Economics and Human Biology 33 (2019) 29–39

Contents lists available at ScienceDirect

Economics and Human Biology

journal homepage: www.elsevier.com/locate/ehb

The effects of prenatal exposure to Ramadan on stature during childhood and adolescence: Evidence from the Indonesian Family Life Survey

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ARTICLE INFO

Article history:
Received 23 April 2018
Received in revised form 22 November 2018
Accepted 6 December 2018
Available online 19 December 2018

JEL classification:
JEL I12
JEL Z12

Keywords:
Prenatal exposure
Ramadan
Fasting
Malnutrition
Stature
Childhood
Adolescence

ABSTRACT

Many pregnant Muslim women fast during the Muslim holy month of Ramadan. A number of studies have reported negative life outcomes in adulthood for children who were prenatally exposed to Ramadan. However, other studies document minimal to no impact on neonatal indicators. Using data from the Indonesian Family Life Survey consisting of 45,246 observations of 21,723 children born to 9771 mothers, we contribute to the current discussion on prenatal exposure to Ramadan by examining the effects on stature (height-for-age Z-scores, weight-for-age Z-scores, and body-mass-index-for-age Z-scores: HAZ, WAZ, and BAZ, respectively) from early childhood to late adolescence (0–19 years of age). We introduce an objective mother's religiosity indicator to improve the intention-to-treat estimations. Children were classified into three groups based on their mother's religion-religiosity: religious Muslims, less-religious Muslims, and non-Muslims. Using cluster-robust mother fixed-effects, we found negative effects on stature for children born to religious Muslim mothers. The effects were age-dependent and timing-sensitive. For example, children born to religious Muslim mothers were shorter in late adolescence (15–19 years of age) compared to their unexposed siblings if they were prenatally exposed in the first trimester of pregnancy (HAZ difference = −0.105 SD; p-val. <0.05). Interestingly, we found positive effects on stature for exposed less-religious Muslim children that peak in early adolescence (10–14 years of age) and negative effects on stature for exposed non-Muslim children that occur only in early childhood (0–4 years of age). We nuance our discussion of health and socioeconomic factors to explain these surprising results.

1. Introduction

Research on the effects of prenatal exposure to Ramadan is as yet inconclusive. Several studies have reported that children who are prenatally exposed to Ramadan are lighter at birth, but most evidence is limited to small differences (Almond and Mazumder, 2011; Savitri et al., 2014). Other studies have even reported the contrary, showing a higher birth weight for children whose mother fasted during Ramadan (Alwasel et al., 2011; Savitri et al., 2018). The debate continues because weak to no evidence has emerged of negative effects of prenatal exposure to Ramadan on neonatal indicators (Makvandi et al., 2013; Seckin et al., 2014). Interestingly, many large sample studies analysing adult life outcomes corroborate one another's findings. These large sample studies document not only ill-health in adulthood (van Ewijk, 2011; van Ewijk et al., 2013; Almond et al., 2014) but also negative effects on labour outcomes (Majid, 2015; Schultz-Nielsen et al., 2016). The evidence regarding negative life outcomes at birth is weak, but the clear evidence of negative effects in adulthood raises questions on whether prenatal exposure to Ramadan does have effects and whether the effects are age-dependent.

Despite their potential to settle the conflicting evidence at birth versus in adulthood, studies on the effects of prenatal exposure to Ramadan on life outcomes in childhood and adolescence are scarce. Previous large sample studies used intention-to-treat estimations, using prenatal exposure to Ramadan as the proxy for maternal fasting during Ramadan. As most interpretations of Islam exempt pregnant Muslim women from fasting for health reasons, not all pregnant Muslim women fast during Ramadan (Joosoph et al., 2004; Mubeen et al., 2012; van Bilsen et al., 2016). Therefore, intention-to-treat estimations underestimate the real effects of maternal fasting during Ramadan. Previous studies are

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https://doi.org/10.1016/j.ehb.2018.12.001
1570-677X/

also uncertain regarding whether maternal fasting during Ramadan is the main cause of negative effects of prenatal exposure to Ramadan, because other factors such as alternating diet and sleep disturbance might also be influential.

We contribute to the current discussion on the effects of prenatal exposure to Ramadan in three ways. First, instead of using the life-cycle approach whereby different life outcomes at different life stages are analysed, we adopt a life-course perspective, analysing stature from early childhood to late adolescence (0–19 years of age). This approach allows us not only to examine whether prenatal exposure to Ramadan affects stature, but also to offer evidence on whether the effects are age-dependent. Second, we improve the intention-to-treat estimations by utilising the mother's religiosity, similar to Majid (2015). However, instead of inferring the mother's religiosity from her adult child's self-reported perceived religiosity as Majid (2015) did, we introduce an objective indicator that directly measures the mother's religious practice. Along with the Ramadan fasting, another one of the five pillars of Islam is the Islamic five daily prayers. We categorise the mother as religious if she is committed to the Islamic five daily prayers. Our rough estimations indicate that the maternal fasting rate during Ramadan for religious pregnant Muslim women is notably higher than that for the less-religious (Tables A1–3). We use this association to improve our estimations by differentiating Muslim children based on their mother's religiosity. Third, we tabulate health and socioeconomic factors that may produce different experiences of prenatal exposure to Ramadan for different religion-religiosity groups in Indonesia. The table enables us to be more certain of the probable cause(s) of the effects on stature for different religion-religiosity groups.

We use data from the Indonesian Family Life Survey (IFLS) over the period 1993–2015. The survey consists of 45,246 observations of 21,723 children born to 9771 mothers. Analysing IFLS data has a significant societal relevance because Indonesia is the country with the largest Muslim majority. Furthermore, Ramadan follows the lunar calendar, which shifts about 11 days each year ahead of the Gregorian calendar. As Ramadan fasting is governed by daylight, people who live in the far southern and northern hemispheres experience varying daylight depending on the month in which Ramadan falls in relation to the Gregorian calendar. Any statistical estimation of the effects of prenatal exposure to Ramadan becomes complicated because each birth cohort experiences a different duration of Ramadan fasting. Indonesia is an appropriate study site for the topic because of its location near the equator, and thus the Ramadan fasting always lasts for about 13 h a day.

We analyse three standardised measures of stature: height-for-age Z-scores (HAZ), weight-for-age Z-scores (WAZ), and body-mass-index-for-age Z-scores (BAZ). These measurements are based on the World Health Organization's (WHO) growth standard portraying long-term (HAZ) and short-term nutritional status (WAZ, BAZ) in childhood and adolescence (WHO, 2006; de Onis et al., 2007). We used the overlap between Ramadan and pregnancy as the proxy for prenatal exposure to Ramadan. We categorised children in our sample in three religion-religiosity groups in accordance to their mother's religiosity and religion: religious Muslims, less-religious Muslims, and non-Muslims. We expect to find the highest negative effects on stature in the religious Muslims group; the other two groups are used for falsification purposes to identify the probable cause(s) of the exposure effects on stature.

We structure the rest of the article as follows. In Section 2, we contextualise Ramadan, particularly in Indonesia. In Section 3, we review previous studies on prenatal exposure to Ramadan. We start with a general literature review on prenatal exposure to malnutrition and continue with findings from previous studies on the effects of prenatal exposure to Ramadan on various life outcomes from birth to adulthood. In Section 4, we describe the data and methods used, before concluding with results in Section 5 and a discussion in Section 6.

