the hospitals, while 4% were telephone interviews and 1% were online interviews. Over half of the interviews were conducted in German (52%), while 26% and 20% were conducted in Arabic and Turkish respectively. The remaining 2% were conducted in English. The distribution over the two hospitals (47%/53%) reflects the actual distribution in the two hospitals for the year 2017 (45% (2028 births)/55% (2482 births)).

Table 5-1 gives an overview of the descriptive statistics[51]. Ramadan overlap is equally distributed over the three trimesters, with slightly fewer women overlapping with Ramadan during the second trimester. This can be explained by first and third trimester overlap including women whose pregnancy overlapped with Ramadan for fewer than 29 days, due to either having conceived or given birth during Ramadan (see Appendix Table 5-3). The average gestational age at birth is 39 weeks and 51% of the children are male. Women are on average 30 years old at the time of delivery with an average pre-pregnancy BMI of 24.8, which is at the upper end of the normal weight category of BMI. It is the first pregnancy for 36% of the respondents and 39% report having worked either part or full time prior to their parental leave.

[51] Note that the descriptive statistics in Table 5-1 refer to the 303 observations that are also included in the analyses on birth outcomes. More information on all 326 study participants, including those who could not be included in the analysis on birth outcomes (see Figure 5-1), is provided in the appendix (Appendix Table 5-1, Appendix Table 5-2).

Table 5-1. Descriptive Statistics

	Number of Observations	Share
Maternal Fasting Behavior		
Fasted at least one day	116	38%
Religiosity		
More religious	175	58%
Pregnancy Characteristics		
Ramadan Overlap in Trimester 1	109	36%
Ramadan Overlap in Trimester 2	83	27%
Ramadan Overlap in Trimester 3	111	37%
Average gestational age (in weeks)	39.0 1)	1.9 2)
Male child	154	51%
Birth Country		
Germany	86	28%
Syria	51	17%
Morocco	45	15%
Turkey	37	12%
South Asia	23	8%
Other Arab countries	20	7%
Somalia	12	4%
Other	29	10%
Living in Germany <3 years	84	28%
Maternal Risk Factors		
Average age at birth	30.1 1)	5.8 2)
Average pre-pregnancy BMI	24.8 1)	5.4 2)
Nulliparous	109	36%
Risky behavior	42	14%
Pregnancy not known in Ramadan	27	9%
Maternal Socio-Economic Status		
Partially/fully employed 3)	118	39%
Technical/university degree	96	32%
Total N	303	

Note: Share refers to the share of the total sample.
1) Average value instead of number of observations.
2) Standard deviation instead of share of the sample.
3) Employment status refers to the employment status prior to entering parental leave.

Of the interviewed women, 38% state that they fasted for at least one day during Ramadan 2017.[52] Among these women, 50% report fasting at least 20 days, see Figure 5-2. The fasting rates differ by trimester, with 52% of women fasting at least one day if Ramadan overlapped with the first trimester, while 33% and 29% of women whose pregnancy overlapped in the second and third trimester, respectively, report fasting, see Figure 5-3. Further differentiating by conceiving or giving birth during Ramadan shows the highest fasting rate of 86% among women conceiving during Ramadan and the lowest fasting rate of 19% among women giving birth during Ramadan, see Appendix Figure 5-1.

Figure 5-2. Number of Days Fasted among Women Fasting at Least One Day (N=116)

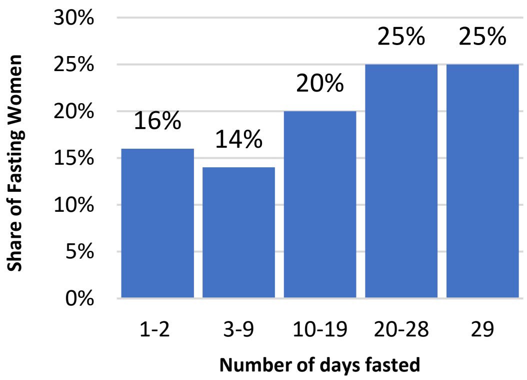
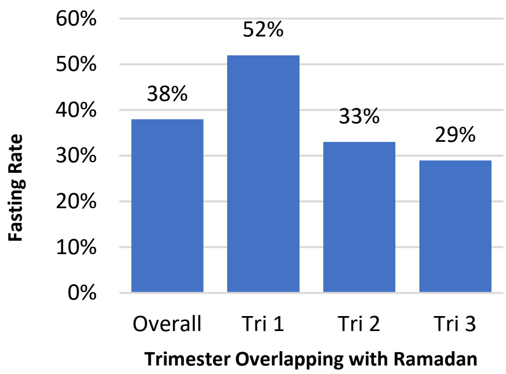


Figure 5-3. Fasting Rates by Trimester (N=303)



Fasting rates also vary by country of birth, with the lowest fasting rates among women born in Germany and Turkey (16% and 22% respectively) and the highest fasting rates among women born in Syria, Morocco and other Arab countries (63%, 69% and 75% respectively, see Appendix Figure 5-2 for further details).[53] In our sample, 72% of the women were born outside of Germany (N=217, see Table 5-1). The majority of these first-generation immigrants were born in Syria (24%, N=51), Morocco (21%, N=45) and Turkey (17%, N=37). Of those women born in Germany (N=86), only 3% (N=3) had parents who were both born in Germany, while both parents were born in Turkey for 60% (N=52) of these women. The average fasting rate among women born in Germany is low at 16% (N=14). However, there is heterogeneity by country of birth of the parents. Only 10% (N=5) of women born in Germany whose parents were born in Turkey report fasting at least one day, while

[52] The interview team was comprised of both veiled and unveiled women. Comparing the fasting rates among veiled and unveiled interviewers showed no significant difference of fasting rates. This indicates that justification bias – that women may feel compelled to not answer the fasting questions truthfully to conform to what they believe the interviewer wants to hear – is unlikely to be a problem.

[53] Other Arab countries include women from Algeria, Egypt, Iraq, Lebanon, Palestine and Tunisia.

50% (N=6) of the women born in Germany whose parents were born in Morocco (N=12) fast. The differences in fasting rates by country seem to persist in the second generation.

The differences between women who fast during pregnancy and those who do not are illustrated in Table 5-2. Women who fast are more religious, less educated and less likely to have held a part- or full-time job prior to their parental leave. They are less likely to have been born in Germany. However, a similar share of women of both groups (around 40%) have been living in Germany at least 3 years. This indicates that fasting and other behavioral changes are relevant not only among women who have recently immigrated to Germany, but can also be found among women born in Germany or living in Germany for a substantial amount of time.

Fewer women who fast believe that fasting has a negative effect on the child or themselves. While more partners of women who fast believe pregnant women should fast, overall only a very small number of partners (8% of the partners of fasting and 3% of non-fasting women) believes pregnant women should fast. More women who fast talked to their doctor or midwife about Ramadan during pregnancy and/or sought information from a different source (such as internet, books, friends or family). However, almost a third of the women who fasted did not indicate having informed themselves.

Almost all women who fasted (97%) lived in a household where other members fasted, while 77% of those who did not fast also reported living in a household with fasting individuals. The latter women are very likely to be exposed to other behavioral changes related to Ramadan, despite deciding not to fast. For example, non-fasting pregnant women may participate in the breaking of the fast during evening and night hours and thus consume different foods than outside of Ramadan. This is supported by our data, which showed that the changes in sweet food consumption was similar among women who fasted and women who did not, see Table 5-2. Both groups of women also showed similar changes to sleeping behavior, with 37% of fasting women and 38% of non-fasting women reporting sleeping less during Ramadan. The large share of non-fasting women living in households with members who fast supports the hypothesis that sleep behavior and dietary composition could be altered during Ramadan, independent of the fasting decision. This highlights the importance to investigate potential effects of other Ramadan-related adjustments on health. Unlike in chapter 4 of this dissertation, women who fasted are not found to be younger on average. Pre-pregnancy BMI is similar between the two groups, which does not support the idea that more health-conscious women are less likely to fast. Lastly, no significant difference exists in the average

Table 5-2: Comparison of Means of Fasting and Non-Fasting Women using Univariate Analysis

	Non-Fasting	Fasting	p-Value for Diff.
Pregnancy			
Birthweight (in grams)	3 362.88	3 335.23	0.660[1)]
5-minute APGAR score (0-10)	9.65	9.72	0.542[1)]
Gestational age (in weeks)	39.00	39.03	0.907[1)]
Male child	0.49	0.53	0.474[2)]
Religiosity			
Normally fasts & wears veiling	0.44	0.79	<0.001[2)]
Time Spent in Germany			
Born in Germany	0.39	0.12	
≥3 years in Germany	0.42	0.44	<0.001[2)]
<3 years in Germany	0.19	0.44	
Maternal Risk Factors			
Age at birth (in years)	30.34	29.79	0.430[1)]
BMI prior to pregnancy (in kg/m^2)	24.96	24.61	0.588[1)]
Nulliparity	0.36	0.35	0.857[2)]
Risky behavior	0.11	0.18	0.092[2)]
Maternal Socio-Economic Status			
Less than secondary education	0.12	0.19	
Secondary education	0.34	0.39	0.069[3)]
Vocational training	0.21	0.13	
University degree	0.33	0.29	
Employed prior to pregnancy	0.47	0.26	<0.001[2)]
Opinions			
Fasting has negative effect on child	0.57	0.20	<0.001[2)]
Fasting has negative effect on mother	0.60	0.25	<0.001[2)]
Partner believes pregnant women should fast	0.03	0.08	0.080[2)]
Living Environment			
Other household members fasted	0.77	0.97	<0.001[2)]
Sought Information			
Advice asked from medical personnel	0.26	0.47	<0.001[2)]
Information sought from any other source	0.37	0.57	0.001[2)]
General Behavioral Changes			
Slept less	0.38	0.37	0.866[2)]
Ate less sweet foods	0.35	0.39	
Ate same amount of sweet foods	0.45	0.36	0.279[3)]
Ate more sweet foods	0.20	0.25	
Behavioral Changes Among Fasting Women			
Ate less fatty foods	N/A	0.37	
Ate same amount of fatty foods	N/A	0.46	N/A
Ate more fatty foods	N/A	0.17	
Ate less fruits & vegetables	N/A	0.18	
Ate same amount of fruits & vegetables	N/A	0.41	N/A
Ate more fruits & vegetables	N/A	0.41	
Drank less fluids	N/A	0.18	
Drank same amount of fluids	N/A	0.44	N/A
Drank more fluids	N/A	0.38	
N	187	116	

Note: 1) t-test 2) chi-squared test 3) Mann-Whitney test. Table presents fractions unless stated otherwise. Behavioral changes are based on a question asking the respondent to compare her behavior during Ramadan to the month prior to Ramadan. The sleep questions were phrased to inquire whether a woman got up earlier, went to bed later and napped differently during Ramadan compared to the month prior to Ramadan. Only women who fasted were asked the questions about the consumption of fatty foods, fruits & vegetables and fluids.

Table 5-3. The Effect of Fasting on Birth Outcomes using Different Fasting Definitions

	Birthweight (1)	5-min. APGAR (2)	Gestational Age (3)
Fasted ≥1 Day			
Fasted	-116.97*	-0.12	0.16
	(68.34)	(0.15)	(0.26)
Fasted ≥1 Day by Trimester			
Trimester 1	-336.90***	-0.26	0.02
	(90.96)	(0.23)	(0.35)
Trimester 2	-3.78	-0.20	0.47
	(120.58)	(0.31)	(0.59)
Trimester 3	45.66	0.14	0.04
	(98.63)	(0.11)	(0.37)
Fasting Intensity Indicators			
Fasted 1-9 days	29.97	-0.09	0.01
	(92.39)	(0.22)	(0.44)
Fasted 10-19 days	-191.68**	0.02	0.44
	(87.36)	(0.17)	(0.37)
Fasted 20-29 days	-201.29**	-0.21	0.13
	(84.71)	(0.23)	(0.32)
Fasting Intensity Count Variable			
Number of days fasted (1-29 days)	-7.53**	-0.01	0.00
	(2.92)	(0.01)	(0.01)
N	298	298	298

Note: Birthweight is measured in grams; APGAR score takes on the value of 0 (worst) to 10 (best); gestational age is measured in completed weeks. The fasting intensity count variable is the number of days fasted; its coefficient in column (1), can be interpreted as the number of grams newborns weigh less per additional day a mother fasted. All other fasting variables are indicator variables. All regressions control for gestational age in weeks, gestational age in weeks squared (except in column (3)), gender of child, trimester exposure (indicators for the 2nd and 3rd trimester), religiosity, country of birth, being in Germany less than 3 years, age, age squared and age cubed of the mother at birth, nulliparity, risky behavior, pregnancy unknown during Ramadan, employment prior to parental leave, and education. Robust standard errors reported in parentheses. Significance levels: ***p<0.01, **p<0.05, *p<0.1

value of the birth outcomes. Children of women who do not fast have a slightly higher average birthweight, however, this difference is not statistically significant in a simple univariate analysis.

5.7.2. Regression analyses

5.7.2.1. The effects of Ramadan fasting on birth outcomes

Other than the simple univariate analysis in Table 5-2, the regression analysis shows that fasting at least one day during pregnancy is associated with a marginally significant lower birthweight, driven by those fasting during the first trimester and by those fasting 10 or more days. The other birth outcomes, APGAR score and gestational age, are not significantly affected by a mother’s decision to fast (see Table 5-3).[54] Further tables will show results using the fasting intensity count variable (number of days fasted), since the count variable does not depend on the somewhat arbitrary groupings of 1-9, 10-19 and 20-29 days. Results for the intensity indicator variables analyses are available upon request.

To understand whether the effect on birthweight can be cautiously interpreted as causal or whether our result is driven by omitted variable bias, we investigate the importance of our control variables by adding them consecutively and checking how they affect the size and statistical significance of the coefficient of the fasting variable (Table 5-4).

Table 5-4. The Effect of Fasting on Birthweight when Adding Groups of Covariates Consecutively

Birthweight	(1)	(2)	(3)	(4)	(5)	(6)
Fasted ≥ 1 Day						
Fasted	-39.46	-48.37	-83.71	-149.34**	-122.63*	-116.97*
	(62.24)	(55.92)	(59.86)	(69.63)	(67.69)	(68.34)
Fasted ≥1 Day by Trimester						
Trimester 1	-125.28	-222.13**	-251.89***	-314.50***	-344.45***	-336.90***
	(84.17)	(87.72)	(89.88)	(98.68)	(91.78)	(90.96)
Trimester 2	20.14	60.24	25.01	-41.61	3.42	-3.78
	(89.70)	(119.61)	(121.70)	(120.96)	(119.64)	(120.58)
Trimester 3	63.67	76.87	40.16	-18.41	36.76	45.66
	(92.48)	(87.13)	(89.07)	(96.67)	(97.49)	(98.63)
Number of Days Fasted (1-29 Days)						
Fasted	-3.01	-2.89	-4.88*	-7.27**	-7.62***	-7.53**
	(3.03)	(2.42)	(2.75)	(3.05)	(2.90)	(2.92)
Controls						
Pregnancy	No	Yes	Yes	Yes	Yes	Yes
Religiosity	No	No	Yes	Yes	Yes	Yes
Birth Country	No	No	No	Yes	Yes	Yes
Risk Factors	No	No	No	No	Yes	Yes
Socio-Eco.	No	No	No	No	No	Yes
N	298	298	298	298	298	298

Note: Birthweight is measured in grams. The coefficient when using the number of days fasted is the effect on newborns per additional day a mother fasted; other fasting variables are binary. Covariates clustered into five different group, added in order of importance determined by our assessment based on previous research. Column (6) represents main specification. Pregnancy: trimester exposure (indicators for the 2nd and 3rd trimester), gestational age in weeks, gestational age in weeks squared, gender of child. Religiosity: indicator equal to 1 if a woman reported fasting normally when not pregnant and wearing a veil on a daily basis. Birth country: Syria, Turkey, Morocco, Somalia, South Asia, other Arab countries or other. Risk factors: living in Germany less than three years, age, age squared and age cubed of the mother at birth, BMI prior to pregnancy, nulliparity, risky behavior (smoking, taking drugs, or drinking alcohol during pregnancy or consanguinity), and pregnancy unknown during Ramadan. Socio-economic: technical or university degree and part- or full-time employed prior to parental leave. Robust standard errors reported in parentheses. Significance levels: ***p<0.01, **p<0.05, *p<0.1.

[54] In Section 5.4., we reported that our sample contains 303 women. In our main regression analysis, we lose five women for whom we do not have information on the pre-pregnancy BMI. We also conduct the analysis without controlling for pre-pregnancy BMI and results are similar (available upon request).