2. Ramadan and the Indonesian context

Ramadan is the ninth month of the Islamic Hijri lunar calendar. During Ramadan, every healthy adult Muslim should fast from dawn to dusk. It is not only food and drink consumption that is forbidden; certain activities including smoking are also banned during daylight hours. After sunset, adult Muslims may break their fast, traditionally with sweet drinks and snacks before dinner. As one of the five pillars of Islam, Ramadan fasting is mandatory (Trepanowski and Bloomer, 2010). Some adult Muslims are exempt from it: people who are travelling, those who are too old or sick, and women in their monthly cycle or postnatal period. Pregnant and breastfeeding women are also allowed not to fast if they are concerned about their health or the health of their offspring. However, some interpretations of Islam suggest that these women should fast as soon as their health permits. As fasting alone after Ramadan is not easy, many pregnant Muslim women continue to fast during Ramadan (Mirghani et al., 2003; Robinson and Raisler, 2005).

Located in Southeast Asia, Indonesia is home to more than 250 million inhabitants. Nearly 87% of Indonesians are Muslims (Statistics Indonesia, 2011). Sleeping patterns are disturbed during Ramadan because most mosques have a morning call to awaken people for prayer and to take breakfast before dawn, locally called *sahur*. Some people go around voluntarily, helping people to awaken so that they will not miss *sahur*. Office hours change to early morning and end a few hours before sunset to allow Muslims to prepare the evening breaking of the fast (Abe, 2010). The law mandates employers to give an annual bonus known as *Tunjangan Hari Raya* (THR) before their employees' most important religious day (MoL, 1994). Muslims receive this annual bonus at Ramadan. Giving money to family members, donating to the poor – known as *zakat* –, and food price hikes due to high demand for animal-source foods and spices are common during Ramadan. The two-week national sugar fest holiday, or *Eid Mubarak*, signals the end of Ramadan.

Information on the Ramadan fasting behaviour of Indonesian pregnant Muslim women is limited. One study showed that 80% of pregnant Muslim women fasted at least one day during Ramadan (van Bilsen et al., 2016). The percentage is lower than 87% in Singapore (Joosoph et al., 2004) and 88% in Pakistan (Mubeen et al., 2012). Regarding pregnant Muslim women who fast for a full month, whereas the percentage is as high as 33% in Singapore and 42.5% in Pakistan, only 14% of Indonesian pregnant Muslim women in Bilsen et al.'s (2016) study fasted for a full month. However, it should be noted that Bilsen et al.'s (2016) sample might not reflect the actual maternal fasting rate of the Indonesian population, as the study was based on samples from one private hospital in Jakarta, Indonesia's capital city. Moreover, the sample disproportionally consists of more highly educated pregnant women who can be assumed to be more health conscious and therefore probably might not adhere to Ramadan fasting for health reasons. Another study in the same hospital showed maternal food consumption was lower during Ramadan (Savitri et al., 2018). However, similar to Kiziltan et al.'s (2005) findings on the dietary intake of Turkish pregnant Muslim women during Ramadan, remedial action to compensate for the low nutrition intake was evident a month after Ramadan. This might allow pregnant Muslim women who fasted during Ramadan to maintain maternal weight gain and thus sustain a healthy pregnancy.

3. Effects of prenatal exposure to Ramadan on life outcomes at different life stages

The Foetal Origin Hypothesis (FOH) documents a number of evidence linking maternal nutrition and foetal development (Harding, 2001; Langley-Evans, 2015). FOH underlines the importance of maternal blood glucose level. Abstinence from consuming food and drink during the night may cause a 10% fall in a mother's blood glucose level (Saleh et al., 1989; Casele et al., 1996). Although less severe than the effects of complete starvation such in the Dutch Famine studies (Susser and Stein, 1994; Roseboom et al., 2006, 2011), low blood glucose may still induce metabolic abnormality, so-called accelerated-starvation. Accelerated-starvation makes the mother's body burn fats to produce energy instead of processing food and drink (Metzger et al., 1982; Malhotra et al., 1989). A side effect is an increase in ketone concentration, which causes the blood to become toxic (Herrmann et al., 2001). As the unborn shares its mother's blood circulation, the development of specific foetal tissues might be impaired depending on the timing of the exposure to the low maternal blood glucose level (Paterson et al., 1967; Saleh et al., 1989; James, 1997). Pregnant Muslim women who fast during Ramadan also experience accelerated-starvation (Prentice et al., 1983; Arab, 2004). Their accelerated-starvation might be even worse because they fast during the day when physical activities peak and cannot be simply avoided. Dehydration due to hot temperatures during the day also reduces a mother's blood volume (Bayoglu Tekin et al., 2016) and lowers the amniotic fluid index (Sakar et al., 2015). Both circumstances may create a hostile environment for the unborn to grow healthily.

Epidemiological studies often use birth weight as an early marker of how well the baby is growing during pregnancy (Kelly et al., 2009; Habibov and Fan, 2011). Hypothetically, prenatal exposure to undernutrition stunts foetal organ development. Thus, the exposed baby is expected to have a low birth weight and relatively poorer life outcomes in later life stages. However, not all prenatal exposure to such malnutrition is followed by low birth weight. The Dutch Famine is one example (Susser and Stein, 1994; Roseboom et al., 2006, 2011). Although the famine in winter 1944–1945 meant that the Dutch, including pregnant women, could consume no more than 800 calories per person a day, birth weight and birth length of babies prenatally exposed in the first trimester of pregnancy were not affected (Roseboom et al., 2006, 2011). A prompt food supply recovery after the Dutch liberation from the German occupation was thought to improve maternal nutrition and buffer the immediate effects at birth (Roseboom et al., 2011). However, negative effects of the famine proved to be unavoidable in later life stages. Compared to their unexposed siblings, adults who were prenatally exposed to the Dutch Famine in the first trimester of pregnancy experienced more health problems than those who were exposed in later stages of pregnancy (Susser and Stein, 1994; Roseboom et al., 2006, 2011).

Similar to the findings in Dutch Famine studies, birth weight does not always clearly indicate a malnourished pregnancy due to maternal fasting during Ramadan. Almond and Mazumder (2011), who used data from Michigan, USA, and Savitri et al. (2014), who used data from Amsterdam and Zaanstad in the Netherlands, reported that children who were prenatally exposed to Ramadan in the first trimester of pregnancy were lighter at birth (Almond and Mazumder, 2011: 18 g; Savitri et al., 2014: 272 g). However, other studies from Birmingham, UK (Cross et al., 1990), Kashan, Iran (Sarafraz et al., 2014), and Germany (Jürges, 2015) showed no effect on birth weight. Several studies even found that children who were prenatally exposed to Ramadan in the third trimester of pregnancy were heavier at birth (Alwasel et al., 2011; Savitri et al., 2018). The inconsistent evidence on birth weight is followed by weak to no evidence on other neonatal indicators, including non-significant differences between exposed and unexposed babies regarding Apgar score (Malhotra et al., 1989) and gestational duration (Hizli et al., 2012).

Although studies on prenatal Ramadan exposure effects in childhood and adolescence are scarce, some evidence has started to emerge. Analysing height, an unpublished manuscript examining Demographic Health Survey of 37 low- and lower-middle income countries indicated that prenatal exposure to Ramadan reduced Muslim male children's height by as much as 1.2 cm at age 4 years if they were exposed four months before birth (Karimi, 2016). Schoeps et al. (2018) found that being prenatally exposed to Ramadan before the third trimester of pregnancy was associated with a higher under-5 mortality rate in Burkina Faso. Another study in the UK found that 7-year-old school-aged Muslim children who were prenatally exposed to Ramadan in early pregnancy had an average cognitive test score 0.05–0.08 SD (standard deviation) lower than unexposed Muslim children (Almond et al., 2014). No study specifically examines the effects of prenatal exposure to Ramadan in adolescence.

Most evidence on the effects of prenatal exposure to Ramadan relates to adulthood. A number of studies have reported ill-health among exposed Muslims. Health problems include shorter and thinner stature in Indonesia (van Ewijk et al., 2013), symptoms of coronary heart disease and type-2 diabetes in Indonesia (van Ewijk, 2011), higher risk of sight and hearing problems in Uganda (Almond and Currie, 2011), and psychological disorders in Iraq (Almond and Mazumder, 2011). Recent studies in economics have gone further by examining the effects of prenatal exposure to Ramadan on labour outcomes (Majid, 2015; Schultz-Nielsen et al., 2016). Majid (2015) found that exposed Indonesian Muslim adults worked fewer hours and were more likely to be self-employed. Majid (2015) applied the life-cycle approach, assessing lack in cognitive ability at age 7 to age 14 as the possible channel through which the exposure reduces labour outcomes. Similarly, Schultz-Nielsen et al. (2016) found that exposed Muslim males in Denmark had 2.6% less chance of being employed and also received a lower salary than unexposed Muslim males, on the basis of exposure in the seventh month of pregnancy.

4. Data and method

We pool five waves of the IFLS: the largest household panel survey in Indonesia. IFLS collects a wide array of information on economic, health, and social conditions (Strauss et al., 2016). The first IFLS was conducted in 1993/1994 and the following surveys 2, 3, 4, and 5 were conducted in 1997/1998, 2000, 2007/2008, and 2014/2015. The IFLS sampling scheme covers the 13 most populated provinces in Indonesia, representing 83% of the 1993 Indonesian population. The original IFLS-1 (1993/1994) collected data on 7224 households. The follow-up surveys also collected data on new-borns and split-off households. IFLS has high follow-up rates, thus reducing possible bias due to sample attrition; 92% of IFLS-1 (1993/1994) households participated in IFLS-5 (2014/2015).

There are 83,770 participants interviewed in at least one of the IFLS waves. The IFLS dataset enabled us to trace the biological mother of 40,758 children. We excluded a number of children from this initial sample for several reasons. First, as classifying whether someone was prenatally exposed to Ramadan is sensitive to the exact date of birth, we excluded 3622 children whose birth date was unknown or inconsistently reported in different IFLS waves. Second, we excluded 7924 children for whom the height and weight were never measured between the ages of 0 and 19 years. Third, we excluded 349 children whose HAZ, WAZ, or BAZ are biologically impossible based on the World Health Organization (WHO) growth standards (WHO, 2006; de Onis et al., 2007): ±6 SD from the median for HAZ and WAZ; ±5 SD from the median for

BAZ. Fourth, 1371 children born in Bali were excluded. Aside from Bali which is predominantly Hindu, the other IFLS provinces are mainly Muslim. Therefore, children born in Bali might experience prenatal exposure to Ramadan differently than children born in the other IFLS provinces. Fifth, 1646 children were excluded because they could be misclassified as prenatally exposed to Ramadan (see Sub-section 4.2 for details). Finally, we excluded 4123 Muslim children because data on the religiosity of their mother were not available. The final sample consists of 45,246 observations of 21,723 children born to 9771 mothers.

4.1. Outcome variables

In each IFLS wave, trained nurses collected height (cm) and weight (kg) up to a single digit decimal of all household members who were present during the interview. As children have not yet attained their final stature, we standardised their stature by sex and age by using the WHO growth standards (WHO, 2006; de Onis et al., 2007). Three standardised stature measurements were produced: HAZ as the indicator for height, WAZ as the indicator for weight, and BAZ as the indicator for body mass. These standardised measurements cover childhood and adolescence life stages (0–19 years of age) except for WAZ, for which the WHO provides standardised measurement only during childhood (0–9 years of age) (de Onis et al., 2007).

4.2. Explanatory variables

We use three explanatory variables in our analyses: prenatal exposure to Ramadan dummy/dummies), mother's religion-religiosity dummies, and age group dummies. To identify children who were prenatally exposed to Ramadan, a similar approach to that of others in the literature was used (see van Ewijk, 2011; Majid, 2015). On average, a full-term pregnancy lasts for 266 days after conception. An individual is considered prenatally exposed to Ramadan if Ramadan overlaps with a full-term pregnancy period. As we categorise children in three religion-religiosity groups, our measure of prenatal exposure to Ramadan is no longer a simple proxy of maternal fasting during Ramadan. Therefore, based on the Indonesian context, we developed Table 1 to summarise health and socioeconomic factors that may affect the experiences of prenatal exposure to Ramadan by religion-religiosity groups.

We code prenatal Ramadan exposure with a single dummy differentiating the unexposed and the exposed children. Another set of dummies is created to analyse the timing-effects of prenatal Ramadan exposure. These dummies categorise the exposed children into three groups: a) exposed in the first trimester (Ramadan starts 0–89 days after conception), b) exposed in the second trimester (Ramadan starts 90–178 days after conception), and c) exposed in the third trimester (Ramadan starts 179–266 days after conception). Unexposed children are the reference group. Some exposed children might be born after their due date and consequently be misclassified as unexposed. These misclassified children could confound the estimations. Therefore, children who were conceived less than 21 days following the end of Ramadan were excluded.

We use mother's religion-religiosity dummies to classify children into three groups: religious Muslims, less-religious Muslims, and non-Muslims. We start the process by differentiating children by their mother's religion: Muslim and non-Muslim. Muslim children are further classified into religious Muslims and less-religious Muslims based on their mother's commitment to the Islamic five daily prayers. In IFLS-4 (2007/2008) and IFLS-5 (2014/2015), adult Muslim participants were asked to indicate how many times a day they prayed. We used this information to develop an innovative measure of mother's religiosity. We classified Muslim children whose mother prayed at least five times a day as religious Muslims. If their mother did not practice the Islamic five daily prayers in either IFLS-4 (2007/2008) or IFLS-5 (2014/2015), we classified them as less-religious Muslims.

We estimated maternal fasting rate for religious Muslims and less-religious Muslims by using logit regression (see Tables A1–3 for details). The estimations were based on small sample observations of Muslim adults who were interviewed during Ramadan in IFLS2 (1997/1998) and IFLS3 (2000). The analysis shows that maternal fasting rate during Ramadan differs by mother's religiosity: religious Muslim pregnant women (66%; CI 90%: [48%, 84%]), less-religious Muslim pregnant women (18%; CI 90%: [4%, 32%]). These confidence intervals should be interpreted with cautions because these were based on a low number of

Table 1
Different experiences of prenatal exposure to Ramadan by religion-religiosity groups.

	religious Muslims	less-religious Muslims	non-Muslims
health related factors:			
maternal fasting[a]	yes, estimated maternal fasting rate CI 90%: [48%, 84%]	yes, estimated maternal fasting rate CI 90%: [4%, 32%]	no
the mother experienced sleep disturbance[b]	yes	yes	yes
the mother has better diet quality compared to other months[c]	yes	yes	no, compared to time during the non-Muslims' religious days
better in-home air quality[d]	yes	yes	no
socioeconomic context:			
food price hike	yes	yes	yes
received THR in Ramadan	yes	yes	no
received zakat	yes, if they were poor	yes, if they were poor	no

THR or *Tunjangan Hari Raya* is an annual bonus that by law in Indonesia should be given by employers to employees at least two weeks before the employees' main religious day. CI 90% is 90% confidence interval.

[a] These are rough estimations due to low N = 949 observations and very low N = 29 pregnancies (see Tables A1-A3 for details). Non-Muslims are obviously unexposed to maternal fasting during Ramadan.