Covariates were clustered into five groups (pregnancy related covariates, religiosity indicator, country of birth, risk factors and socio-economic aspects) and added in order of importance, as determined by our assessment based on previous research, to arrive at our main specification. Table 5-4 shows that there are two main changes in the coefficient of interest: when religiosity (column (3)) and country of birth (column (4)) are controlled for.[55]

Adding further control variables has little effect on the coefficient of interest (please refer to Appendix Table 5-4 for a more detailed table in which the variables are added individually and not in clusters). Adding the control variables moves the coefficient of interest mainly away from zero, i.e. making the effect of fasting stronger. Omitting these control variables would therefore lead to an underestimation of the true effect. This is due to the fact that variables that increase the likelihood to fast also lead to higher birthweights. Taking the example of religiosity, we can see that more religious women are more likely to fast (see Table 5-2). At the same time, more religious women also have heavier babies. This could be due to more religious women living a less stressful and more sheltered life than women who are less religious. Since adding more control variables moves the effect of fasting further away from 0, it is unlikely that the potentially omitted control variables would move the coefficient so far towards zero to lead to the conclusion that fasting does not affect birthweight. The stability of the fasting coefficient from column (4) onwards gives a first indication that our results are not driven by omitted variable bias. Please refer to Appendix Table 5-5 for the effects on the coefficient of interest when consecutively adding covariates when using the APGAR score and gestational age as outcome variables.

As discussed in the previous section, observing the change in the coefficient as the control variables are added consecutively is not sufficient. It could still be possible that unobserved variables are biasing our results and if these were also controlled for, our effect would be 0. Therefore, we apply the method presented by Oster (2017) to make sure that selection on unobservables is not driving our results. Table 5-5 summarizes the results of this analysis. The baseline model includes no control variables, while the main model includes all control variables described in the previous section. In her example of the effect of maternal behavior on birthweight, Oster includes gestational age and gender of child in the baseline model, arguing that these are unrelated controls. However, since fasting potentially affects gestational age and the sex ratio, we decide against using any controls in the baseline model.

[55] Running the regression with all control variables except these two sets of control variables reduces the magnitude of the coefficient and the effect is then no longer different from 0.

Table 5-5. Assessing the Potential Selection on Unobservables

Birthweight (in grams)	Baseline Model (1)	Main Model (2)	99.5% CI of Main Model (3)	Assumed δ (4)	Bias-adjusted β (5)	Assumed β (6)	δ (7)
Panel A: $R_{max} = 0.52$							
Fasted ≥ 1 day	-39.46	-116.97*	[-310.36,	1	-165.14		
	(62.24)	(68.34)	76.43]	-1	-84.15		
R^2	0.00	0.40				0	-6.94
Number of days fasted	-3.01	-7.53***	[-13.27,	1	-9.71		
	(3.03)	(2.92)	-1.79]	-1	-5.84		
R^2	0.00	0.40				0	-7.77
Panel B: $R_{max} = 1$							
Fasted ≥ 1 day	-39.46	-116.97*	[-310.36,	1	-1178.28		
	(62.24)	(68.34)	76.43]	-1	-18.59		
R^2	0.00	0.40				0	-1.46
Number of days fasted	-3.01	-7.53***	[-13.27,	1	-34.26		
	(3.03)	(2.92)	-1.79]	-1	-1.68		
R^2	0.00	0.40				0	-1.64

Note: Panel A uses the suggested R_{max} of 1.3 times the R^2 from the controlled regression, resulting in an R_{max} of 0.52, to calculate the bias-adjusted β in column (5) and δ in column (7). Panel B uses a more conservative value of $R_{max} = 1$. The baseline model in column (1) includes no control variables, while the main model contains the full set of control variables. Columns (4) and (6) show the δ and β assumed to calculate the relevant values. The bias-adjusted β are calculated assuming selection of unobservables is just as important as selection on observables in the same (δ=1) or the opposite (δ=-1) direction. To calculate δ in column (7), we assume the true effect of fasting on birthweight is 0. Calculations were done using the `psacalc` command for Stata (Oster, 2013). Robust standard errors reported in parentheses. Significance levels: ***p<0.01, **p<0.05, *p<0.1.

To calculate the bias-adjusted β and δ, using the `psacalc` command for Stata (Oster, 2013), we follow Oster's suggestion and use 1.3 times the R^2 from the controlled regression ($\widetilde{R}$) to determine the relevant R_{max}, resulting in $R_{max} = 1.3 * \widetilde{R} = 1.3 * 0.40 = 0.52$ (Panel A of Table 5-5). For more conservative measures, we will also use $R_{max} = 1$ (Panel B of Table 5-5).

To calculate the bias-adjusted β, a value for δ (how important unobservables are compared to observables) needs to be assumed. Oster suggests making the assumption that the selection on unobservables is just as important as the observables in the same direction ($\delta = 1$). This is done because researchers usually attempt to include the most important controls, whereas the unobservables should be less important. Assuming a $\delta = 1$ allows for the unobservables to have a greater effect than they are assumed to have. Furthermore, we also calculate the bias-adjusted β in the opposite direction ($\delta = -1$), as adding our controls moved the coefficient of interest away from 0, indicating that the unobservables will have to move the effect back towards 0, i.e. in the opposite direction, in order to invalidate our result. As can be seen in Table 5-5, the bias-adjusted β (column (6)) lies within the 99.5% confidence interval of the controlled regression and can therefore be considered as robust.

Using the `psacalc` command, we also calculate δ assuming that the true effect of fasting on birthweight is zero, i.e. $\beta = 0$, since we are trying to establish whether the null hypothesis of fasting not having an effect on birth outcomes can be rejected. The δ value is calculated to give an idea of how important the unobservables would have to be in order to fail to reject the hypothesis of a null effect. The values of δ (column (7) in Table 5-5) are smaller than -1, which means that selection on unobservables has to be more important than selection on observables and into the opposite direction in order to eliminate our identified effect.

Results are similar for the model using the number of days fasted instead of a binary fasting indicator. Since the δ and bias-adjusted β can only be calculated if you have one coefficient of interest, this method cannot be applied to the models with fasting indicators per trimester or per intensity category. The results of the models using a binary fasting indicator and the number of days fasted do support the validity of our results.

5.7.2.2. The effects of sleep and dietary changes on birth outcomes

So far, our analyses have shown that fasting during Ramadan negatively affects birthweight. To understand whether it is the fasting decision alone, an interaction with further behavioral changes or the other behavioral changes themselves driving this effect, we turn to the results presented in Table 5-6 and Table 5-7.

The first behavior we analyze is the effect of a changed sleeping pattern during Ramadan (columns (1) and (2) in Table 5-6). Controlling for having slept less reduces the coefficient of the binary fasting indicator slightly (from -116.97 – see column (1) in Table 5-3 – to -112.44) and removes the marginal significance. Including the interaction terms of the sleeping behavior and the fasting behavior (column (2)) shows that the negative effect of fasting on birthweight is more pronounced among those women who slept less. The coefficient for the variable sleeping less in column (2) now captures the effect of sleeping less among women who do fast. While is it negative, the magnitude is low with very large standard errors. Columns (3) and (4) investigate how changes in the consumption of sweet foods affect birthweight and the effect of fasting on birthweight. Controlling for the changes in sweet foods consumption also reduces the magnitude of the binary fasting indicator slightly (from -116.97 – see column (1) in Table 5-3 – to -108.64) and removes the significance. Interacting fasting with changed sweet foods consumption shows that the effect of fasting is strongest among those consuming less sweet food (or the same amount of sweet foods –

Table 5-6. The Effect of Changes in Sleep Behavior and Sweet Food Consumption on Birthweight

Birthweight (in grams)	(1)	(2)	(3)	(4)	(5)
Fasted ≥ 1 day	-112.44		-108.64		-108.67
	(68.52)		(69.50)		(69.12)
Sleep Behavior					
Slept less	-62.10	-21.13			-46.79
	(52.49)	(67.78)			(53.21)
Slept less*fasted ≥ 1 day		-175.61**			
		(87.77)			
Did not sleep less*fasted ≥ 1 day		-71.03			
		(83.82)			
Sweet Food Consumption					
Less			-93.48	-77.77	-89.25
			(61.22)	(70.00)	(61.18)
More			-99.01	-136.70	-94.88
			(71.35)	(85.57)	(71.72)
Less*fasted ≥ 1 day				-165.24*	
				(98.67)	
Same*fasted ≥ 1 day				-118.69	
				(96.93)	
More*fasted ≥ 1 day				-22.91	
				(100.97)	
N	298	298	298	298	298

Note: Columns (1), (2) and (5) control for changes in sleeping patterns columns (3), (4) and (5) for changes in sweet food consumption. In columns (2) and (4), the behavioral changes are further interacted with the fasting behavior. All regressions control for gestational age in weeks, gestational age squared, gender of child, trimester exposure (indicators for the 2nd and 3rd trimester), religiosity, country of birth, being in Germany less than 3 years, age, age squared and age cubed of the mother at birth, parity, risky behavior, pregnancy unknown during Ramadan, employment prior to parental leave, and education. Behavioral changes were collected by asking the respondents to compare their behavior during Ramadan to their behavior in the month right before Ramadan. Robust standard errors reported in parentheses. Significance levels: ***p<0.01, **p<0.05, *p<0.1.

although this is not significant at conventional levels). This suggests that the effect of fasting is exacerbated by certain simultaneous dietary and sleep changes.

Table 5-6 does not support the hypothesis that behavioral and dietary changes among women who did not fast influence birth outcomes. The behavioral changes among women who do not fast do not have a significant effect on birthweight, although coefficients are negative (see the coefficients for the variables slept less in column (2), as well as more sweets and less sweets in column (4)). Furthermore, controlling for sleep and sweet food consumption in general, without the interaction terms, shows that these behavioral changes did not greatly bias the binary main result (see column (5)). Controlling for behavioral changes does not affect the effect of fasting on the other birth outcomes – APGAR score and gestational age – and the behaviors also do not affect the birth outcomes themselves (see Appendix Table 5-6 and Appendix Table 5-7 for details).

Table 5-7. The Effect of Changes in Food Consumption on Birthweight

	Interaction of Fasting with Behavior			
Birthweight (in grams)	Fatty Foods (1)	Fruits & Vegetables (2)	Healthy (3)	Fluids (4)
Less*fasted ≥ 1 day	-173.96**	-115.46	0.89	-179.03**
	(81.39)	(97.04)	(90.31)	(87.21)
Same*fasted ≥ 1 day	-174.59**	-35.74	-124.34	-108.24
	(80.07)	(80.31)	(78.55)	(92.38)
More*fasted ≥ 1 day	156.70	-201.89**	-316.27***	-92.25
	(128.30)	(87.66)	(97.15)	(82.57)
N	298	298	298	298

Note: The specifications in columns (1) through (4) include interaction terms of the binary fasting indicator with changes in food and fluid intake. Behavioral changes were collected by asking the respondents to compare their behavior during Ramadan to their behavior in the month right before Ramadan. Column (3) combines changes in food composition, where eating healthier (more healthy) is equal to 1 for those women who reported eating less sweets and fatty foods, while eating more fruits and vegetables. Eating unhealthier (less healthy) is equal to 1 if a woman reported eating more sweets or fatty foods All regressions control for gestational age in weeks, gestational age squared, gender of child, trimester exposure (indicators for the 2nd and 3rd trimester), religiosity, country of birth, being in Germany less than 3 years, age, age squared and age cubed of the mother at birth, parity, risky behavior, pregnancy unknown during Ramadan, employment prior to parental leave, and education. Robust standard errors reported in parentheses. Significance levels: ***p<0.01, **p<0.05, *p<0.1.

Controlling for these behavioral changes in the models using fasting by trimester or by fasting intensities (see Appendix Table 5-7 and Appendix Table 5-8), there are some indications that sleeping less during the first trimester, independent of the fasting decision, reduces birthweight significantly. Sleeping less while fasting in the third trimester also reduces birthweight, while those who fast but did not sleep less actually have heavier children. The effects of sweet consumption also appear to depend on the trimester – while a changed sweets consumption during the first and second trimester lowers birthweight (although mostly not significant), it has no effect during the third trimester.

Further nutritional changes were only collected among women who fasted. As can be seen in Table 5-7, the effect of fasting differs between women who reported eating more fatty foods as opposed to those eating less or the same amount of fatty foods. While women with increased fatty food consumption had, on average, heavier babies, women who ate either the same amount or less fatty foods had lighter babies. When differentiating the effect of fasting by fruit and vegetable consumption, we can see that the effect of fasting is especially negative when consuming more fruits and vegetables. Column (3) uses summary indices combining sweet, fatty foods and fruit and vegetable consumption. The results confirm the previous separate results and show that women who observe a diet considered healthier under normal circumstances while fasting, have significantly lighter children, while those eating more unhealthily do not experience a negative effect of fasting on birthweight. Lastly, the negative effect of fasting on birthweight is exacerbated by drinking less fluids (see column (4)). The effect of fasting split up by these different behaviors has no effect on APGAR score or gestational age (see Appendix Table 5-9).

Conducting the analysis including nutritional changes by trimester becomes more imprecise, as fewer women fall into each group. However, the analysis shows that the results discussed above are not confounded by nutritional changes being concentrated within a certain trimester (Appendix Table 5-10). Results indicate that consuming less or the same amount of fatty foods during the first trimester has the largest negative effect on birthweight. While fasting itself leads to lower birthweight during the first trimester no matter how much fruits and vegetables are consumed, the negative effect is largest amongst those fasting women who reported eating more fruits and vegetables during the first trimester. Results are also similar when using the number of days fasted instead of a binary fasting indicator (see Appendix Table 5-11). Results for APGAR score and gestational age are available upon request – there are no significant effects in these model estimations.

5.7.3. Heterogeneity

As can be seen in Table 5-8, the negative effect of fasting on birthweight is driven by those women whose pregnancy overlapped with Ramadan during the first trimester, but who did not conceive during Ramadan. By investigating the differential effects among women who either conceived or gave birth during Ramadan, we can also see some indication that women who conceive during Ramadan have shorter gestational periods.

As can be seen in Table 5-9, the effect of fasting on birthweight is driven by the effect fasting has on male children. We also find that the negative effect of fasting is more pronounced among those children who are not their mother's firstborn child. Looking at the effect of fasting among women who have been in Germany less than three years compared to more than three years, we see that the effect is larger among women who have been living in Germany at least three years. Conducting the heterogeneity analyses for the other outcome variables shows that there are no subgroups which are significantly affected in terms of APGAR score or gestational age. Using the other fasting definitions, by trimester and number of days fasted, confirms that the effects identified in the main analysis are driven by male offspring and those children whose mother has previously given birth to at least one other child (see Appendix Table 5-12).

Table 5-8. Heterogeneity Analysis: Controlling for Conception and Birth During Ramadan

	Birthweight	5-min. APGAR	Gestational Age
	(1)	(2)	(3)
Fasted ≥ 1 day by Timing			
Conceived	1.69	-0.23	-2.04***
	(307.07)	(0.57)	(0.66)
Trimester 1 (excl. conceived)	-377.35***	-0.16	0.48
	(98.29)	(0.14)	(0.36)
Trimester 2	-5.70	-0.21	0.45
	(120.70)	(0.31)	(0.59)
Trimester 3 (excl. born)	38.65	0.20	0.31
	(111.64)	(0.13)	(0.39)
Born	11.46	-0.13	-0.64
	(177.65)	(0.30)	(0.85)
N	298	298	298

Note: Birthweight is measured in grams; APGAR score takes on the value of 0 (worst) to 10 (best); gestational age is measured in completed weeks. All regressions control for gestational age in weeks, gestational age in weeks squared (except in column (3)), gender of child, trimester exposure (indicators for the 2nd and 3rd trimester, birth and conception), religiosity, country of birth, being in Germany less than 3 years, age, age squared and age cubed of the mother at birth, parity, risky behavior, pregnancy unknown during Ramadan, employment prior to parental leave, and education. Robust standard errors reported in parentheses. Significance levels: ***p<0.01, **p<0.05, *p<0.1.