[b] The morning call, *sahur*, and the volunteers who go around helping people to awaken before dawn will of course awaken either Muslims or non-Muslims; either fasting or not.

[c] Despite the fasting, we argue that Muslims' diet quality is probably better during Ramadan relative to other months because, despite food price hikes, they have more money to spend on quality food due to THR and *zakat*. The opposite might apply to non-Muslims, as they most likely do not receive THR or *zakat* at Ramadan but still experience food price hikes.

[d] Kim et al. (2016) showed that in-home air pollution negatively affects children's stature in Indonesia. As smoking is forbidden during daylight hours, Muslims probably benefit from better in-home air quality during Ramadan.

observations (N = 949) and a very low number of pregnancies (N = 29). Non-Muslim mothers definitely did not fast during Ramadan. Concern has been expressed that mother's religiosity may vary in time and that this, therefore, may bias the analyses. We show in Table A4 that mother's religiosity in IFLS-4 (2007/2008) is highly correlated with mother's religiosity in IFLS-5 (2014/2015) (Pearson $\chi^2(1) = 1.3e+03$, p-val. < 0.01), and the immobility index shows that 85.6% of the mothers remain in the same religiosity category in IFLS-4 (2007/2008) and IFLS-5 (2014/2015), thus indicating that mother's religiosity is relatively constant over time.

For age group dummies, we categorised the observations into four groups with 5-year intervals depending on the age at which the measures of stature were collected. The four groups are: a) early childhood (0–4 years of age), b) late childhood (5–9 years of age), c) early adolescence (10–14 years of age), and d) late adolescence (15–19 years of age). These age groups were used to analyse the age-dependency (age-effects) of prenatal exposure to Ramadan.

4.3. Control variables

We used a number of control variables to rule out within-sibling confounders. First, we controlled for the child's sex, because previous studies suggested that the proportion of males born to undernourished mothers was lower, indicating the male foetus's inability to adapt to a hostile environment (Almond and Mazumder, 2011; van Ewijk, 2011). Second, the intra-household allocation of family resources might be different by birth order (Black et al., 2015). Mothers might also vary their Ramadan fasting behaviour from one pregnancy to the next. We used birth order fixed-effects to control for these confounding factors. Third, spatial factors including birthplace and current living place might influence within-sibling health. We controlled for effects of birthplace and current living place by using dummies, differentiating born in and living in: urban vs rural, Java vs other islands. Fourth, as Ramadan shifts about 11 days ahead per year, controlling for month of birth is critical to separate the effects of prenatal exposure to Ramadan from possible seasonal effects. Month of birth fixed-effects were included to control for seasonal effects. Fifth, birth year as a continuous variable was included to account for changes in the overall environment.

4.4. Analysis

We used cluster-robust mother fixed-effects regressions to estimate our model specifications. The use of mother fixed-effects regressions restricts any statistical estimation to within-sibling comparison only and therefore cancels out any systematic differences between families, including differences in nutritional intake and genetic variability that may bias the results. Table 1 shows that each religion-religiosity group may experience prenatal exposure to Ramadan differently. Therefore, we start the analyses with Model 1, which includes the interaction effects between prenatal Ramadan exposure and religion-religiosity groups as follow:

$$Y_{ijm} = \beta_1 exp_{jm} + \beta_2 rel_m + \beta_3 age_{ijm} + \beta_4 (exp_{jm} \times rel_m) + \beta_5 X_{jm} + \varepsilon_{ijm} \quad (1)$$

Y_{ijm} is the outcome variables (HAZ, WAZ, and BAZ) for observation in IFLS-i (i = 1, 2, ..., 5) of individual j born to mother m, exp_{jm} is prenatal Ramadan exposure dummy (unexposed vs exposed), rel_m is mother's religion-religiosity dummies, age_{ijm} is a vector for age group dummies, X_{jm} is a vector for control variables, and residual ε_{ijm}. rel_m is constant within-sibling and thus omitted in mother fixed-effects estimations. However, we preserve the notation in Model 1 for demonstrative purpose. Model 1 tests the main-effects of prenatal exposure to Ramadan differentiated by religion-religiosity groups. We expect to find higher negative effects of prenatal exposure to Ramadan on stature for children born to religious Muslim mothers. The effects are expected to occur more on HAZ, as HAZ reflects a long-term nutritional status.

We then estimate Model 2, which involves three-way interactions of prenatal exposure to Ramadan, mother's religion-religiosity, and age groups. Model 2 allows us to examine age-effects of prenatal exposure to Ramadan on stature, answering the question of whether the effects of prenatal Ramadan exposure develop with age (age-effects).

$$Y_{ijm} = \beta_1 exp_{jm} + \beta_2 rel_m + \beta_3 age_{ijm} + \beta_4 (exp_{jm} \times rel_m) + \beta_5 (exp_{jm} \times age_{ijm}) + \beta_6 (exp_{jm} \times rel_m \times age_{ijm}) + \beta_7 X_{jm} + \varepsilon_{ijm} \quad (2)$$

The final model is Model 3, whereby we examine whether the age-effects of prenatal exposure to Ramadan on stature are different depending on the timing of the exposure relative to the pregnancy stage (timing-age-effects). Model 3 is based on Model 2, with exp_{jm} being substituted by exp^*_{jm}. The exp^*_{jm} consists of expanded prenatal exposure to Ramadan dummies: unexposed vs. exposed in the first trimester, exposed in the second trimester, and exposed in the third trimester.

$$Y_{ijm} = \beta_1 exp^*_{jm} + \beta_2 rel_m + \beta_3 age_{ijm} + \beta_4 (exp^*_{jm} \times rel_m) + \beta_5 (exp^*_{jm} \times age_{ijm}) + \beta_6 (exp^*_{jm} \times rel_m \times age_{ijm}) + \beta_7 X_{jm} + \varepsilon_{ijm} \quad (3)$$

We used cluster-robust standard errors at the mother level because the sample consists of multiple observations of children born to the same mother (Cameron and Miller, 2015). As our models involve up to three-way interaction effects, a presentation of the estimation results using a standard regression table would be difficult to interpret. Therefore, we use predictive marginal contrasts to present all the models. These predictive marginal contrasts are analogous to linear combinations of the regression coefficients (Mitchell, 2012). The predictive marginal contrasts compare children who were prenatally exposed to Ramadan with their unexposed siblings. A predictive margin of less than zero indicates negative effects on stature due to prenatal exposure to Ramadan, and vice versa. We developed a figure for each religion-religiosity group to present the main-effects (Model 1), the age-effects (Model 2), and the timing-age-effects (Model 3) of prenatal Ramadan exposure on stature. The standard regression tables of Models 1–3 are in the supplementary materials (Tables A5–A7).

5. Results

Table 2 shows the sample descriptive statistics by religion-religiosity groups. The mean HAZ, WAZ, and BAZ are below zero, indicating that the sample is from an undernourished population. The non-Muslims are, overall, better on stature as they were taller, heavier, and thicker than both religious Muslims and less-religious Muslims. We show additional information on socioeconomic status (SES) using nominal Personal Consumption Expenditure (PCE) as the indicator. High SES has been associated with better health (Braveman et al., 2005; Shavers, 2007; Blumenshine et al., 2010). The majority of non-Muslims lived in high SES households (54.65%). This might explain the non-Muslims' better stature. As we used mother fixed-effects, the analyses controlled for all observed and unobserved family differences. Therefore, the SES differences do not affect the results. The less-religious Muslims are, on average, a year younger than the other religion-religiosity groups. There are differences in current living place at the time of interview. In contrast to the other religion-religiosity groups, most of religious Muslims lived in an urban area (50.44%) and in Java (62.05%). The majority of less-religious Muslims lived in a rural area (52.62%) and nearly three-quarters of non-Muslims lived on other islands outside Java (74.18%).

Table 2
Sample characteristics.

	religious Muslims		less-religious Muslims		non-Muslims		
	Mean	SD	Mean	SD	Mean	SD	p-val.
time-varying characteristics[a]:							
HAZ	−1.55	(1.25)	−1.56	(1.27)	−1.48	(1.36)	<0.01
WAZ	−1.25	(1.27)	−1.23	(1.25)	−1.01	(1.31)	<0.01
BAZ	−0.57	(1.28)	−0.51	(1.28)	−0.29	(1.27)	<0.01
age (in years)	9.24	(5.23)	8.28	(5.12)	9.24	(5.21)	<0.01
lived in urban area (%)	50.44		47.38		49.58		<0.01
lived in rural area (%)	49.56		52.62		50.42		
lived in Java (%)	62.05		40.95		25.83		<0.01
lived in other islands (%)	37.95		59.05		74.18		
low SES (%)	71.30		66.84		45.35		<0.01
high SES (%)	28.70		33.16		54.65		
time invariant characteristics[b]:							
unexposed to Ramadan (%)	10.98		10.48		12.30		0.18
exposed in 1 st trimester	34.34		34.27		34.77		
exposed in 2 st trimester	27.47		27.38		27.08		
exposed in 3rd trimester	27.21		27.87		25.86		
males (%)	50.88		52.81		51.97		0.08
females (%)	49.12		47.19		48.03		
1 st child (%)	37.39		40.41		33.60		<0.01
2nd child (%)	30.90		31.94		27.63		
3rd child or later (%)	31.72		27.65		38.77		
born in urban area (%)	51.17		48.42		47.27		<0.01
born in rural area (%)	48.83		51.58		52.73		
born in Java (%)	61.69		40.29		25.00		<0.01
born in other islands (%)	38.31		59.71		75.00		
born in January–June	50.89		51.98		52.63		0.20
born in July–December	49.11		48.02		47.37		
born in 1974–2000 (%)	59.52		41.27		59.92		<0.01
born in 2000–2015 (%)	40.48		58.73		40.08		
N of observations[a]	33,654		7925		3667		
N of individuals[b]	15,674		4073		1976		
N of mothers	7054		1884		833		

The p-values are from ANOVA tests for continuous variables and from χ^2-tests for categorical variables. High SES is assigned if children lived in a household with a nominal PCE above the sample mean in a specific IFLS wave. WAZ consisted only of observations of age less than 10 years (0–9 years of age). For WAZ (N of observations/children/mothers): religious Muslims (18,497/12,602/6273); less-religious Muslims (4956/3562/1769); non-Muslims (2003/1468/674).

The proportion of children in different categories of prenatal Ramadan exposure does not differ by religion-religiosity groups (p-val. = 0.18). There are indications of more males than females in all religion-religiosity groups (p-val. = 0.08). However, the proportion of males for religious Muslims is lower than that for other religion-religiosity groups (religious Muslims = 50.88%; less-religious Muslims = 52.81%; non-Muslims = 51.97%). This is probably an indication of sex-related child mortality due to prenatal exposure to Ramadan among children of religious Muslim mothers (see Schoeps et al., 2018). However, further studies are required before a firm conclusion could be made. The average family size in all religion-religiosity groups is small, as the percentage of children born as the third child or later was not higher than the total percentage of the first and the second born combined. Birth place differs by religion-religiosity groups (urban vs rural, p-val. < 0.01; Java vs other islands, p-val. < 0.01), similar to the pattern for living place. This may suggest that the sample had a low migration rate. There are no differences in birth months (p-val. = 0.20). More children were born to less-religious mothers (58.73%) after the millennium.

Fig. 1 summarises main-effects (Model 1), age-effects (Model 2), and timing-age-effects (Model 3) of prenatal exposure to Ramadan on stature for religious Muslims. The figure shows no main-effects of prenatal exposure to Ramadan on stature (Model 1). Only when age-dependency is considered (Model 2) do indications of the effects of prenatal exposure to Ramadan on HAZ emerge. Children who were prenatally exposed to Ramadan experienced a lag in height growth compared to their unexposed siblings. This lag in height growth starts in late childhood (5–9 years of age) and becomes significant in late adolescence, as the exposed children are -0.077 SD (p-val. < 0.10) shorter than their unexposed siblings. The effects become more evident once the timing-age-effects are considered (Model 3). Children who were prenatally exposed in the first trimester of pregnancy showed a strong pattern of lag in height growth, which led to -0.105 SD (p-val. < 0.05) shorter stature compared to their unexposed siblings in late adolescence (15–19 years of age). Although not significant, a similar pattern of lag in height growth also occurred for children who were exposed in the second trimester of pregnancy. There is an indication that children who were prenatally exposed to Ramadan in the third trimester of pregnancy had -0.094 SD (p-val. < 0.10) lower BMI than their unexposed siblings in early adolescence (10–14 years of age). This is probably related to a lower weight in early adolescence as well which, unfortunately, cannot be shown in our estimations because the WHO does not provide WAZ standards for adolescents.

We conducted additional analysis to test whether the timing-age-effects on stature differed by sex. For this purpose, we added interaction by sex to Model 3. Table A8 shows the predictive marginal contrasts for the timing-age-effects by sex on HAZ and BAZ for religious Muslims. The results indicate that the negative effects on stature are higher for boys than for girls (for HAZ exposed in 1st trimester vs unexposed at late adolescence: boys=-0.126 SD, p-val. < 0.05; girls=-0.004 SD; for BAZ exposed in 3rd trimester vs unexposed at early adolescence: boys=-0.145 SD, p-val. < 0.05; girls=-0.091 SD). These indicative findings support the hypothesis that male foetuses are less able than female foetuses to adapt to a hostile environment (see Almond and Mazumder, 2011; van Ewijk, 2011).