Table 5-9. Heterogeneity Analysis by Gender of Child, Parity and Time Spent Living in Germany

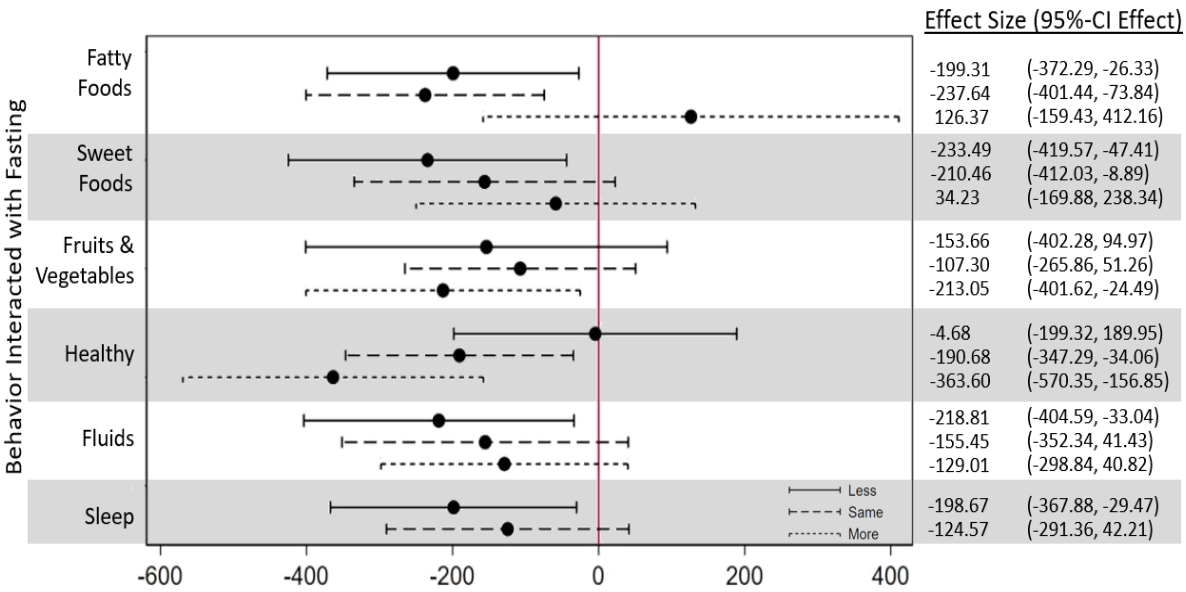
	Birthweight	5-min. APGAR	Gestational Age
	(1)	(2)	(3)
Gender of the Child			
Fasted ≥ 1 day*Female child	-25.57	-0.14	-0.10
	(76.27)	(0.17)	(0.37)
Fasted ≥ 1 day*Male child	-222.52**	-0.09	0.45
	(92.59)	(0.21)	(0.36)
Parity			
Fasted ≥ 1 day*Multiparous	-146.98*	-0.26	0.09
	(83.31)	(0.21)	(0.32)
Fasted ≥ 1 day*Nulliparous	-61.20	0.16	0.28
	(86.40)	(0.14)	(0.39)
Time Spent Living in Germany			
Fasted ≥ 1 day*< 3 years	-62.18	0.05	0.30
	(97.72)	(0.16)	(0.34)
Fasted ≥ 1 day*≥ 3 years	-140.28*	-0.18	0.10
	(79.57)	(0.19)	(0.33)
N	298	298	298

Note: Birthweight is measured in grams; APGAR score takes on the value of 0 (worst) to 10 (best); gestational age is measured in completed weeks. All regressions control for gestational age in weeks, gestational age squared (except in column (3)), gender of child, trimester exposure (indicators for the 2nd and 3rd trimester), religiosity, country of birth, being in Germany less than 3 years, age, age squared and age cubed of the mother at birth, parity, risky behavior, pregnancy unknown during Ramadan, employment prior to parental leave, and education. Robust standard errors reported in parentheses. Significance levels: ***p<0.01, **p<0.05, *p<0.1.

5.7.4. Robustness checks

In order to make sure our results are not driven by our sample or our model specification, we run several robustness checks. When defining fasting as having fasted at least 3 days during pregnancy, the association between fasting and birthweight becomes stronger (-164.03, 95% CI: -299.66; -28.40). Also, the pattern of results with respect to sleep and dietary changes during Ramadan is stable to defining fasting as having fasted at least 3 days during pregnancy (Figure 5-4, Appendix Figure 5-3).

Figure 5-4. Effect of Fasting at Least 3 Days on Birthweight Interacted with Behavioral Changes



Note: The figure shows the effect of fasting at least three days interacted with indicators for behavioral (sleep & dietary) changes in the respective categories (less/decreased, same/unchanged, more/increased intake), along with the effect size and 95% confidence interval. The reference group is always the children of mothers who did not fast. Both regressions also control for all other covariates listed in the main text.

To better control for monthly differences in birth outcomes, we run our analysis using pregnancy month overlapping with Ramadan indicators instead of controlling for trimester overlap. Furthermore, we interact the month of overlap with the fasting variables to further investigate the effect fasting has on birth outcomes on a more detailed level (see Appendix Table 5-13). Results are stable to these modifications of the model. Furthermore, results are robust to a multitude of different sample restrictions (see Appendix Table 5-14). We reduce our sample size to only full-term babies (gestational age of 37 weeks or older) and to normal-term babies (gestational age of 37 to 42 weeks). Results are also robust when excluding deceased children. While we did not find significant effects of fasting on gestational age, it may be that part of the effect on birthweight is driven by slight effects on gestational age. Not controlling for gestational age and gestational age squared in the analysis on birthweight however yields similar results.

5.8. Discussion and conclusion

Our results show that Ramadan during pregnancy is a relevant topic for health care in Germany, since 38% of our respondents fasted at least one day during pregnancy. As it is estimated that around 5% of the German population is Muslim, with an even larger share of births being to Muslim mothers, the short- and long-term consequences of Ramadan during pregnancy cannot be neglected. No statistics are available on how many Muslims are living in Mainz. However, a very rough estimate can be based on a website listing the mosques in Mainz, reporting that around 2770 individuals attend the Friday prayers (Moscheesuche.de, 2019). Assuming that 25%[56] of the Muslim population in Mainz goes to Friday prayers would indicate that roughly 11 000 Muslims are living in Mainz, 5% of the total population. This is in line with the estimation for the entire German population, indicating that Mainz is roughly representative for Germany. As there is no systematic registry of Muslims in Germany (Stichs, 2016), further and more substantiated comparisons of the Muslim population in Mainz to the rest of Germany are not possible.

5.8.1. Survey study set-up

A main advantage of our study is the high quality of the data – linking survey with hospital medical data – in conjunction with a systematic and representative sampling design and a high response rate of 71%. Hospital data allowed us to exactly classify Ramadan exposure by pregnancy trimester utilizing estimated due date as calculated based on physical examination. We cover an entire cross section of Muslims in one city whose pregnancy overlapped with a Ramadan – from the women giving birth on the first day of Ramadan to those conceiving on the last day of Ramadan – so that offspring with in utero exposure to Ramadan at all stages of pregnancy are included. Through the continuous presence in the two obstetric wards in Mainz, starting on the first day of Ramadan 2017 until April 2018, we were able to maximize the number of approached women. As the interview team was present in both obstetric wards in Mainz, we did not have to depend on the participation of certain hospitals or midwife/gynecologist practices. In comparison, Savitri et al. (2014) approached women through participating health workers in a subsample of all midwifery practices (18 out of 34) and hospitals (4 out of 7) in their study location (representing around 60% of the entire population).

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[56] Mostly men attend Friday prayer in the Mosques. Women and children remain at home.

We also did not rely on antenatal care visits to identify women, but were able to approach women coming to the hospital for delivery, where 98% of children in Germany are born (Statistical Office Rhineland-Palatinate, 2018). Several other studies were only able to approach and contact women who came in for antenatal care (Savitri et al., 2014; Savitri et al., 2018). This introduces a selection into the sample, as some women may not attend a doctor for regular antenatal checkups. It has been shown that women with migration background are more likely to enter antenatal care at a late stage of pregnancy in the Netherlands and Germany (Choté et al., 2011; Breitenstein, 2016).

Another issue introduced by approaching women who came in for antenatal care is that not all stages of pregnancy overlapping with Ramadan will be included in the dataset. The study by Savitri et al. (2018) interviewed women who came in for antenatal care during Ramadan 2013. Since women usually do not see a doctor for antenatal care at the very beginning of their pregnancy, the dataset includes more women at later stages of their pregnancy. Savitri et al. (2014) excluded women with gestational ages of less than 4 weeks at the start of Ramadan. While there is neither information on how the sample was selected in Petherick et al. (2014) nor information on the overall distribution of the sample by trimester of overlap with Ramadan, looking at the provided information on trimester overlap for women who fasted indicates that the sample overrepresents women whose pregnancy overlapped with Ramadan during the second trimester. As our results are strongest for first trimester overlap, it is very important to ensure that future datasets include information on all pregnancy stages overlapping with Ramadan before drawing general conclusions on effects on health outcomes.

Muslim women were identified in our study by either having indicated Islam as their religion in the hospital registration forms or by having a first and/or last name that indicated a possibility of a Muslim background. This identification strategy ensured that the largest number of Muslim women would be identified. Relying solely on the registration forms could have introduced selection bias. On the one hand, not all women formally register for their delivery with the hospital and therefore do not fill out the registration form. Women who fail to register in advance are likely to be systematically different, which could therefore bias results. Furthermore, some women who do register and fill out the form may not want to indicate their religion, again introducing potential bias. Women who either did not fill out the registration form or did not indicate their religion, could still be identified through their name. A limitation to this strategy is that women who do not indicate their religion and have names that do not indicate an ethnicity that could be Muslim are not identified. However, we believe that our identification strategy was able to identify a larger share of Muslim women living in Mainz than previous studies, which often only relied on ancestry. For example, Petherick et al. (2014) only included women of Asian or Asian British decent who also reported their religion as Islam, excluding Muslims with other ethnicities. Through this process, our dataset has fewer issues with selection than previous survey studies leading to more externally valid results.

5.8.2. Ramadan behavior during pregnancy

Our results on Ramadan fasting is in line with previous results for Europe. The average fasting rate of 38% was slightly lower than the 43% fasting rate we found in our previous study conducted after Ramadan 2016 (chapter 4 of this dissertation). This higher fasting rate during Ramadan 2016 can be explained by the sampling design, as no women whose pregnancy overlapped in the third trimester, where we found fasting rates to be lowest, were interviewed in our previous study (80% overlapped with Ramadan during the second trimester, while 20% during the end of their first trimester). Furthermore, Ramadan 2016 had slightly shorter fasting durations at lower temperatures. As Ramadan 2017 overlapped with the longest days of the year in Germany and coincided with a hot spell, the 38% fasting rate can be considered a lower bound of fasting rates. Higher fasting rates during the first trimester could explain why intention to treat studies, which compare individuals who were in utero during a Ramadan to those who were not, have been able to identify the strongest effects for the first trimester. In addition to lower fasting rates, a higher vulnerability of the fetus during the early stages of pregnancy as well as phenotypic plasticity in earliest pregnancy stages may also explain why intention to treat analyses seldom find effects among those exposed during the second or third pregnancy trimester.

Although our fasting rate is similar to those found in the Netherlands (54%) and the UK (43%) in previous studies (Petherick et al., 2014; Savitri et al., 2014), drawing conclusions about fasting rates in other countries or even in Germany in the past or future has to be done with caution. The origins of the Muslim population in Germany have changed drastically over the past few decades. While around 80% of all Muslims were of Turkish ancestry in 1987 (Deutscher Bundestag, 2000), this share dropped to 50% by 2015 (Stichs, 2016). As we have discussed, fasting rates differ greatly by country of origin (see), so the characteristics of Muslim populations have to be considered. When drawing conclusions for other European countries, the make-up of the Muslim population has to be considered. For example, the largest share of Muslims in the UK is of Bangladeshi or Pakistani descent, as in Petherick et al. (2014). Our dataset does not allow any conclusions to be drawn about fasting behavior or the effects of fasting among these groups, as our sample only included 10 women from the two countries – only 3 of which reported fasting. Results will be more relevant for countries with a more similar Muslim population, such as the Netherlands.

Our results also show the importance of considering other behavioral and dietary changes of pregnant Muslims during Ramadan. The majority of women (85%; 77% of non-fasting and 97% of fasting women) live in households where other household members fast, which increases the probability that lifestyle adjustments to Ramadan can occur even if a woman does not fast. Independent of the fasting decision, around 40% of all women reported sleeping less during Ramadan, while 35-39% reported eating more sweet foods.

5.8.3. Health effects at birth

While the fetal programming hypothesis posits that health effects may remain latent until adulthood, we are able to show that Ramadan intermittent fasting affects birth outcomes in terms of birthweight, while not affecting the 5-minute APGAR score and gestational age at birth. Fasting during the first pregnancy trimester has a strong, negative effect of birthweight, while fasting during other pregnancy trimesters does not significantly affect birthweight. The effect of fasting increases with the number of days fasted.

This is the first study to analyze aspects of Ramadan beyond fasting itself. While nutritional patterns during non-fasting hours and sleeping patterns have been hypothesized as further channels or moderators for the health effects, previous literature did not have the necessary data to investigate (Savitri et al., 2020; Seiermann & Gabrysch, 2020). All existing theories and previous research on Ramadan during pregnancy has focused on intermittent fasting as the driver of all identified effects. For the first time, we demonstrate that other aspects of Ramadan are important, in particular dietary changes and sleep behavior in combination with fasting. We find that the negative effect of fasting on birthweight is concentrated among women who reported having slept less during Ramadan and among those who reported consuming fewer fatty foods, more fruits and vegetables or less fluids. These results indicate that changes in sleep and nutrition during Ramadan may be a contributing factor to how fasting will affect the health of the offspring. The detected moderating role of dietary choices during Ramadan sheds light on why the evidence on the association between Ramadan during pregnancy and birth outcomes has remained inconclusive. To the extent that dietary choices vary across Muslim communities, it is also plausible that birthweight effects of Ramadan (fasting) during pregnancy can be found in some populations and not in others.

A possible explanation for our results is that the actual channel through which fasting affects health could be caloric deficiencies. We saw that fasting women who reported having consumed more fatty foods did not have a negative effect on birthweight, whereas women eating more fruits and vegetables had significantly lighter children. Since fatty foods have higher caloric contents, eating what would traditionally be considered more unhealthy food, may lead to pregnant women consuming the required number of calories. A diet rich in fruits and vegetables may lead to caloric deficiencies. Dehydration, which has been shown to lead to lower amniotic fluid levels (Sakar et al., 2014), may be a further channel, as our results showed a stronger effect among women with reduced fluid intake.

In comparison to other survey studies with information on fasting behavior, we find a larger, robust negative effect on birthweight. One reason why Petherick et al. (2014) and Savitri et al. (2018) may not have been able to identify effects is that they were not able to control for important covariates such as religiosity, BMI or country of birth, which we showed had a large effect on the size of the treatment coefficient. Without the inclusion of these controls in our model, we do not find significant effects on birthweight. In line with the previous literature, we do not find effects on 5-minute APGAR score. We also do not find any effects on gestational age, in contrast to Van Ewijk (2011) and Almond & Mazumder (2011).

The differential fasting rates by country of birth may explain in part why Jürges (2015) did not identify an effect on birthweight in his intention to treat analysis based on German registry data. His dataset from 1996-2010 probably contains a large share of Turkish women, where only 1 in 5 women in our sample reported fasting. Due to population changes over the past years, this introduces a bias with respect to the generalization of these results to contemporary Germany. The highest fasting rates in our sample were found among Moroccan, Syrian and women of other Arab countries, which represented less than 10% of Muslims in Germany in 2000 (compared to over 40% in our dataset). Furthermore, his sample depends on all Muslim women being correctly identified in his dataset. As we found that not all women indicated their religion on the hospitals' medical forms, it is unlikely that all Muslim women are correctly identified in Jürges' dataset. Lastly, he is only able to determine overlap with Ramadan using the date of birth in combination with the average gestational length of a pregnancy, potentially misclassifying the trimester of overlap or if an overlap occurred at all.

Several limitations to our study should be noted. We only study birth outcomes, but are unable to study longer-run health effects. Nevertheless, birthweight, 5-minute APGAR score and gestational age at birth have been found to be predictive of various later-life-outcomes. Moreover, we only have data for one birth cohort. As it has been shown that effects potentially differ by the hours fasted (Almond & Mazumder, 2011), it is unclear whether our effect in part depends on Ramadan 2017 coinciding with the longest potential fasting durations in Germany (up to 18 hours) as well as very high temperatures. The bias introduced by these conditions could run in different directions. We may overestimate the average effect of fasting and other behavior during pregnancy, if the effect is weaker for shorter fasting durations at milder temperatures. Another source of bias could come from a potential selection into fasting. If only the healthiest women fasted during the hot Ramadan of 2017, we may underestimate the effect as unhealthier women, who tend to have worse birth outcomes, are more likely to be in our control group. If mainly very religious or women from certain backgrounds fasted, or women who are not very health conscious, the direction is ambiguous. Our regression showed that more religious women have, on average, heavier children, which would mean our estimate is a lower bound if only the very religious women fast. A rough proxy for health consciousness, pre-pregnancy BMI, showed no differences between fasting and non-fasting women, indicating that such a selection may not have occurred. Furthermore, we do not have exact protocols of maternal nutrition and sleep behaviors of the participants during Ramadan and rely on self-reports. This was a choice based on our experiences in the Mainz Survey on Ramadan during Pregnancy 2016 (chapter 4 of this dissertation), in order to avoid overburdening our interviewees by keeping interview length for new mothers/women in the last stages of pregnancy as short as possible. The interviews were retrospective. However, as the interviews took place a maximum of 9-10 months after Ramadan – and usually considerably less – the recall period was relatively short so that recall bias will likely have been limited.