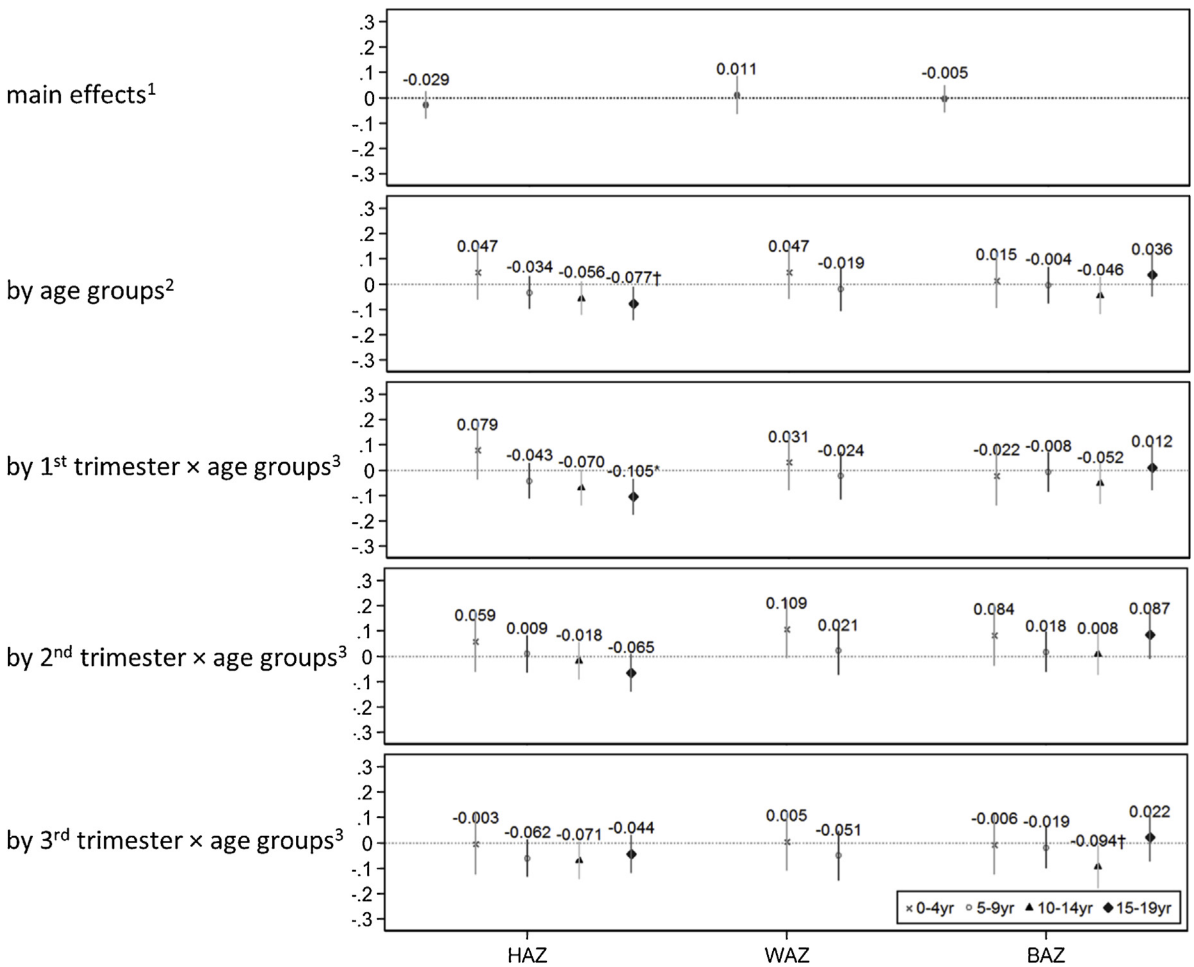

Fig. 1. Effects of prenatal Ramadan exposure on stature for religious Muslims.
† p < 0.10; * p < 0.05; ** p<0.01.
Model 1; ² Model 2; ³ Model 3.
Unexposed siblings (ref.). Cluster-robust standard errors at mother level. The complete regression tables are in the supplementary materials.

Fig. 2 visualises the main-effects, age-effects, and timing-age-effects of prenatal Ramadan exposure on stature for less-religious Muslims. The less-religious Muslims are an interesting religion-religiosity group because they experience exactly the same exposure to Ramadan as the religious Muslims, except for the lower estimated maternal fasting rate (see Table 1). Therefore, the less-religious Muslims group is a strong falsification sample to be certain whether the lag in height growth and the lower BMI shown in Fig. 1 are due to maternal fasting during Ramadan. Initially, we expected no effects of prenatal Ramadan exposure in Fig. 2, because approximately only 18% of less-religious pregnant Muslim women fasted during Ramadan (see Tables A1–3 for details). Surprisingly, Fig. 2 shows indications of positive effects of prenatal Ramadan exposure on BAZ. The main-effects shows that those who were prenatally exposed to Ramadan had 0.127 SD higher BAZ than their unexposed siblings. The effects become more evident when age-effects are considered, as Fig. 2 shows a peak of BAZ in early adolescence (10–14 years of age) (0.271 SD, p-val. < 0.01). The higher BAZ of the exposed children when compared to their unexposed siblings seemed to be consistent across the timing-age-effects. For example, those who were prenatally exposed in the first trimester of pregnancy started to have higher BAZ than their unexposed sibling in late childhood (0.206 SD, p-val. < 0.10) and peaked in early adolescence (0.237 SD, p-val. < 0.05). As there is no evidence of prenatal Ramadan exposure effects on height (HAZ), the higher weight growth in early adolescence might be the factor driving the BAZ peak in early adolescence.

Fig. 3 depicts the effects of prenatal exposure to Ramadan on stature for non-Muslims. It should be noted that the non-Muslims experienced exposure to Ramadan differently than the Muslim groups (see Table 1). Not only were the non-Muslims unexposed to maternal fasting during Ramadan; they also experienced different health and socioeconomic factors than the Muslims: poorer diet quality, no better in-home air quality, different timing of THR, no *zakat*. There is no evidence of main-effects of prenatal Ramadan exposure in Fig. 3. However, negative age-effects of prenatal Ramadan exposure emerged for WAZ (-0.387 SD, p-val. < 0.05) in early childhood (0–4 years of age). The effects on weight in early childhood for those who were prenatally exposed to Ramadan seemed to be greater than those of their unexposed siblings if the former were prenatally exposed at later pregnancy stages (1st trimester=-0.294 SD, p-val. < 0.10; 2nd trimester=-0.400 SD, p-val. < 0.05; 3rd trimester=-0.504 SD, p-val. < 0.01). Those who were exposed in the third trimester of pregnancy had the worse negative effects on stature during early childhood as they were shorter (-0.392 SD, p-val. < 0.10), lighter (-0.504 SD, p-val. < 0.01), and thinner (-0.358 SD, p-val. < 0.10) than their unexposed siblings. Interestingly, these negative effects occurred specifically only in early childhood (0–4 years of age) and did not continue in later ages, thus indicating that exposed children are able to catch up with their unexposed siblings on stature.