5.8.4. Outlook

Beyond fasting, the practice of Ramadan involves changes to dietary composition and sleep schedule that are relatively easily modifiable. Moreover, the month of Ramadan has impacts on the behavior and diets of both fasting and non-fasting pregnant women. As Savitri et al. (2018) underline, cultural and dietary habits could be important in explaining why birthweight effects of in utero Ramadan exposure can be found in some populations and not in others. Our analysis of behavioral changes supports this hypothesis. We encourage similar studies in other settings, in particular since dietary traditions during Ramadan vary across Muslim communities. Future analyses on Ramadan during pregnancy should not only focus on fasting. Further research should rather focus on disentangling the dynamics between fasting, nutrition, other behaviors and health outcomes. It is also necessary to gain insights into how important Ramadan-related changes beyond fasting are in determining health in adulthood. While in many cases, such as in our study, birthweight is the best measure available, its predictive power for adulthood health is limited (for an umbrella review see Belbasis et al. (2016)). The pathways of disease along the entire life course will need to be investigated by future research.

By gaining a better understanding of the channels and mechanisms behind the effects of Ramadan during pregnancy, further research may lead to more insights into how nutritional restrictions can affect the health and human capital accumulation of the offspring in the short and long run. These results may have implications for an even larger share of women exposed to milder nutritional restrictions. Research on the effects of Ramadan fasting and potential moderators will potentially allow us to gain insight into effects of dieting or meal skipping during pregnancy. Thereby, it needs to be acknowledged that Ramadan is a highly sensitive, religious practice. Each year millions of Muslim offspring whose own time in utero overlapped with a Ramadan are born. A growing body of research on how various lifestyle changes during Ramadan – such as dietary changes, sleep adaptations or stress levels – may moderate the short- and long-run health effects of Ramadan during pregnancy may contribute to the development of guidelines that help practitioners in giving advice to their Muslim patients in childbearing age, and in particular patients who wish to adhere to the Ramadan fast during pregnancy. Our study thus highlights that research on culture-specific habits and traditions is pivotal in order to promote a healthy start to life for all children.

Appendix Chapter 5.A Survey questionnaire

Questionnaire "Pregnancy during Ramadan"

Version for personal interviews

Note: Everything that is written in red should not be read out loud! (Support for the interviewer)

Introduction

Short introduction: Hello, my name is ________. We, at the University of Mainz, are conducting a survey study among Muslim women about the topic pregnancy and Ramadan. I would appreciate it, if I could ask you some questions. The interview will last around 5-10 minutes.

1. Are you:

   O Muslim

   O Other religion → **End of questionnaire**

2. We are interviewing Muslim women who are either pregnant or have recently delivered about how they experienced Ramadan. May I ask you some questions about this?

   O Yes

   O No, I would not like to participate in this study. → **End of questionnaire**

For the interviewer:

If the woman is interested in participating in the survey study:

- *Ask, if the interview can be conducted right then and there or if she prefers going somewhere else*
- *Introduce the project using the info-sheet, especially explain the confidentiality clause*
- *Mention that all Muslim women are of interest to us, whether or not they fasted during Ramadan*
- *Fill out the informed consent sheet and have the woman sign it (incl. their agreement that the survey data will be linked with the data of the birth registry/ data of the obstetric department of the University Hospital of Mainz)*

First Name Last Name	______________________		
Birthday (tt.mm.jjjj)	______________________		
Birth number(s)	______________________		
Date of Interview (tt.mm.jjjj)	______________________		
Hospital	**O** Uniklinik **O** KKM		
Interviewer Name	☐ Asmaa	☐ Kheira	
	☐ Asiye	☐ Hatem	

Before completing the survey, the informed consent form has to be completed and signed!

Questionnaire "Pregnancy during Ramadan"

Version for personal interviews

Note: Everything that is written in red should not be read out loud! (Support for the interviewer)

Introduction

Short introduction: Hello, my name is ________. We, at the University of Mainz, are conducting a survey study among Muslim women about the topic pregnancy and Ramadan. I would appreciate it, if I could ask you some questions. The interview will last around 5-10 minutes.

3. Are you:

   O Muslim

   O Other religion → **End of questionnaire**

4. We are interviewing Muslim women who are either pregnant or have recently delivered about how they experienced Ramadan. May I ask you some questions about this?

   O Yes

   O No, I would not like to participate in this study. → **End of questionnaire**

For the interviewer:

If the woman is interested in participating in the survey study:

- *Ask, if the interview can be conducted right then and there or if she prefers going somewhere else*
- *Introduce the project using the info-sheet, especially explain the confidentiality clause*
- *Mention that all Muslim women are of interest to us, whether or not they fasted during Ramadan*
- *Fill out the informed consent sheet and have the woman sign it (incl. their agreement that the survey data will be linked with the data of the birth registry/ data of the obstetric department of the University Hospital of Mainz)*

First Name Last Name	________________	
Birthday (tt.mm.jjjj)	________________	
Birth number(s)	________________	
Date of Interview (tt.mm.jjjj)	________________	
Hospital	**O** Uniklinik **O** KKM	
Interviewer Name	☐ Asmaa	☐ Kheira
	☐ Asiye	☐ Hatem

Before completing the survey, the informed consent form has to be completed and signed!

Pregnancy

5. *In case the child was already born:* When did you give birth to your child? (dd/mm/yyyy)

   __________/__________/ 20__________

6. When is/ was the expected date of delivery? (dd/mm/yyyy)

   __________/ __________/ 20__________

Careful: If the expected date of delivery is **March 2018** or later, ask if the woman was pregnant during Ramadan 2017. If not, continue with the interview and skip those questions that ask explicitly about pregnancy during Ramadan.

7. Is this your first pregnancy or have you been pregnant before?

   O This is my first pregnancy.
   O I have been pregnant before.
   → How many children do you have (*in case the child was already born*: including your newborn)?

   ____

   Of these ____________ pairs of twins.

Ramadan - general questions

8. Did you fast for one or more days during the Ramadan of **2017**?

   O Yes → ***continue with question 7 (on page 3)***
   O No, I did not fast → ***continue with question 15 (on page 5)***

Ramadan – questions for women who fasted

I would like to start out by asking you some questions about the days you fasted.

9. How many days did you fast during the Ramadan 2017?

   O On all days (29 days) → ***continue with question 9***
   O On most days (20-28 days) → ***starting here continue with question 8***
   O On about half of the days (10-19 days)
   O On some days (3-9 days)
   O On few days (1-2 days)
   In case an explanation or the exact number of days fasted were offered, please note down:

10. Are you planning to make up the days you did not fast?

    O I already made up these days
    O Yes, I am planning to make up these days at the following point in time:

    O No, because:

11. On the days you fasted, did you fast normally – in other words, did you give up food and drink during the day?

    O Yes
    O No

12. Did you abstain from anything else during the day, for example medicine?

    Medicine: O Yes O No
    O Other:

The next few questions are about your diet on the days on which you fasted.

13. Compared to the month before Ramadan, did you:

eat:	O more	O less	or	O the same amount	
drink:	O more	O less	or	O the same amount	
eat:	O more	O less	or	O the same amount	**of fruit and vegetables**
eat:	O more	O less	or	O the same amount	**of sweets**
eat:	O more	O less	or	O the same amount	**of greasy/ fatty food**

O Further changes to my diet:

14. In comparison to your diet during Ramadan when you are not pregnant, did you change your diet during this Ramadan because you were pregnant? Please consider both **what** and **how much** you ate and drank.

O Yes, I changed my eating habits in the following way:

O No, I did not change my eating and drinking habits because I was pregnant

15. What did you eat during the breaking of the fast?

16. Why did you fast during this Ramadan?

Ramadan - all

17. Did other members of your household fast?

O No

O Yes, the following people fasted:

O Husband O Parents O Parents-in-law O Children O Others:

In case respondent fasted: ***I would now like to ask you several questions about those days during Ramadan 2017, on which you did NOT fast.***

18. We are interested in whether or not your diet also changed on those days on which you did **not** fast – because, for example, you still celebrated the breaking of the fast with your family. On the days on which you did not fast, compared to the month directly before Ramadan, did you eat:

O more	O less	or	O the same amount	**in the evening/ at night**
O more	O less	or	O the same amount	**during the day**
O more	O less	or	O the same amount	**sweets and candy**

O Further changes:

O This question does not apply because I fasted on all days of Ramadan.

19. Why did you not fast / not fast on all days during this Ramadan?

O This question does not apply because I fasted on all days of Ramadan.

20. Do you normally fast when you are not pregnant?

O No ***→continue with question 20***

O Yes, I normally fast: ***→continue with question 19***

O On all days (29/30 days)

O On most days (20-28/29 days)

O On about half of the days (10-19 days)

O On some days (3-9 days)

O On few days (1-2 days)

In case an explanation or the exact number of days fasted were offered, please note down:

21. In case you are not able to fast on all days, do you make these days up at a later point in time?

O Yes
O No
If further comments/ explanations are given:

22. What effect do you think fasting during Ramadan has on the health of the unborn child?

O No effect
O Negative effect
O Positive effect
O Depends on the health of the mother
O No (direct) answer
If further comments are made in regards to the type of impact, please note down:

23. What effect do you think fasting during Ramadan has on the health of a pregnant woman?

O No effect
O Negative effect
O Positive effect
O No (direct) answer
If further comments are made in regards to the type of impact, please note down:

24. What does your partner think about fasting during pregnancy?

O He believes that pregnant women should fast
O He believes that pregnant women should **not** fast
O He has no opinion
O I do not know
O I do not have a partner
O Other:

25. Were you already aware of your pregnancy during Ramadan 2017?

O Yes → ***continue with question 25***
O No → ***continue with question 24***
O I found out during Ramadan that I was pregnant → ***continue with question 24***

26. If you had known about your pregnancy, would you have changed your fasting behavior? If so, how? (*Or* if you became aware of your pregnancy during Ramadan, did you change your behavior?)

    O Yes, I would have/did change:

    O No

27. Did you inform yourself about fasting during pregnancy? *(please mark all that apply)*

    O Yes, using the following sources of information:
    - 0 internet
    - 0 family
    - 0 friends/ acquaintances
    - 0 magazines/ books
    - 0 Other:

    O No, I did not inform myself

28. Did you discuss your fasting plans with your midwife and/ or gynecologist?

    O Yes **→ *continue with question 27***
    O No **→ *continue with question 28***

29. What advice did your midwife / your gynecologist give you?

30. Did you suffer from morning sickness during this Ramadan?

    O No, never
    O Yes, sometimes
    O Yes, often

31. Did you get up earlier during Ramadan 2017 than you normally do in comparison to the month before Ramadan?

    O Yes
    O Sometimes
    O No
    If further comments/ explanations are given:

32. Did you go to bed later during Ramadan 2017 than you normally do in comparison to the month before Ramadan?

    O Yes
    O Sometimes
    O No
    If further comments/ explanations are given:

33. Did you sleep more during the day during Ramadan 2017 than you normally do in comparison to the month before Ramadan?

    O Yes
    O Sometimes
    O No
    If further comments/ explanations are given:

34. Did you fast during past pregnancies?

    O Yes
    O No
    O Not applicable, since this is the first pregnancy
    O Not applicable, since past pregnancy was not during Ramadan
    O I do not know / I do not remember

    In case other things are mentioned, please note down:

35. How tall are you? ______________________ m
36. a. How much did you weigh before your pregnancy? _________________ kg

    b. How much weight did you gain during your pregnancy? ___________________kg

    (Alternatively –how much do you weigh today? ______________kg)

Personal information

Finally, I would like to ask you for some personal information.

37. What is your date of birth? (dd/mm/yyyy) ________/________ /________

38. In which country were you born?
    O Germany O Syria O Turkey O Morocco
    O Other:

39. *If you were not born in Germany:* how long have you been living in Germany?
    years

40. Is your partner Muslim?
    O Yes O No O I do not have a partner

41. In which country was your partner born?

42. In which country was your mother born?

43. In which country was your father born?

44. Which of the following situations was most applicable to you before this pregnancy (before the beginning of your parental leave)? *(please mark all answers that apply)*
    - O Working full time
    - O Working part time
    - O Unemployed
    - O Student
    - O Not working (such as housewife)

45. What is your highest educational degree?
    - O No degree / elementary school
    - O Secondary school
    - O Completed vocational training
    - O Technical college
    - O University degree (bachelor/ master)

    Alternatively: Until what age did you go to school? years

46. Do you wear a veiling in everyday life?
    - O No
    - O Yes, I wear:
        - 0 A hijab (Face free, hair / ears / neck covered)
        - 0 A burqa (Body and face veiled, net in front of the eyes)
        - 0 A niqab (Face completely hidden, narrow slit for the eyes)
        - 0 A chador (dark cloth, hair and body covered, face free)

End of questionnaire

The survey is now completed. Thank you very much for your participation! If you have any other comments or questions, feel free to ask them now.

If the respondent has further comments, please note them down here:

To be filled out by the interviewer:

1. Did the respondent wear a veil during the interview?

   0 No, no veiling
   0 Yes, a hijab (face free, hair / ears / neck covered)
   0 Yes, a burqa (Body and face veiled, net in front of the eyes)
   0 Yes, a niqab (Face completely hidden, narrow slit for the eyes)
   0 Yes, a chador (dark cloth, hair and body covered, face free)

2. Was the respondent alone during the interview?

   0 Yes, alone
   0 No, her partner/husband was with her
   0 No, she was accompanied by:
      0 a child (not her newborn!)
      0 a man (not her husband)
      0 a woman
   0 Interview took place in a room with other occupants, another patient was present

3. Did the interview take place during an extended hospital stay before the birth?

   O Yes
   O No

Uniklinik: In case the interview took place before the birth, please remember to place the pink sticker on the medical record.

Further comments / notes / suggestions by the interviewer:

Appendix Chapter 5.B Informed consent form

Informed Consent Form for the Participation in the Research Project "Pregnancy during Ramadan"

I participate voluntarily in this study. I was informed clearly and fully about the research project and my rights as a study participant. All of my questions were answered satisfactorily and project staff is available at any time if I have further questions.

I have read and understood the information leaflet for study participants. I have had enough time to make my decision. I am aware that I can withdraw my participation at any time (orally or in writing), without it causing me any disadvantages.

I have understood and agree that my study-related data will be pseudonymized (meaning they will be coded without recording my name, address, initials or something to this effect), compiled, saved and used for analysis by the study management and staff.

Personal data will not be given to third parties. The publication in scientific journals will only occur in such a manner that no conclusions can be drawn about my person.

☐ **I would like to participate in this survey study.**

☐ **I agree that my survey data will be pseudonymized and linked with the data of the obstetric department of the University Hospital of Mainz.**

____Mainz_____, _____/______ / 201_____
(Location, Day / Month / Year)

______________________________ ____________________________________
(Name, first name) (Signature of the study participant)

I confirm that the study participant has been comprehensively informed about the study and that I have obtained her informed consent:

____Mainz_____, _____/______ / 201_____
(Location, Day / Month / Year)

______________________________ ____________________________________
(Name, first name) (Signature of the project staff)

Appendix Chapter 5.C Information leaflet

Information about the research project

"Pregnancy during Ramadan"

We would like to ask you to participate in a study which is exploring how pregnant women experience Ramadan and what effects it has.

The project

We are interested in how you experienced Ramadan during your pregnancy: Did you fast? If yes, how? What were the reasons why you decided to fast or not to fast? Additionally, we would like to examine whether Ramadan has an effect on the course of the pregnancy or the newborn.

Your participation is very important, whether or not you fasted during Ramadan 2017.

Survey Procedure

We kindly ask you to answer a series of questions about your pregnancy. These questions mainly deal with your behavior during Ramadan 2017. It will take around 5-10 minutes to complete the survey.

Furthermore, we would like to link the information you give in this survey with the data of the obstetric department of the University Hospital of Mainz. After we link these data, all information will be encoded. No personally identifiable data (such as your name) will be stored in connection with survey results or medical data (see "Privacy" section).

Your Participation in this Project

Your participation in this study is completely voluntary. You may decide at any point in time, without giving a reason, that you would like to withdraw your participation. Your participation decision will in no way influence the medical treatment you are receiving. You have the right to verify and, if necessary, correct the data we are recording. You may also request for your data to be deleted at any point in time.

Data Privacy

The questionnaires are numbered consecutively. Only through this number will the information given in the survey be connected to medical data regarding your pregnancy and birth. This is called "pseudonymization".

What does pseudonymization mean?

To pseudonymize data means that every participant in this study will receive an ID number. All survey data as well as the data from the obstetric department of the University Hospital of Mainz will be included in the dataset used for analysis with this number. The first page of the survey, which asks for your name, will only be kept to link the survey data with the data from the obstetric department of the University Hospital of Mainz; once this link is established, the page will be destroyed. Data that has been pseudonymized connects all data of one participant using the ID number. Of course, we will only link your data to the medical data if you give us written permission to do so.