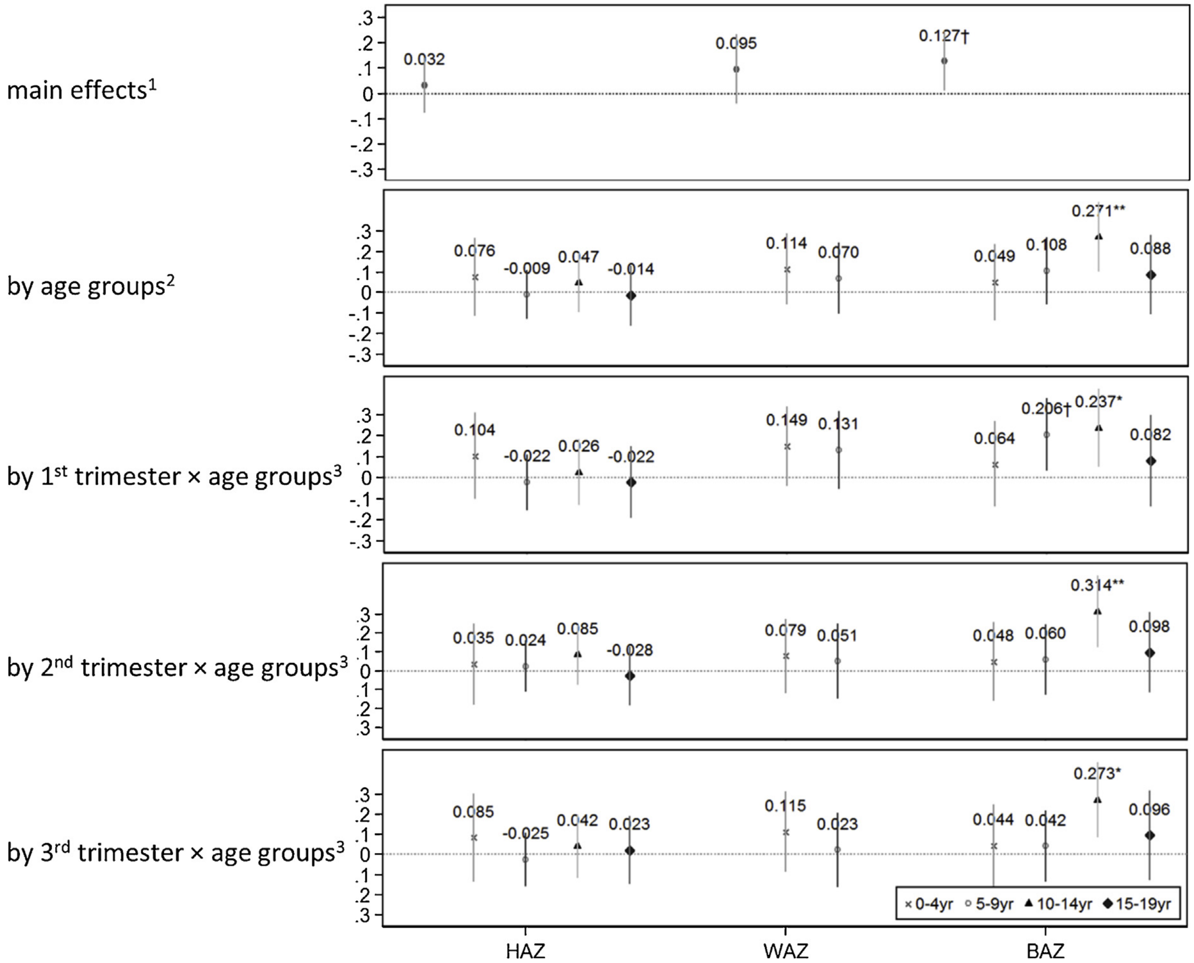

Fig. 2. Effects of prenatal Ramadan exposure on stature for less-religious Muslims.
† p < 0.10; * p < 0.05; ** p<0.01.
Model 1; [2] Model 2; [3] Model 3.
Unexposed siblings (ref.). Cluster-robust standard errors at mother level. The complete regression tables are in the supplementary materials.

6. Discussion

This study is based on a wealth of information on stature during childhood and adolescence from the country with the largest Muslim majority. Our sample contains a greater number of observations than preceding studies that used data from Indonesia (cf. van Ewijk, 2011; van Ewijk et al., 2013; Majid, 2015). We analysed stature from early childhood to late adolescence (0–19 years of age), allowing us to offer evidence on whether the effects of prenatal Ramadan exposure develop with age. Inspired by Majid (2015), we introduce an objective mother's religiosity to improve intention-to-treat estimations; and we contextualise the exposure by tabulating different experiences of prenatal exposure to Ramadan for different religion-religiosity groups.

Our results suggest that prenatal exposure to Ramadan does affect stature. The effects differ by religion-religiosity groups and are age-dependent and timing-sensitive. We present three main findings. First, the exposed children born to religious Muslim mothers experienced negative effects of prenatal exposure to Ramadan on height (HAZ) and body mass (BAZ). Religious Muslims' children who were prenatally exposed to Ramadan experienced a lag in height growth starting from late childhood (5–9 years of age). In late adolescence (15–19 years of age), the lag in height growth caused them to be shorter than their unexposed siblings, particularly if they were prenatally exposed in the first trimester of pregnancy. In addition to this height deficit, in early adolescence (10–14 years of age), religious Muslims' children who were prenatally exposed in the third trimester of pregnancy had lower body mass than their unexposed siblings. Second, the exposed children born to less-religious Muslim mothers experienced positive effects of prenatal exposure to Ramadan on body mass. The effects are apparent even in the main-effects and persistent across the exposed trimester of pregnancy, with a peak in body mass during early adolescence (10–14 years of age). Third, we found that the exposed non-Muslim children experienced negative effects of prenatal Ramadan exposure on stature. This has never been reported in previous studies. However, unlike the exposed religious Muslim children, the exposed non-Muslim children experienced the negative effects only in early childhood (0–4 years of age). At a later age, they were able to catch up with their unexposed siblings on stature.

These results lead us to further interpretations of the effects of prenatal Ramadan exposure on stature. First, we are more certain that maternal fasting during Ramadan is the probable main cause of the negative effects of prenatal exposure to Ramadan for religious Muslims. This is because the only experience of prenatal exposure to Ramadan that differentiates religious Muslims from less-religious Muslims is the higher maternal fasting rate during Ramadan. Second, we suggest that maternal fasting during Ramadan has negative effects that are probably irreversible. We arrive at this interpretation because the exposed non-Muslim children, who can only be prenatally undernourished because of

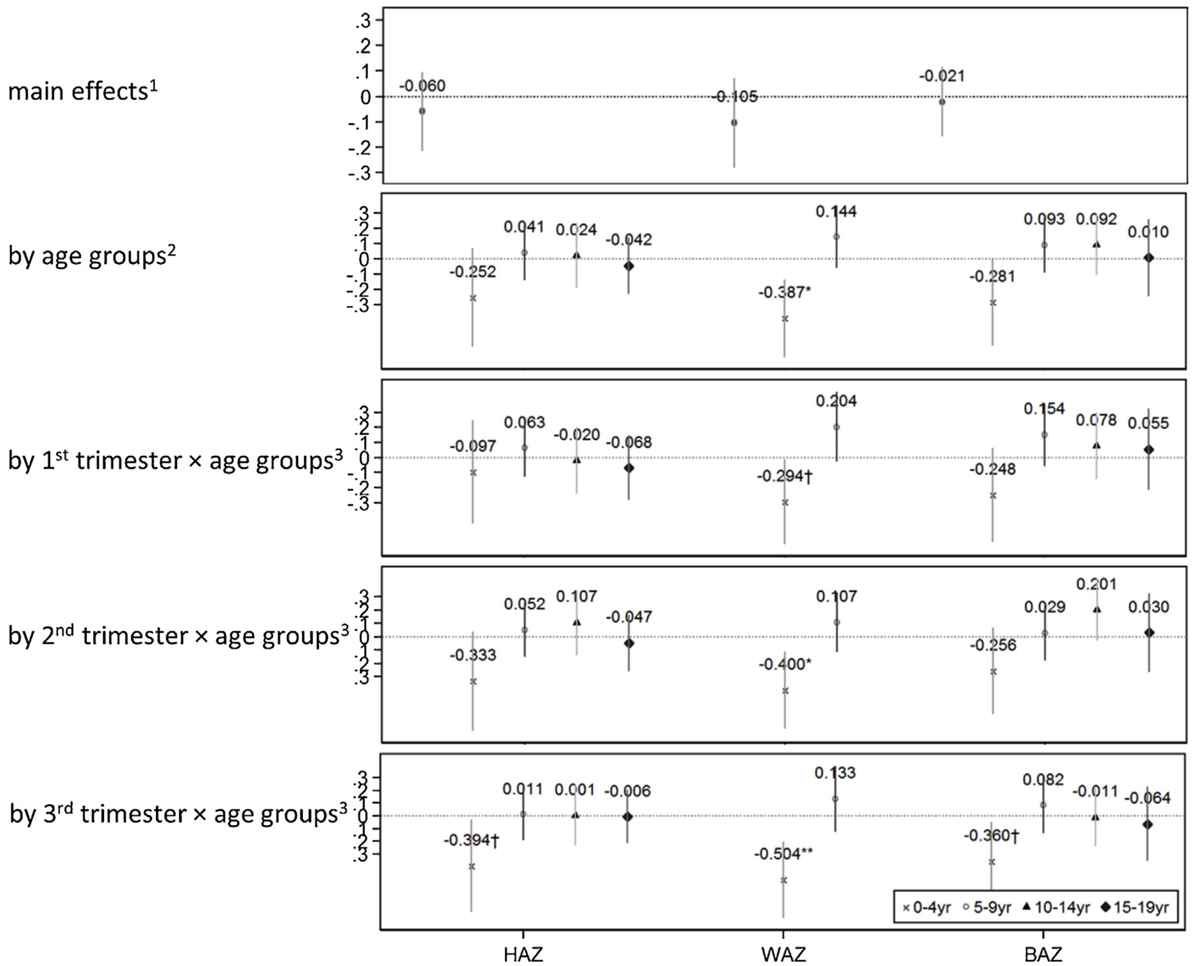

Fig. 3. Effects of prenatal Ramadan exposure on stature for non-Muslims.
† $p < 0.10$; * $p < 0.05$; ** $p<0.01$.
Model 1; [2] Model 2; [3] Model 3.
Unexposed siblings (ref.). Cluster-robust standard errors at mother level. The complete regression tables are in the supplementary materials.

their mother's lower diet quality during Ramadan, are able to catch up on stature at a later age, whereas the opposite is true for the exposed religious Muslims, for whom the negative effects on stature increase with age. Third, there seem to be specific effects of prenatal exposure to Ramadan on weight and body mass in early adolescence (10–14) for Muslim children: negative effects for religious Muslims and positive effects for less-religious Muslims. This might merit further study, because the effects occurred during the onset of puberty. Fourth, findings on exposure's positive effects for less-religious Muslims and negative effects for non-Muslims lead us to new hypotheses that may pave the way for further studies. We suggest that the THR and the *zakat* that Muslims receive at Ramadan might unlock their access to quality food and thus improve their diet quality. As their maternal fasting rate during Ramadan is low, the less-religious pregnant Muslim women can benefit their exposed children through improved diet quality during pregnancy. This should give the foetus a better environment in which to grow healthily (see Harding, 2001; Langley-Evans, 2015). The opposite happens for non-Muslims. Most non-Muslims do not receive THR or *zakat* at Ramadan but still have to cope with the food price hikes. We argue that the diet quality of non-Muslim mothers during Ramadan is lower than in other months, particularly during the non-Muslims' main religious days. Thus, for non-Muslim children, instead of those who were exposed, it was those who were prenatally unexposed to Ramadan who benefit from a better diet quality and therefore grow better in stature.

For religious Muslim children specifically, we found that negative effects of prenatal exposure to Ramadan on stature developed with age. This evidence should explain why previous studies found very few negative to no effects at birth (Alwasel et al., 2011; Makvandi et al., 2013; Seckin et al., 2014; Savitri et al., 2018) but reported a number of negative life outcomes in adulthood (Almond and Mazumder, 2011; van Ewijk, 2011; van Ewijk et al., 2013; Majid, 2015; Schultz-Nielsen et al., 2016). The negative effects of prenatal exposure to Ramadan at an early age are probably buffered. Mothers who fast might be able to compensate their low nutrition intake during Ramadan by improving their diet and gaining adequate pregnancy weight a month after Ramadan (see Kiziltan et al., 2005; Savitri et al., 2018). This condition is similar to the hypothetical effects of prompt food supply recovery in the Dutch Famine studies that enabled the suppression of the immediate effects of the famine at birth but not in adulthood (see Susser and Stein, 1994; Roseboom et al., 2006, 2011). Regarding timing-age-effects, we found that the negative effects on height in late adolescence (15–19 years of age) were higher for religious Muslims who were prenatally exposed in the first trimester of pregnancy. This finding corresponds with that of Roseboom et al. (2006) on greater health problems in adulthood resulting from exposure to the Dutch Famine in the first trimester of pregnancy.

Similar to van Ewijk et al. (2013) who reported the negative effects of prenatal Ramadan exposure on adult stature (18 years or older), we found a height deficit in late adolescence (15–19 years of age) following exposure in the first trimester of pregnancy. However, we could not find any other negative effect on stature except for a lower body mass in early adolescence (10–14 years of age) following exposure in the third trimester of pregnancy. These findings differ from those of van Ewijk et al. (2013), who found negative effects on weight and body mass in adulthood (18 years of age or older) following exposure in the second trimester of pregnancy or later. We suggest that the contrast arises because van Ewijk et al. (2013) analysed stature at an advanced life stage where age-effects become more pronounced. An alternative explanation would be that van Ewijk et al. (2013) used much older birth cohorts than we did. Pregnant Muslim women from an older generation probably have lower pregnancy health than a later generation. Thus, the older birth cohort might not be protected from negative effects of the exposure on weight and body mass. Such cohort-effects, however, require further studies.

Our study is not without limitations. First, the negative effects on stature that we found for religious Muslims' children might seem clinically subtle compared with those found for prenatal exposure to the Dutch Famine (Susser and Stein, 1994; Roseboom et al., 2006, 2011). However, in contrast to famines, maternal fasting during Ramadan is an avoidable risk, as pregnant Muslim women can desist from Ramadan fasting at any time. Furthermore, pregnant Muslim women who do not observe the fast could benefit their children through improved diet quality during pregnancy. We aimed to improve our intention-to-treat estimations by differentiating the Muslims into religious Muslims and less-religious Muslims. However, the improved diet quality of pregnant Muslim women who did not fast during Ramadan may still bias our estimations downwards on the real size of the negative effects. Some prospective case-control studies are attempting to overcome such underestimation bias by using primary data on actual maternal Ramadan fasting observance (e.g. Sakar et al., 2015; Savitri et al., 2018). These studies are still in early phases and are currently limited to early life outcomes. However, because effects of the exposure most likely develop with age, some time is required before any results on later life outcomes become available. Second, we define timing-effects by trimester when prenatal Ramadan exposure started. This approach offered practical interpretations but at the expense of accuracy to signal the exact critical time for being prenatally exposed to Ramadan. Further study focusing specifically on the precise timing-effects could adopt a different design by using month dummies or even days on a continuous scale instead of by trimester. Third, the positive effects that we found for the exposed less-religious Muslims indicated that prenatal Ramadan exposure could benefit a certain group. Our tabulation of different experiences of prenatal Ramadan exposure by religion-religiosity groups indicated that the positive effects probably arose because of the combination of the low maternal fasting rate among the less-religious Muslims and mothers' better diet during Ramadan. However, to test this hypothetical explanation, further studies are required to collect primary data on the daily dietary intake of pregnant Muslim women during Ramadan.

In conclusion, this study found negative effects of prenatal Ramadan exposure on stature during childhood and adolescence for religious Muslims. The negative effects were most likely due to maternal fasting during Ramadan, developed with age, and were sensitive to the timing of the exposure. As many studies have demonstrated that stature correlates with other life outcomes including cognitive ability (Sánchez, 2017), psychosocial aspects (Sohn, 2016), and labour market performance (Bargain and Zeidan, 2017), any negative effect on stature should not be underestimated. Raising societal awareness that pregnant Muslim women have the right not to observe the Ramadan fast should be top of the agenda for policymakers. However, the aspiration of pregnant Muslim women who want to continue to fast during Ramadan should also be respected. Public healthcare should facilitate, and provide pregnant Muslim women with, better access to maternal healthcare such as additional pregnancy check-ups and dietary advice to help them manage a healthy pregnancy and reduce the negative effects of prenatal exposure to Ramadan for their offspring.

Conflict of interest

No conflict of interest to be declared.

Acknowledgements

We thank Prof. Reyn van Ewijk for his input during the initial stage of this article. The Indonesian government funded this study through BPP-LN DIKTI grant number: 124.15/E4.4/2014. An early version of this article was presented as a poster at the European Population Conference 2016 in Mainz, Germany.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ehb.2018.12.001.

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