After the data analysis, the results will be anonymous and can be published as group results in a scientific journal. These results will not allow for conclusions to be made about a single individual. Additionally, only the scientific members of the project will receive access to the data.

All documents will be saved in accordance with the privacy laws. The retention period for scientific studies is 10 years. The ethics committee of the State Chamber of Medicine in Rheinland-Pfalz reviewed and approved this study.

Further Information

If you would like to participate in this study, we would kindly ask you to read and sign the attached informed consent form. Please give this signed form back to the project staff.

We thank you in advance for your support of our research!

In case you have questions about this research, feel free to contact us.

Prof. Dr. Reyn van Ewijk
Chair for Statistics & Economentrics

Project managers: Fabienne Pradella & Birgit Leimer
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Jakob-Welder-Weg 4
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Appendix Chapter 5.D Further descriptives and analyses

Appendix Table 5-1. Descriptives for the Entire Sample of Survey Participants, with Comparison of Fasting and Non-Fasting Women using Univariate Analysis

	Total Sample (N=326)		Fasting Women (N=119)		Non-Fasting Women (N=207)		P-value for Diff.
Category	Mean/ Obs.[1]	SD/ Share[2]	Mean/ Obs.[1]	SD/ Share[2]	Mean/ Obs.[1]	SD/ Share[2]	
Birth Outcomes							
Birthweight	3350	532	3335	502	3359	551	0.712 [3)]
5-minute APGAR score	9.7	0.9	9.7	1.1	9.6	0.8	0.542 [3)]
Gestational age (weeks)	39.0	1.9	38.9	2.1	39.0	1.8	0.911 [3)]
Male child	154	51%	62	53%	92	49%	0.445 [4)]
Religiosity							
More religious	185	57%	94	79%	91	44%	<0.001 [4)]
Maternal Birth Country							
Germany	91	28%	15	13%	76	37%	<0.001 [4)]
Syria	52	16%	32	27%	20	10%	
Morocco	48	15%	32	27%	16	8%	
Turkey	39	12%	8	7%	31	15%	
South Asia	28	9%	8	7%	20	10%	
Other Arab countries	23	7%	16	13%	7	3%	
Somalia	14	4%	3	3%	11	5%	
Other	31	10%	5	4%	26	13%	
Living in Germany <3 years	90	28%	50	42%	40	19%	<0.001 [4)]
Maternal Characteristics							
Age at birth	30.1	5.9	29.9	6.3	30.2	5.6	0.598 [3)]
Pre-pregnancy BMI	24.9	5.3	24.6	4.3	25.0	5.9	0.507 [3)]
Nulliparous	117	36%	42	35%	75	36%	0.865 [4)]
Pregnancy risk factors [5)]	45	14%	22	18%	23	11%	0.063 [4)]
Pregnancy not known during Ramadan	27	8%	23	19%	4	2%	<0.001 [4)]
Household members fast	274	85%	116	97%	158	77%	<0.001 [4)]
Maternal Socio-Economic Status							
Partially/fully employed	130	40%	32	27%	98	47%	0.001 [4)]
Technical/university degree	99	30%	34	29%	65	31%	0.593 [4)]

P-Values are for tests for differences between fasting vs. non-fasting women.
1) Means for continuous variables; number of observations in category for categorical variables
2) Standard deviations for continuous variables; share of observations in category for categorical variables. Share refers to the share of the respective sub-sample (total sample, fasting women, non-fasting women), excluding missing data (if applicable).
3) t-test
4) $\chi 2$ test
5) Pregnancy risk factors includes smoking, alcohol consumption, drug use and/or consanguinity.

Appendix Table 5-2. Descriptives on Fasting, Sleep & Nutrition on the Entire Sample of Survey Participants, with Comparison of Fasting and Non-Fasting Women using Univariate Analysis

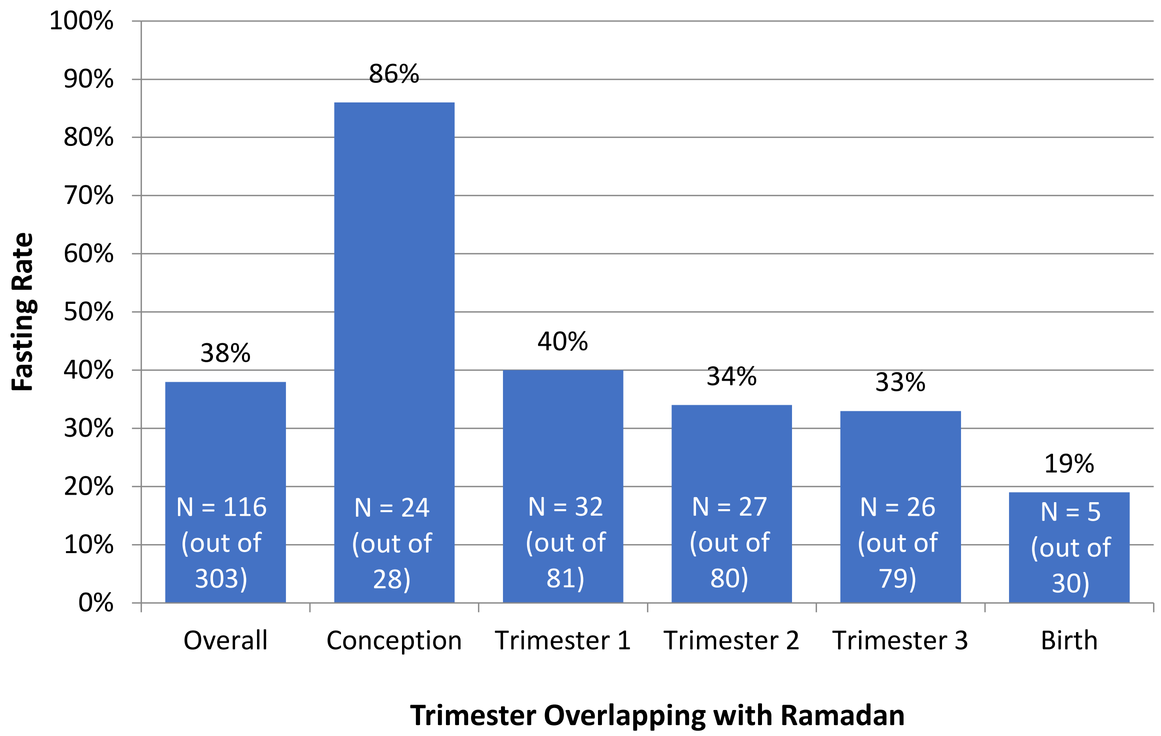
Category	Total Sample (N=326)		Fasting Women (N=119)		Non-Fasting Women (N=207)		P-Value for Diff.
	Obs.	**Share**	**Obs.**	**Share**	**Obs.**	**Share**	
Fasting Behavior							
Fasted at least 1 day	119	37%	119	100%		N/A	
Trimester of Ramadan Overlap							
Trimester 1	117	36%	57	48%	60	29%	
Trimester 2	92	28%	29	24%	63	31%	0.003 1)
Trimester 3	116	36%	33	28%	83	40%	
Sleep & Diet during Ramadan							
Slept less	124	38%	46	39%	78	38%	0.940 1)
Ate less sweet foods	68	21%	29	25%	39	20%	
Ate same amount of sweet foods	117	37%	48	40%	69	34%	0.064 2)
Ate more sweet foods	135	42%	42	35%	93	46%	
Drank less	21	6%	21	18%			
Drank same amount	53	16%	53	45%		N/A	
Drank more	45	14%	45	37%			
Ate less food high in fat	46	14%	46	39%			
Ate same amount of food high in fat	53	16%	53	44%		N/A	
Ate more food high in fat	20	6%	20	17%			
Ate less fruits/vegetables	23	7%	23	20%			
Ate same amount of fruits/vegetables	48	15%	48	40%		N/A	
Ate more fruits/vegetables	48	15%	48	40%			
Ate less healthily during Ramadan	40	12%	40	34%		N/A	
Ate more healthily during Ramadan	32	10%	32	27%			

Share refers to the share of the respective sub-sample (total sample, fasting women, non-fasting women), excluding missing data (if applicable). P-Values are for tests for differences between fasting vs. non-fasting women.
N/A: Information was not collected among non-fasting women.
1) χ2 test
2) Mann-Whitney test

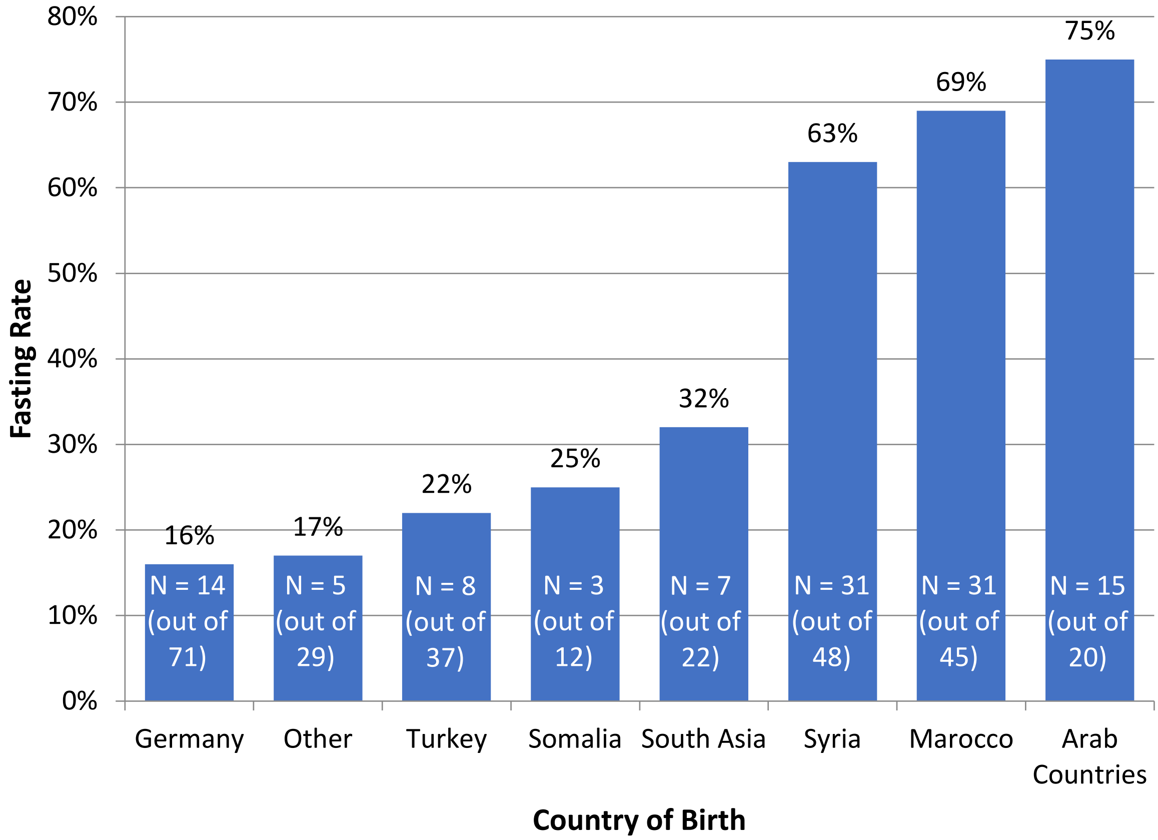
Appendix Table 5-3. Timing of Pregnancy Overlap with Ramadan

	Number of Observations	Share
Pregnancy characteristics		
Conception	28	9%
Trimester 1	81	27%
Trimester 2	83	27%
Trimester 3	80	26%
Birth	31	10%
Total	303	

Appendix Figure 5-1. Fasting Rates by Timing of Pregnancy Overlap with Ramadan (N=303)



Appendix Figure 5-2. Fasting Rates by Country of Birth (N=303)



- "Other" includes: Azerbaijan, Bosnia-Herzegovina, Bulgaria, Kosovo, Macedonia, Serbia, Spain, Iran, Guinea-Bissau, Moldova, Poland, Togo, Tadzhikistan, Gambia, Austria, Ghana
- "Arab Countries" include: Algeria, Egypt, Iraq, Lebanon, Palestine and Tunisia

Appendix Table 5-4. The Effect of Fasting on Birthweight when Adding Covariates Consecutively

Birthweight (in grams)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Fasted ≥ 1 day	-39.46				-43.89	-48.37	-83.71	-149.34**	-144.82**	-140.16**	-131.89**	-130.23**	-116.73*	-122.63*	-120.28*	-116.97*
	(62.24)				(52.83)	(55.92)	(59.86)	(69.63)	(69.51)	(67.87)	(65.25)	(65.68)	(66.07)	(67.69)	(67.83)	(68.34)
Gestational age		147.70***	353.13	340.47	336.63	345.05	331.23	313.86	308.20	220.03	238.70	232.88	230.37	238.19	239.85	236.48
		(24.66)	(362.27)	(375.68)	(380.04)	(377.63)	(382.06)	(377.70)	(376.94)	(388.53)	(368.72)	(370.61)	(357.48)	(362.61)	(358.94)	(358.15)
Gest. age squared			-2.81	-2.64	-2.59	-2.69	-2.48	-2.19	-2.11	-0.90	-1.16	-1.08	-1.05	-1.15	-1.17	-1.13
			(4.81)	(4.99)	(5.05)	(5.01)	(5.08)	(5.05)	(5.04)	(5.23)	(4.97)	(5.00)	(4.80)	(4.87)	(4.82)	(4.80)
Male child				147.88***	148.99***	151.60***	144.91***	130.95**	132.02**	119.64**	119.85**	121.11**	127.28**	126.34**	123.99**	126.12**
				(51.68)	(51.61)	(51.89)	(52.12)	(51.94)	(51.86)	(51.00)	(50.50)	(50.61)	(50.53)	(50.64)	(51.12)	(51.49)
Tri 2 overlap						23.12	12.51	-11.85	-13.93	-12.83	-15.07	-13.65	-16.74	-8.38	-6.01	-6.58
						(71.54)	(71.67)	(72.85)	(72.81)	(70.28)	(68.44)	(68.72)	(69.09)	(71.65)	(71.68)	(71.79)
Tri 3 overlap						-37.04	-43.47	-80.35	-79.21	-59.71	-65.38	-65.33	-57.09	-49.96	-48.37	-48.53
						(60.52)	(60.31)	(65.36)	(65.28)	(64.87)	(64.65)	(64.49)	(63.91)	(65.92)	(65.90)	(66.05)
Religiosity							96.99*	95.64	106.13*	97.63	87.04	77.50	82.21	81.29	65.59	61.45
							(54.85)	(59.98)	(61.73)	(61.58)	(61.69)	(61.61)	(59.74)	(59.90)	(62.64)	(64.22)
Syria								33.91	101.16	95.76	113.69	103.49	89.41	91.35	59.50	54.66
								(81.78)	(101.19)	(98.06)	(97.78)	(98.33)	(97.45)	(97.44)	(102.51)	(103.14)
Turkey								33.02	40.22	-5.50	15.21	11.47	41.68	39.43	24.72	26.82
								(82.47)	(81.33)	(81.21)	(79.94)	(80.75)	(83.08)	(83.80)	(86.09)	(86.32)
Morocco								179.19*	192.18*	148.81	146.28	136.45	114.62	114.28	89.72	87.22
								(101.46)	(103.42)	(100.03)	(99.69)	(100.39)	(100.56)	(100.60)	(101.90)	(102.18)
South Asia								-140.88	-114.24	-124.13	-94.01	-105.19	-97.03	-98.26	-125.53	-127.78
								(109.87)	(114.82)	(118.03)	(117.89)	(119.64)	(117.69)	(117.44)	(118.77)	(119.43)
Other Arab								81.33	101.78	90.34	74.89	64.67	60.49	62.89	33.02	24.92
								(127.96)	(130.06)	(122.20)	(111.20)	(113.94)	(113.54)	(113.52)	(117.93)	(117.78)
Somalia								-265.08*	-228.13	-179.26	-182.38	-187.84	-210.89	-212.82	-241.11*	-233.67
								(138.43)	(142.52)	(140.80)	(139.31)	(138.02)	(137.76)	(138.48)	(140.39)	(141.97)
Other countries								-44.13	-17.56	-18.77	-11.35	-28.18	-32.31	-33.48	-58.78	-60.24
								(89.47)	(93.94)	(91.77)	(92.31)	(92.27)	(89.28)	(88.99)	(91.55)	(92.09)

This table continues on the next page.

Appendix Table 5-4: continued

Birthweight (in grams)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
In Germany < 3 years									-85.39	-34.41	-36.73	-28.37	-9.14	-9.23	-22.53	-19.00
									(75.18)	(69.58)	(69.02)	(68.42)	(69.20)	(69.03)	(70.26)	(70.91)
Maternal age at birth										289.46	241.83	253.07	191.95	180.32	164.85	160.27
										(196.39)	(187.42)	(189.57)	(201.13)	(202.27)	(198.67)	(198.04)
Maternal age at birth squared										-9.49	-7.97	-8.46	-6.64	-6.25	-5.61	-5.54
										(6.46)	(6.16)	(6.24)	(6.55)	(6.60)	(6.49)	(6.47)
Maternal age at birth cubed										0.11	0.09	0.10	0.08	0.07	0.07	0.07
										(0.07)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)
Pre-pregnancy BMI											11.82*	11.33*	11.30*	11.43*	10.74	10.87
											(6.69)	(6.69)	(6.68)	(6.66)	(6.60)	(6.70)
Nulliparous												-53.86	-67.16	-68.44	-56.62	-64.46
												(55.48)	(55.19)	(55.30)	(55.93)	(57.55)
Risk behavior													-161.15**	-158.90**	-158.71**	-157.00**
													(79.12)	(78.94)	(78.66)	(78.58)
Pregnancy unknown in Ram.														40.64	49.77	49.76
														(101.03)	(99.77)	(99.92)
Employed prior to pregnancy															-74.47	-73.78
															(66.71)	(66.90)
University/vocational degree																27.30
																(60.11)
Constant	3370.04***	-2406.99**	-6129.34	-5971.10	-5885.83	-6061.39	-5870.00	-5598.65	-5507.63	-6928.84	-7047.46	-6950.15	-6248.22	-6288.17	-6155.90	-6018.56
	(40.56)	(967.72)	(6834.94)	(7085.20)	(7164.65)	(7119.75)	(7177.70)	(7058.32)	(7035.30)	(7192.19)	(6831.07)	(6867.95)	(6634.10)	(6682.30)	(6618.45)	(6584.38)
N	298	298	298	298	298	298	298	298	298	298	298	298	298	298	298	298

Note: Columns (1), (6), (7), (8), (14) and (16) are the same as columns (1) through (6) in Table 5-4. Robust standard errors reported in parentheses. Significance levels: ***p<0.01, **p<0.05, *p<0.1.

Appendix Table 5-5. The Effect of Fasting on APGAR score and Gestational Age when Adding Groups of Covariates Consecutively

	(1)	(2)	(3)	(4)	(5)	(6)
5-min. APGAR Score						
Fasted ≥ 1 Day						
Fasted	0.06	0.06	0.05	-0.09	-0.11	-0.12
	(0.12)	(0.11)	(0.11)	(0.14)	(0.15)	(0.15)
Fasted ≥1 Day by Trimester						
Trimester 1	0.01	-0.06	-0.07	-0.20	-0.26	-0.26
	(0.19)	(0.18)	(0.17)	(0.19)	(0.23)	(0.23)
Trimester 2	-0.09	-0.07	-0.08	-0.20	-0.20	-0.20
	(0.24)	(0.28)	(0.28)	(0.31)	(0.30)	(0.31)
Trimester 3	0.29***	0.33***	0.32***	0.15	0.14	0.14
	(0.08)	(0.11)	(0.10)	(0.11)	(0.11)	(0.11)
Number of Days Fasted (1-29 Days)						
Fasted	0.00	0.00	0.00	-0.00	-0.01	-0.01
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Gestational Age (in completed weeks)						
Fasted ≥ 1 Day						
Fasted	0.01	0.04	0.12	0.12	0.13	0.16
	(0.23)	(0.24)	(0.23)	(0.24)	(0.26)	(0.26)
Fasted ≥1 Day by Trimester						
Trimester 1	-0.09	-0.15	-0.08	-0.02	-0.03	0.02
	(0.29)	(0.36)	(0.35)	(0.36)	(0.34)	(0.35)
Trimester 2	-0.04	0.38	0.46	0.46	0.48	0.47
	(0.51)	(0.58)	(0.57)	(0.55)	(0.59)	(0.59)
Trimester 3	0.25	0.00	0.09	0.02	0.01	0.04
	(0.29)	(0.30)	(0.31)	(0.34)	(0.37)	(0.37)
Number of Days Fasted (1-29 Days)						
Fasted	-0.00	0.00	0.00	0.00	0.00	0.00
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Controls						
Pregnancy	No	Yes	Yes	Yes	Yes	Yes
Religiosity	No	No	Yes	Yes	Yes	Yes
Birth Country	No	No	No	Yes	Yes	Yes
Risk Factors	No	No	No	No	Yes	Yes
Socio-Eco.	No	No	No	No	No	Yes
N	298	298	298	298	298	298

Note: APGAR score takes on the value of 0 (worst) to 10 (best). The coefficient when using the number of days fasted is the effect on newborns per additional day a mother fasted; other fasting variables are binary. Covariates clustered into five different group, added in order of importance determined by our assessment based on previous research. Column (6) represents main specification. Pregnancy: trimester exposure (indicators for the 2nd and 3rd trimester), gestational age in weeks, gestational age in weeks squared, gender of child. Religiosity: indicator equal to 1 if a woman reported fasting normally when not pregnant and wearing a veil on a daily basis. Birth country: Syria, Turkey, Morocco, Somalia, South Asia, other Arab countries or other. Risk factors: living in Germany less than three years, age, age squared and age cubed of the mother at birth, BMI prior to pregnancy, nulliparity, risky behavior (smoking, taking drugs, or drinking alcohol during pregnancy or consanguinity), and pregnancy unknown during Ramadan. Socio-economic: technical or university degree and part- or full-time employed prior to parental leave. Robust standard errors reported in parentheses. Significance levels: ***p<0.01, **p<0.05, *p<0.1.

Appendix Table 5-6. The Effect of Changes in Sleep Behavior and Sweet Food Consumption on APGAR Score and Gestational Age by the Binary Fasting Decision

	(1)	(2)	(3)	(4)	(5)
5-min. APGAR Score					
Fasted ≥ 1 day	-0.12		-0.12		-0.12
	(0.15)		(0.15)		(0.15)
Sleep Behavior					
Slept less	0.11	0.20*			0.13
	(0.12)	(0.11)			(0.12)
Slept less*fasted ≥ 1 day		-0.25			
		(0.26)			
Did not sleep less*fasted ≥ 1 day		-0.03			
		(0.15)			
Sweet Food Consumption					
Less			-0.12	0.03	-0.13
			(0.11)	(0.11)	(0.11)
More			-0.06	-0.04	-0.07
			(0.12)	(0.14)	(0.12)
Less*fasted ≥ 1 day				-0.36	
				(0.30)	
Same amount*fasted ≥ 1 day				0.09	
				(0.14)	
More*fasted ≥ 1 day				-0.05	
				(0.17)	
Gestational Age (in completed weeks)					
Fasted ≥ 1 day	0.16		0.14		0.14
	(0.27)		(0.27)		(0.27)
Sleep Behavior					
Slept less	-0.11	-0.19			-0.16
	(0.23)	(0.29)			(0.24)
Slept less*fasted ≥ 1 day		0.28			
		(0.42)			
Did not sleep less*fasted ≥ 1 day		0.08			
		(0.31)			
Sweet Food Consumption					
Less			0.16	-0.02	0.17
			(0.29)	(0.31)	(0.29)
More			0.40	0.17	0.41
			(0.29)	(0.33)	(0.29)
Less*fasted ≥ 1 day				0.26	
				(0.40)	
Same amount*fasted ≥ 1 day				-0.27	
				(0.45)	
More*fasted ≥ 1 day				0.46	
				(0.39)	
N	298	298	298	298	298

Note: APGAR score takes on values of 0 (worst) to 10 (best). Columns (1), (2) and (5) control for changes in sleeping patterns columns (3), (4) and (5) for changes in sweet food consumption. In columns (2) and (4), the behavioral changes are further interacted with the fasting behavior. All regressions control for gestational age in weeks, gestational age squared, gender of child, trimester exposure (indicators for the 2nd and 3rd trimester), religiosity, country of birth, being in Germany less than 3 years, age, age squared and age cubed of the mother at birth, parity, risky behavior, pregnancy unknown during Ramadan, employment prior to parental leave, and education. Robust standard errors reported in parentheses. Significance levels: ***p<0.01, **p<0.05, *p<0.1.

Appendix Table 5-7. The Effect of Changes in Sleep Behavior and Sweet Food Consumption on Birthweight by Trimester

Birthweight (in grams)	(1)	(2)		(3)	(4)
Fasted ≥ 1 day*T1	-344.18***		Fasted ≥ 1 day*T1	-315.34***	
	(91.31)			(92.71)	
Fasted ≥ 1 day*T2	-1.88		Fasted ≥ 1 day*T2	10.24	
	(115.07)			(121.23)	
Fasted ≥ 1 day*T3	59.51		Fasted ≥ 1 day*T3	59.21	
	(98.64)			(101.64)	
Sleep Behavior			**Sweet Food Consumption**		
Slept less*T1	-168.78**	-233.66*	Less*T1	-146.67	-190.02
	(81.79)	(127.81)		(102.66)	(137.17)
Slept less*T1*fast		-244.69**	More*T1	-109.56	-234.72*
		(121.34)		(106.16)	(139.63)
Did not sleep less*T1*fast		-391.02***	Less*T1*fast		-462.82***
		(118.93)			(129.25)
Slept less*T2	14.80	3.72	Same*T1*fast		-328.68**
	(103.36)	(116.57)			(154.81)
Slept less*T2*fast		9.48	More*T1*fast		-140.02
		(184.19)			(140.93)
Did not sleep less*T2*fast		-14.71	Less*T2	-143.12	-107.18
		(131.25)		(114.95)	(120.83)
Slept less*T3	-35.98	112.57	More*T2	-236.89*	-249.54
	(78.44)	(95.98)		(142.54)	(186.30)
Slept less*T3*fast		-264.63**	Less*T2*fast		44.84
		(109.97)			(167.01)
Did not sleep less*T3*fast		256.14**	Same*T2*fast		-85.02
		(124.58)			(214.55)
			More*T2*fast		64.28
					(239.55)
			Less*T3	36.80	48.84
				(97.70)	(106.34)
			More*Tri 3	28.28	19.82
				(118.12)	(122.33)
			Less*Tri 3*fast		64.01
					(177.64)
			Same*Tri 3*fast		29.60
					(139.95)
			More*Tri 3*fast		104.24
					(174.10)
N	298	298	**N**	298	298

Note: Columns (1) and (2) control for changes in sleeping patterns and columns (3) and (4) for changes in sweet food consumption. In columns (2) and (4), the behavioral changes are further interacted with the fasting behavior. All regressions control for gestational age in weeks, gestational age squared, gender of child, trimester exposure (indicators for the 2nd and 3rd trimester), religiosity, country of birth, being in Germany less than 3 years, age, age squared and age cubed of the mother at birth, parity, risky behavior, pregnancy unknown during Ramadan, employment prior to parental leave, and education. Robust standard errors reported in parentheses. Significance levels: ***p<0.01, **p<0.05, *p<0.1.

Appendix Table 5-8. The Effect of Changes in Sleep Behavior and Sweet Food Consumption on Birthweight by Number of Days Fasted

Birthweight (in grams)	(1)	(2)	(3)	(4)	(5)
Number of days fasted (1-29 days)	-7.24**		-6.87**		-6.77**
	(2.91)		(2.94)		(2.92)
Sleep Behavior					
Slept less	-55.26	-22.47			-41.29
	(51.99)	(61.01)			(52.95)
Slept less*number of days fasted		-9.91***			
		(3.25)			
Did not sleep less*number of days fasted		-5.14			
		(3.94)			
Sweet Food Consumption					
Less			-82.23	-78.19	-78.65
			(60.06)	(69.75)	(60.08)
More			-90.60	-146.78*	-87.12
			(71.63)	(83.70)	(72.01)
Less *number of days fasted				-8.71**	
				(4.01)	
Same amount *number of days fasted				-9.17**	
				(4.47)	
More *number of days fasted				-0.86	
				(4.90)	
N	298	298	298	298	298

Note: The coefficients for number of days fasted can be interpreted as the number of grams newborns weigh less per additional day a mother fasted. Columns (1), (2) and (5) control for changes in sleeping patterns columns (3), (4) and (5) for changes in sweet food consumption. In columns (2) and (4), the behavioral changes are further interacted with the fasting behavior. All regressions control for gestational age in weeks, gestational age squared, gender of child, trimester exposure (indicators for the 2nd and 3rd trimester), religiosity, country of birth, being in Germany less than 3 years, age, age squared and age cubed of the mother at birth, parity, risky behavior, pregnancy unknown during Ramadan, employment prior to parental leave, and education. Robust standard errors reported in parentheses. Significance levels: ***p<0.01, **p<0.05, *p<0.1.

Appendix Table 5-9. The Effect of Changes in Food Consumption Among Fasting Women on APGAR Score and Gestational Age

	Interaction of Fasting with Behavior			
	(1)	(2)	(3)	(4)
	Fatty Foods	Fruits & Vegetables	Healthy	Fluids
5-min. APGAR				
Less*fasted ≥ 1 day	-0.19	-0.01	-0.01	-0.04
	(0.23)	(0.13)	(0.13)	(0.15)
Same*fasted ≥ 1 day	-0.15	0.04	0.03	0.01
	(0.18)	(0.11)	(0.10)	(0.13)
More*fasted ≥ 1 day	0.14	-0.33	-0.58	-0.29
	(0.18)	(0.29)	(0.37)	(0.28)
Gestational Age (in completed weeks)				
Less*fasted ≥ 1 day	0.34	0.17	0.25	0.44
	(0.32)	(0.40)	(0.41)	(0.38)
Same*fasted ≥ 1 day	0.10	0.38	0.23	0.29
	(0.29)	(0.34)	(0.32)	(0.37)
More*fasted ≥ 1 day	-0.14	-0.08	-0.14	-0.14
	(0.75)	(0.37)	(0.43)	(0.33)
N	298	298	298	298

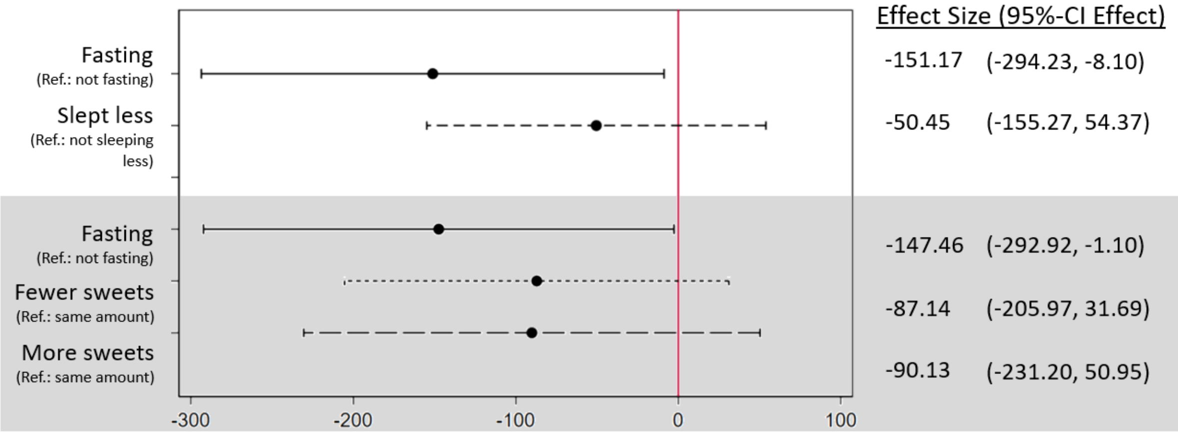
Note: APGAR score takes on the value of 0 (worst) to 10 (best). The specifications in columns (1) through (4) include interaction terms of the binary fasting indicator with changes in food and fluid intake. Behavioral changes were collected by asking the respondents to compare their behavior during Ramadan to their behavior in the month right before Ramadan. Column (3) combines changes in food composition, where eating healthier (more healthy) is equal to 1 for those women who reported eating less sweets and fatty foods while eating more fruits and vegetables. Eating unhealthier (less healthy) is equal to 1 if a woman reported eating more sweets or fatty foods. All regressions control for gestational age in weeks, gestational age squared (except when gestational age is the outcome variable), gender of child, trimester exposure (indicators for the 2nd and 3rd trimester), religiosity, country of birth, being in Germany less than 3 years, age, age squared and age cubed of the mother at birth, parity, risky behavior, pregnancy unknown during Ramadan, employment prior to parental leave, and education. Robust standard errors reported in parentheses. Significance levels: ***p<0.01, **p<0.05, *p<0.1.

Appendix Table 5-10. The Effect of Changes in Food Consumption Among Fasting Women on Birthweight by Trimester

	Interaction of Fasting with Behavior			
	(1)	(2)	(3)	(4)
Birthweight (in grams)	Fatty Foods	Fruits & Vegetables	Healthy	Fluids
Fasted ≥1 Day in Trimester 1				
Less*Trimester 1	-343.60***	-339.09***	-207.13*	-265.45**
	(115.46)	(118.57)	(107.75)	(119.43)
Same*Trimester 1	-422.22***	-214.07**	-344.24***	-344.06***
	(102.98)	(104.27)	(103.83)	(114.46)
More*Trimester 1	-59.81	-490.76***	-590.00***	-379.38***
	(163.80)	(128.40)	(158.14)	(123.48)
Fasted ≥1 Day in Trimester 2				
Less*Trimester 2	-131.46	-13.39	51.10	-106.96
	(161.67)	(165.59)	(180.62)	(177.03)
Same*Trimester 2	-34.10	-34.47	54.18	71.24
	(153.61)	(151.52)	(134.50)	(192.34)
More*Trimester 2	197.24	88.83	-140.83	-61.42
	(280.86)	(138.06)	(182.26)	(129.79)
Fasted ≥1 Day in Trimester 3				
Less*Trimester 3	-16.21	120.45	198.87	-223.39*
	(151.29)	(192.14)	(159.81)	(120.85)
Same*Trimester 3	-7.57	107.91	37.99	20.86
	(116.15)	(136.51)	(134.24)	(144.58)
More*Trimester 3	326.44*	-77.12	-192.77*	132.00
	(194.91)	(129.37)	(99.36)	(129.70)
N	298	298	298	298

Note: The specifications in columns (1) through (4) include interaction terms of the fasting by trimester indicators with changes in food and fluid intake. Behavioral changes were collected by asking the respondents to compare their behavior during Ramadan to their behavior in the month right before Ramadan. Column (3) combines changes in food composition, where eating healthier (more healthy) is equal to 1 for those women who reported eating less sweets and fatty foods while eating more fruits and vegetables. Eating unhealthier (less healthy) is equal to 1 if a woman reported eating more sweets or fatty foods. All regressions control for gestational age in weeks, gestational age squared, gender of child, trimester exposure (indicators for the 2nd and 3rd trimester), religiosity, country of birth, being in Germany less than 3 years, age, age squared and age cubed of the mother at birth, parity, risky behavior, pregnancy unknown during Ramadan, employment prior to parental leave, and education. Robust standard errors reported in parentheses. Significance levels: ***p<0.01, **p<0.05, *p<0.1.

Appendix Figure 5-3. Behavioral Changes and Birthweight (Fasting at Least Three Days vs. Non-Fasting Women)



Note: Each panel represents the results of a separate regression: the first controls for fasting at least three days and having slept less (ref: not sleeping less), while the second regression controls for fasting at least three days and sweet food consumption (ref: same amount of sweet food). Both regressions also control for all other covariates listed in the main text.

Appendix Table 5-11. The Effect of Changes in Food Consumption Among Fasting Women on Birthweight by Number of Days Fasted

	Interaction of Fasting with Behavior			
	(1)	(2)	(3)	(4)
Birthweight (in grams)	Fatty Foods	Fruits & Vegetables	Healthy	Fluids
Less*Number of days fasted	-8.93**	-5.07	-2.23	-11.18***
	(4.25)	(5.16)	(4.07)	(3.48)
Same*Number of days fasted	-9.67***	-4.17	-7.17**	-7.25*
	(3.34)	(3.76)	(3.45)	(3.94)
More*Number of days fasted	0.93	-11.91***	-15.45***	-6.02
	(5.36)	(3.45)	(4.80)	(3.94)
N	298	298	298	298

Note: The coefficients can be interpreted as the number of grams newborns weigh less per additional day a mother fasted. The specifications in columns (1) through (4) include interaction terms of the number of days fasted with changes in food and fluid intake. Behavioral changes were collected by asking the respondents to compare their behavior during Ramadan to their behavior in the month right before Ramadan. Column (3) combines changes in food composition, where eating healthier (more healthy) is equal to 1 for those women who reported eating less sweets and fatty foods while eating more fruits and vegetables. Eating unhealthier (less healthy) is equal to 1 if a woman reported eating more sweets or fatty foods. All regressions control for gestational age in weeks, gestational age squared, gender of child, trimester exposure (indicators for the 2nd and 3rd trimester), religiosity, country of birth, being in Germany less than 3 years, age, age squared and age cubed of the mother at birth, parity, risky behavior, pregnancy unknown during Ramadan, employment prior to parental leave, and education. Robust standard errors reported in parentheses. Significance levels: ***p<0.01, **p<0.05, *p<0.1.

Appendix Table 5-12. Heterogeneity Analysis by Trimester and Number of Days Fasted

	Birthweight	5-min. APGAR	Gestational Age
	(1)	(2)	(3)
Gender of the Child			
Fasted ≥1 Day by Trimester			
Fasted ≥ 1 day*Trimester 1*Female	-189.73*	-0.19	-0.24
	(101.59)	(0.17)	(0.50)
Fasted ≥ 1 day*Trimester 2*Female	-36.42	0.00	-0.19
	(115.90)	(0.15)	(0.55)
Fasted ≥ 1 day*Trimester 3*Female	118.37	-0.26	0.17
	(133.76)	(0.42)	(0.81)
Fasted ≥ 1 day*Trimester 1*Male	-495.81***	-0.33	0.32
	(109.78)	(0.38)	(0.50)
Fasted ≥ 1 day*Trimester 2*Male	72.78	0.22	0.27
	(131.52)	(0.13)	(0.46)
Fasted ≥ 1 day*Trimester 3*Male	-201.56	-0.11	0.96*
	(182.62)	(0.28)	(0.54)
Fasting Intensity			
Number of days fasted*Female	-2.37	-0.00	-0.00
	(3.22)	(0.01)	(0.02)
Number of days fasted*Male	-13.03***	-0.01	0.01
	(3.93)	(0.01)	(0.02)
Parity			
Fasted ≥1 Day by Trimester			
Fasted ≥ 1 day*Trimester 1*Multiparous	-364.63***	-0.45	0.11
	(103.06)	(0.31)	(0.41)
Fasted ≥ 1 day*Trimester 2*Multiparous	29.24	0.06	-0.07
	(125.37)	(0.13)	(0.43)
Fasted ≥ 1 day*Trimester 3*Multiparous	-53.04	-0.34	0.08
	(148.41)	(0.40)	(0.74)
Fasted ≥ 1 day*Trimester 1*Nulliparous	-286.65**	0.09	-0.19
	(115.63)	(0.17)	(0.57)
Fasted ≥ 1 day*Trimester 2*Nulliparous	76.57	0.26*	0.26
	(133.13)	(0.15)	(0.61)
Fasted ≥ 1 day*Trimester 3*Nulliparous	96.77	0.08	1.26**
	(145.29)	(0.29)	(0.56)
Fasting Intensity			
Number of days fasted*Multiparous	-8.06**	-0.01	0.01
	(3.35)	(0.01)	(0.01)
Number of days fasted*Nulliparous	-5.95	0.01*	-0.03
	(4.33)	(0.01)	(0.02)

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Appendix Table 5-12: continued

	Birthweight	5-min. APGAR	Gestational Age
	(1)	(2)	(3)
Time Spent Living in Germany			
Fasted ≥1 Day by Trimester			
Fasted ≥ 1 day*Trimester 1*<3 years	-302.10**	-0.08	-0.17
	(120.46)	(0.22)	(0.55)
Fasted ≥ 1 day*Trimester 2*<3 years	107.63	0.24*	0.51
	(132.74)	(0.14)	(0.46)
Fasted ≥ 1 day*Trimester 3*<3 years	32.14	-0.11	1.07*
	(155.01)	(0.30)	(0.57)
Fasted ≥ 1 day*Trimester 1*≥3 years	-348.34***	-0.34	0.21
	(105.29)	(0.31)	(0.41)
Fasted ≥ 1 day*Trimester 2*≥3 years	2.82	0.09	-0.32
	(138.56)	(0.15)	(0.49)
Fasted ≥ 1 day*Trimester 3*≥3 years	-15.22	-0.22	0.13
	(149.44)	(0.42)	(0.78)
Fasting Intensity			
Number of days fasted*<3 years	-6.32*	0.00	0.00
	(3.69)	(0.01)	(0.02)
Number of days fasted*≥3 years	-8.36**	-0.01	0.01
	(3.80)	(0.01)	(0.01)
N	298	298	298

Note: Birthweight is measured in grams; APGAR score takes on the value of 0 (worst) to 10 (best); gestational age is measured in completed weeks. The variable 'number of days fasted' takes on the value of the number of days fasted. All regressions control for gestational age in weeks, gestational age squared (except in column (3)), gender of child, trimester exposure (indicators for the 2nd and 3rd trimester), religiosity, country of birth, being in Germany less than 3 years, age, age squared and age cubed of the mother at birth, parity, risky behavior, pregnancy unknown during Ramadan, employment prior to parental leave, and education. Robust standard errors reported in parentheses. Significance levels: ***p<0.01, **p<0.05, *p<0.1.

Appendix Table 5-13. Robustness Check - Controlling for Month of Pregnancy Overlapping with Ramadan

	Birthweight	5-min. APGAR	Gestational Age
	(1)	(2)	(3)
Fasted ≥1 Day			
Fasted	-102.15	-0.09	0.24
	(68.15)	(0.14)	(0.26)
Fasted ≥1 Day by Trimester			
Trimester 1	-331.80***	-0.22	0.07
	(95.03)	(0.19)	(0.35)
Trimester 2	30.10	-0.21	0.44
	(110.77)	(0.31)	(0.53)
Trimester 3	23.04	0.17	0.22
	(100.03)	(0.12)	(0.37)
Fasting Intensity			
Number of days fasted (1-29 days)	-6.53**	-0.00	0.01
	(3.10)	(0.01)	(0.01)
Fasted ≥1 Day by Month of Pregnancy Overlapping with Ramadan			
Month 10	39.13	-0.11	-0.08
	(199.99)	(0.31)	(0.63)
Month 9	49.05	0.00	0.15
	(177.80)	(0.17)	(0.64)
Month 8	170.87	0.52*	0.07
	(174.21)	(0.27)	(0.64)
Month 7	25.59	-0.48	0.44
	(145.32)	(0.52)	(0.52)
Month 6	-79.86	0.05	0.86
	(185.47)	(0.29)	(0.69)
Month 5	-0.40	0.07	-0.31
	(236.88)	(0.50)	(1.56)
Month 4	-380.97**	-0.23	0.96
	(160.36)	(0.32)	(0.61)
Month 3	-428.11***	-0.10	0.57
	(162.99)	(0.22)	(0.56)
Month 2	-307.11*	-0.72	0.36
	(159.27)	(0.56)	(0.59)
Month 1	44.64	0.22	-2.22***
	(325.28)	(0.42)	(0.76)
N	298	298	298

Note: Birthweight is measured in grams; APGAR score takes on the value of 0 (worst) to 10 (best); gestational age is measured in completed weeks. The variable 'number of days fasted' takes on the value of the number of days fasted. All regressions control for gestational age in weeks, gestational age squared (except in column (3)), gender of child, month exposure (indicators for each month overlapping with Ramadan), religiosity, country of birth, being in Germany less than 3 years, age, age squared and age cubed of the mother at birth, parity, risky behavior, pregnancy unknown during Ramadan, employment prior to parental leave, and education. The reference month is pregnancy overlapping with the sixth month (i.e. overlap during the second trimester). Note that months 2 through 10 are assumed to last 28 days and month 1 14 days, since the first 14 days of the first month are prior to conception. Month 1 therefore contains individuals who conceived during Ramadan. Robust standard errors reported in parentheses. Significance levels: ***p<0.01, **p<0.05, *p<0.1

Appendix Table 5-14. Robustness Check - Different Sample Restrictions

	Birthweight	5-min. APGAR	Gest. Age
	(1)	(2)	(3)
Gestational Age ≥37			
Fasted ≥ 1 day	-131.67**	-0.09	0.04
	(64.68)	(0.11)	(0.17)
Fasted ≥1 Day by Trimester			
Trimester 1	-318.59***	-0.07	-0.17
	(89.07)	(0.10)	(0.25)
Trimester 2	-50.94	-0.40	0.25
	(112.16)	(0.29)	(0.31)
Trimester 3	22.26	0.14	0.12
	(97.30)	(0.10)	(0.27)
Fasting Intensities			
Number of days fasted	-7.20**	0.00	0.00
(1-29 days)	(2.91)	(0.00)	(0.01)
N	280	280	280
Gestational Age ≥37 & ≤42			
Fasted ≥ 1 day	-135.30**	-0.09	0.08
	(64.36)	(0.11)	(0.17)
Fasted ≥1 Day by Trimester			
Trimester 1	-317.35***	-0.07	-0.16
	(88.31)	(0.10)	(0.25)
Trimester 2	-55.76	-0.39	0.26
	(112.67)	(0.27)	(0.31)
Trimester 3	16.74	0.16*	0.22
	(97.64)	(0.09)	(0.25)
Fasting Intensities			
Number of days fasted	-7.20**	0.00	0.00
(1-29 days)	(2.91)	(0.00)	(0.01)
N	279	279	279
Children Alive			
Fasted ≥ 1 day	-123.69*	0.06	0.20
	(67.83)	(0.07)	(0.25)
Fasted ≥1 Day by Trimester			
Trimester 1	-334.93***	-0.03	0.21
	(89.81)	(0.10)	(0.33)
Trimester 2	-14.05	0.03	0.36
	(119.39)	(0.17)	(0.57)
Trimester 3	32.06	0.19**	0.05
	(98.82)	(0.09)	(0.36)
Fasting Intensities			
Number of days fasted	-7.24**	0.00	0.01
(1-29 days)	(2.87)	(0.00)	(0.01)
N	293	293	293

Note: Birthweight is measured in grams; APGAR score takes on the value of 0 (worst) to 10 (best); gestational age is measured in completed weeks. The variable "number of days fasted" takes on the value of the number of days fasted. All regressions control for gestational age in weeks, gestational age squared (except in column (3)), gender of child, trimester exposure (indicators for the 2nd and 3rd trimester), religiosity, country of birth, being in Germany less than 3 years, age, age squared and age cubed of the mother at birth, parity, risky behavior, pregnancy unknown during Ramadan, employment prior to parental leave, and education. Robust standard errors reported in parentheses. Significance levels: ***p<0.01, **p<0.05, *p<0.1.

Chapter 6
Conclusion

This dissertation provided empirical findings on the associations between Ramadan during pregnancy, a comparatively subtle prenatal shock, and health outcomes along the offspring's life course. Chapter 2 and chapter 3 exploit Ramadan during pregnancy as a natural experiment to identify health effects in childhood and adulthood, using data from IFLS. Chapter 4 and chapter 5 link the practice of intermittent fasting during Ramadan, as well as other Ramadan-specific maternal dietary and sleep patterns, to newborn health based on data from the Mainz Survey Study on Ramadan during Pregnancy. This concluding chapter begins by summarizing the key contributions and situates the main findings of all chapters within the literature[57]. The second part is concerned with relevant insights as well as potential avenues for future research. Third, practical implications for public policy and health care professionals are discussed. Lastly, final concluding remarks are made.

6.1. Contributions and key findings

This dissertation is shaped by three overarching themes. First, it sought to explore the dynamics behind the manifestation of health effects in response to Ramadan during pregnancy. By studying health outcomes at birth (chapter 5), in childhood/adolescence (chapter 3) and adulthood (chapter 2, chapter 3), a life course perspective is taken. Adverse effects of Ramadan (fasting) during pregnancy are detected in all life stages. Whereas a substantial part of the empirical literature on the fetal origins hypothesis focuses on outcomes in later, often post-reproductive life, the findings of this dissertation underpin that outcomes along the entire life course may be affected by prenatal shocks.

By investigating potential mediating factors and causal mechanisms linking Ramadan during pregnancy to health outcomes along the life course, the chapters of this dissertation go beyond effect documentation. In chapter 2, we demonstrate that Ramadan during pregnancy is associated with an increased risk of wheezing occurrence among adult Muslims. We show that the effects are concentrated among smokers, leading to the hypothesis that the respiratory system of the prenatally exposed performs worse in mitigating later postnatal harmful influences. In chapter 3, the associations between Ramadan during pregnancy and linear growth are examined. I find suggestive evidence that the materialization of effects on adverse effects on linear growth is concentrated among adolescents who postnatally grew up with unimproved sanitary standards. This integration of later-life circumstances contributes a novel direction of research to the fetal programming literature. These findings suggest that when studying the (long-term) effects of

[57] For an extensive, separate summary of all chapters see chapter 1.5. Here, the focus is on the key contributions of the overall dissertation.

prenatal shocks, the postnatal environment might contribute to the likelihood of effect materialization.

Another potential mediating factor might be maternal behavior during Ramadan, beyond the binary fasting decision. In chapter 5, we find that newborns to mothers who had vs. had not fasted during a Ramadan exhibit lower birthweight. Besides fasting, Ramadan entails temporary changes to dietary composition and sleep schedules. These additional factors are interesting to consider as pregnant women who choose to observe the Ramadan fast can modify them relatively easily. We find that fasting seems to be the main driver of the negative effects on offspring birthweight, since dietary changes and sleep behavior per se are not associated with offspring birthweight. However, our findings suggests that dietary choices during Ramadan meals (i.e. outside of fasting hours) influence how the effects of Ramadan intermittent fasting during pregnancy materialize. The negative fasting-birthweight association disappeared among women with increased intake of foods that are high in fat content during Ramadan. Effects are concentrated among women who slept less, drank less and consumed more fruits and vegetables during Ramadan.

A second main contribution of this dissertation is the provision of first evidence on how pregnant Muslims practice Ramadan in Germany. Besides the above-mentioned investigation of the effects of fasting and other dietary and behavioral changes during Ramadan on newborn health (chapter 5), this includes an assessment of the determinants of Ramadan behavior during pregnancy of Muslims in Mainz. In chapter 4, we find that Ramadan intermittent fasting during pregnancy is common in Germany, with 38% of the interviewed women fasting at least one day. By contrast, awareness among medical personnel turned out to be limited, both regarding the practice of Ramadan as well as potential negative effects of Ramadan intermittent fasting during pregnancy. We also found that many non-fasting pregnant Muslims live in households with fasting household members, which suggests that dietary adjustments and changes to the sleep schedule during Ramadan are relevant to consider among both fasting and non-fasting pregnant Muslims.

Together with the findings on the potential moderating role of dietary choices and sleep patterns (chapter 5), this adds to the topical discussion on whether the effects of Ramadan during pregnancy can clearly be attributed to the intermittent fasting during pregnancy (Seiermann & Gabrysch, 2020) and corroborate that the terms ‘Ramadan during pregnancy’ and ‘Ramadan fasting during pregnancy’ should not be used interchangeably. Note that the practice of Ramadan consistently entails forms of intermittent fasting, yet dietary and behavioral adjustments to Ramadan vary across Muslim communities. To the extent that the latter moderate the effects on offspring health, our research sheds light on why research on Ramadan fasting during pregnancy and newborn health outcomes has found effects in some settings, but not in others.

Lastly, this dissertation addresses several further conceptual developments in the fetal programming literature. The findings of Chapter 2, Chapter 3 and Chapter 5 confirm that in utero exposure to more subtle prenatal shocks is associated with offspring health outcomes along the entire life span. Thereby, first evidence on Ramadan during pregnancy and effects on lung function in adulthood (chapter 2) and infectious disease occurrence among children and reproductive trajectories among women (chapter 3) is provided. The detection of health effects in response to milder in utero shocks implies that human capital formation already starts in utero. From a methodological perspective, it is advantageous that Ramadan is constrained to a clearly confined time period, since it enables differentiation by the stages of pregnancy of overlap with Ramadan (fasting). The earliest pregnancy stages are consistently found to be most sensitive, which is in accordance with epigenetic findings. Similarly in accordance with recent epigenetic findings, chapter 3 finds evidence that periconceptional overlap with a Ramadan also might be associated with later-life outcomes.

6.2. Recommendations for future work

While many recent advancements of the literature have been addressed in this dissertation, there are equally many directions for future research. In order to inform tailored policy making, research on the developmental origins of health and disease is encouraged to examine the pathways to effects, in addition to effect documentation. A life course perspective on health and human capital effects, i.e. the differentiation of effect materialization across different age groups, might help to assess when effects start to appear and to identify vulnerable groups. Future research is thereby encouraged to further inspect the role of the early pregnancy phases, including the periconceptional period.

While chapter 2 and chapter 3 of this dissertation provided first evidence on a potential moderating role of postnatal factors, further research into this direction is necessary. In particular, the postnatal circumstances scrutinized in this dissertation were not subject to exogenous variation (even though we were able to show that they were independent of prenatal overlap with a Ramadan). Studying interactions between (quasi-random) prenatal and (quasi-random) postnatal exposures also has the potential to shed light on dynamic complementarities across life stages in human capital formation, as conceptualized by Heckman (2007). An example could be the success of (randomized) nutritional interventions among individuals with and without prenatal exposure to a (random) prenatal shock.

The need to further study effect moderation also concerns the potential moderating role of diets outside of fasting hours and other Ramadan-related behavioral adjustments, as suggested in chapter 5. While we detected that dietary choices outside of fasting hours may mediate the effects of intermittent fasting on birthweight, this does not guarantee that these dietary choices also prevent effect materialization in the longer term. Since nutritional patterns during Ramadan are diverse across Muslim communities, all analyses should be replicated in other settings. To the extent that effect materialization depends on factors that are context-specific, it is plausible that effects of Ramadan during pregnancy are detected in some settings but not in others.

A further avenue of research is to study transgenerational effects. Since a woman's ovules already develop during her own time in utero, there is a potential for second generation effects. The results of chapter 3 suggest that Ramadan during pregnancy might lead to phenotypes with an altered fertility, which might also induce transgenerational health effects. Transgenerational effects have been documented in response to more extreme prenatal shocks (Painter, Osmond, et al., 2008; Painter, Westendorp, et al., 2008). It still needs to be assessed if also in case of more subtle prenatal shocks, effects on human capital accumulation, including the productivity of health investments by future generations, persist across generations.

Lastly, extending the research on Ramadan during pregnancy and other prenatal shocks hinges on the availability of high-quality data. While IFLS is a rich dataset, the health effects of Ramadan during pregnancy should also be studied in other contexts than Indonesia. However, exact date of birth (including day, month and year) is often not provided in other household surveys (or only for under 5-year olds), which makes it impossible to calculate prenatal overlap with a Ramadan. Smaller-scale survey studies that observe the fasting behaviors and offspring health outcomes typically do not sample women with all pregnancy trimesters of overlap with Ramadan, yet this is necessary to gain a better understanding of the practice of Ramadan during pregnancy and the related health effects in different contexts. In the interdisciplinary cooperation between economics, epidemiology and epigenetics, the increasing availability of data on genetic markers will certainly enrich future research on the developmental origins of health and disease.

6.3. Implications for policy and practice

From a public policy perspective, the detection of health effects in response to more subtle but common prenatal shocks implies that policies need to assist individual women, families and households in the prevention of exposure to milder shocks during pregnancy. Information on Ramadan during pregnancy, and in particular on the practice of the Ramadan fast during pregnancy, is pivotal for Muslim women of childbearing age to make informed decisions on their behavior during pregnancies that overlap with a Ramadan. The developing fetus is most sensitive to environmental influences during early pregnancy, including the periconceptional period, so that counseling should be extended to women of childbearing age. However, it also needs to be acknowledged that making 'healthy choices' is not possible in the same way for everyone. To the extent that access to improved sanitation or adequate nutrition is not affordable for relevant parts of the population, the living context needs to be improved on a wider level (Low et al., 2020). Consequently, the policy recommendations derived from this dissertation are equally context-specific as the practice of Ramadan during pregnancy.

In general, Ramadan during pregnancy is a highly sensitive, religious topic. The WHO's Dietary Recommendations for Ramadan mention that "pregnant women (…) should refer to their doctor for advice", yet to date doctors have no evidence-based guidelines on which to base their advice (World Health Organization, 2020). A main challenge in the translation of research findings to clinical practice is that many of the studied effects only emerge in the longer term and might thus appear less urgent (Hanson et al., 2019). A mere call for sensitization of the medical personnel to fetal programming mechanisms might therefore not be sufficient. By contrast, the connection between shocks early in life (here: Ramadan during pregnancy) and all dimensions of human capital formation might need to be made clearer, in order to acquire relevant funding and support from policy makers to develop guidelines that are based on evidence from different countries and cultures. Thereby, a main focus could be laid on changes to dietary composition and sleep schedules, that are relatively easily modifiable by pregnant woman.

While the fetal period is largely regarded as a window of vulnerability, the complexity of the research on the fetal origins of health and disease reveals that it is also a window of opportunity (Martorell, 2017). Beyond justifying policies that help to avoid prenatal exposure to comparatively subtle shocks, the findings of this dissertation suggest that there are both prenatal and postnatal parameters that have the potential to moderate the materialization of prenatal shocks. For example, if adequate sanitation has the potential to prevent the effects of prenatal shocks from materializing, this is an additional justification for policies aimed at improving the living conditions of the most vulnerable population which is often at highest risk (Almond et al., 2018).

6.4. Concluding remarks

Almost a quarter of the world population is Muslim, with about 75% of Muslim pregnancies overlapping with a Ramadan. Consequently, each year millions of Muslim offspring whose own time in utero overlapped with a Ramadan are born. Moreover, several other forms of and motivations for intermittent fasting during pregnancy exist, including weight loss and metabolic control.

Consequently, the public health relevance of the research on Ramadan during pregnancy transcends the context of Ramadan.

Prenatal shocks are fleeting, but effects on health outcomes persists. In utero, babies learn about and adapt to the world before they enter it, potentially leading to adverse health and human capital outcomes. Policies aiming at favorable prenatal and postnatal conditions should be regarded as a tool to foster equality of opportunity among all children. Actions undertaken in this prevention spirit likely pay off at later ages, when fetal health capital is transformed into benefits to society.

Chapter 7
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Chapter 8
Curriculum Vitae

EDUCATION

since 06/2015 Parental leaves: 03/2016 – 10/2016 (part time until 05/2017) 07/2018 -05/2019	**Ph.D. Candidate in Economics** Supervisor: Prof. Dr. Reyn van Ewijk Research Topic: Interdisciplinary Research on the Developmental Origins of Health and Disease, in particular health and human capital effects of Ramadan during pregnancy DFG Project: "Ramadan during pregnancy and its effects on the health of the child throughout its life course" Johannes Gutenberg-University Mainz, Chair of Statistics and Econometrics, Mainz (Germany)
10/2013 – 09/2015	Selection of courses from **Master of Arts: Governance** Foci: Multi-Level Governance, Governance of Climate Change FernUniversität Hagen, Hagen (Germany)
10/2010 – 11/2013	**Master of Science: Food and Resource Economics** Graduation with Distinction (GPA: 1.1) Foci: European Agricultural Policies, Environmental Economics, International Cooperation in Environmental Protection Master Thesis: "Social Capital Formation in the Relationship between Local Actors and Global Donors in Forest Protection. An Optimal Control Approach" (Grade: 1.0; supervisor: Prof. Dr. Karin Holm-Müller) Rheinische-Friedrich-Wilhelms University Bonn, Bonn (Germany)
09/2007 - 09/2010	**Bachelor of Arts: European Studies** Graduation with Distinction (GPA: 1.3) Foci: EU Common Agricultural Policy, Regional Policies Participation in the honors program Maastricht University, Maastricht (The Netherlands)

WORK EXPERIENCE

06/2015 – present	**Research and Teaching Assistant** Chair of Statistics & Econometrics (Prof. Dr. Reyn van Ewijk) Johannes Gutenberg University Mainz, Mainz (Germany)
05/2015 – 05/2016	**Secretary General** and support to the honorary board Ecological Transport Club (VCD) Rhineland-Palatinate Koblenz (Germany)
04/2006 – 08/2015	**Project Assistant** for organization at large-scale events I-Motion GmbH, Mülheim-Kärlich (Germany)
01/2011 – 06/2013	**Press and Public Relations Student Assistant** JUGEND für Europa, German National Agency for the EU's Erasmus+ YOUTH IN ACTION program, Bonn (Germany)
08/2010 – 09/2010	**Intern** German Embassy Athens Athens (Greece)
10/2009 – 12/2009	**Intern** Friedrich-Ebert Foundation Office Ukraine & Belarus, Kyiv (Ukraine)

RESEARCH GRANTS

2021	German Science Foundation (DFG) (grant number 455841434), “How do prenatal and postnatal circumstances interact in shaping health? An interdisciplinary approach using quasi-experiments”, with Prof. Dr. Reyn van Ewijk and Prof. Dr. Dr. med. Sabine Gabrysch as principal investigators
2021	German Science Foundation (DFG) (grant number 260639091), “Ramadan during pregnancy: effects on health and fertility across the generations”, with Prof. Dr. Reyn van Ewijk as principal investigator (renewal proposal to the project “Ramadan during pregnancy and its effects on the health of the child throughout its life course”)

PUBLICATIONS

Pradella, F. & van Ewijk, R. (2018). As long as the breath lasts: In utero exposure to Ramadan and the occurrence of wheezing in adulthood. *American Journal of Epidemiology, 187(10),* 2100-2108.

Leimer, B*., Pradella, F.*, Fruth, A., Queißer, A. and R. van Ewijk (2018). Ramadan Observance during Pregnancy in Germany: a Challenge for Prenatal Care. *Geburtshilfe und Frauenheilkunde, 78(7),* 684-689. (* shared first-authorship)

AWARDS

since 04/2020	Junior Member of the **Gutenberg Academy**, forum for interdisciplinary exchange & mentoring for the University's top doctoral students Johannes Gutenberg-University Mainz
09/2018	**Best Poster Award** for *"Prenatal exposure to Ramadan and birth outcomes: results of the Mainz survey on Ramadan during pregnancy"* Annual Meeting of the German Society for Epidemiology (DGEpi)
09/2017	Epidemiology **Best Poster Award** for *"Effects of in-utero exposure to Ramadan in Germany: A survey study among pregnant Muslim women"* Annual Meeting of the German Association for Medical Informatics, Biometry and Epidemiology (GMDS)

REFEREEING

2021	Reviewer for the American Journal of Epidemiology

TEACHING & ADVISING

Summer semester 2021	Seminar in Statistics and Econometrics: Climate Change, Pollution and Human Health, Master
Fall semester 2020/21	Seminar in Statistics and Econometrics: A Life Course Perspective on Health, Master
Since 2018	Research and Writing, Bachelor
Since 2017	Supervision of Master Theses
	Supervision of Bachelor Theses
Fall semester 2015/16	Tutor Statistics II, Bachelor

CONFERENCES AND WORKSHOPS ATTENDED

08/2021	Summer School "The Development of Cognitive and Non-Cognitive Skills in Childhood and Adolescence", Johannes Gutenberg-University Mainz & EPoS, virtual summer school
06/2021	33nd Residential Summer Course of the European Educational Programme in Epidemiology, virtual summer school Courses: Applied epidemiology: Environmental epidemiology Advanced topics: Methods to deal with unobserved information in observational studies
02/2021	58. Scientific Congress of the German Society of Nutrition, virtual event
12/2020	inVIVO Planetary Health 2020, virtual event
11/2019	Invited Presentation at the Autumn Meeting of the German Diabetes Federation (DDG), Leipzig (Germany)
09/2019	14th Annual Meeting German Society for Epidemiology (DGEpi), Ulm (Germany) Organization of the workshop „Sustainable Development Goals – Implementation in Ulm and Baden-Württemberg“
09/2019	International Health Economics Workshop, Mainz (Germany)
12/2018	11th European Public Health Conference, Ljubljana (Slovenia)
09/2018	13th Annual Meeting German Society for Epidemiology (DGEpi), Bremen (Germany)
02/2018	4th International Conference German Society of Midwifery Science, Mainz (Germany)
01/2018	Invited Presentation at Heidelberg Epidemiology Seminar Series, Heidelberg Institute for Global Health, Heidelberg (Germany)
09/2017	62th Annual Meeting German Association for Medical Informatics, Biometry and Epidemiology (GMDS), Oldenburg (Germany)
09/2017	Joint Annual Meeting of German Society for Epidemiology (DGEpi), German Society of Social

	Medicine and Prevention (DGSMP) and German Association for Medical Informatics, Biometry and Epidemiology (GMDS), Lübeck (Germany)
04/2017	“Workshop on Health Economics”, Heidelberg (Germany)
10/2016	“The Power of Programming”, Munich (Germany)
11/2015	German Society for Epidemiology autumn workshop “Statistical Analysis of Event and Longitudinal Data", Mainz (Germany)

SCIENTIFIC SOCIETIES

German Association of Epidemiology (DGEpi)

In VIVO Planetary Health

German Alliance for Climate Change and Health (KLUG)

Global Health Hub Germany

EXTRACULLICULAR ACTIVITIES

since 03/2021	Expert, project on the promotion of infant nutritional health, German Federal Agency for Agriculture and Food, Bonn (Germany)
02/2013 – 05/2013	Participant in the Scenario Project “Germany and Russia 2030“, Friedrich-Ebert Foundation, Berlin (Germany) / Moscow (Russia)
08/2012 – 11/2012	Project on Tropical Forest Conservation in the framework of the ASA-Program (Engagement Global gGmbH) NGO GRAPHE, Guebakui (Togo)
11/2003 - 05/2010	Board and press work on regional, federal and European levels, Federation of Young European Greens, Brussels (Belgium)
09/2008 – 03/2009	Vice President of the Organizational Committee of Student Forum Maastricht 2009, Maastricht (The Netherlands)
09/2006 - 08/2007	European Voluntary Service at KAAP Voulas, center for children and youth with disabilities in Athens (Greece)

LANGUAGES

German	Native speaker
English, French	Very good
Modern Greek	Good
Dutch, Russian, Ewé	Basic knowledge