Letter to Editor

Height, weight, body mass index and offspring sex at birth in contemporary Finnish women

Using data on over 22,500 British parents, Kanazawa (2005) reported interesting findings that taller and heavier parents tended to have more sons, while shorter and lighter parents tended to have more daughters. These findings were taken to support the *generalized* Trivers and Willard's hypothesis (sensu Trivers and Willard, 1973), proposed by the author. In brief, this hypothesis states that since in humans body size is heritable, taller and heavier parents should produce an excess of sons, because large body size is much more closely related to high fitness in men compared to women (Kanazawa, 2005). These results obtained by Kanazawa (2005) have, however, recently been heavily criticized on their statistical justification (Gelman, 2007; Denny, 2008). Although this study is not the only one to report an association between high maternal weight and a male bias in secondary offspring sex ratio (see Manning et al., 1996; Cagnacci et al., 2004), more data are needed to answer the question whether bigger and heavier mothers deliver more sons.

I examined how height and weight affected the birth sex ratio of offspring in contemporary Finland. Only women were included, because information on their husband's body size was not available. Data on completed lifetime reproductive history, including the sex of all the offspring born, and the self-reported adult height (reported to the nearest 0.5 cm) and weight (reported to the nearest 0.5 kg) of post-reproductive women born in years 1946–1958 were collected by questionnaires during 2006. These women are a random sample of voluntaries participating in the Finnish national screening program of cervical cancer, ongoing since the 1960s. The mean height of these women was 164.2 cm ($\pm$5.5 SD, range 149–177), mean weight was 71.1 kg ($\pm$13.2 SD, range 46–135). Mean offspring sex ratio at birth was 0.53 ($\pm$0.39 SD), which is significantly higher (an exact binomial test, $z = -7.58$, $P < 0.0001$) than the national birth sex ratio of 0.512 in Finland during the study period 1964–2000. The reason for this high male bias among the women studied is unclear.

Maternal age at delivery (paternal age was not available) and the birth order of offspring may also potentially affect the sex of offspring (Lazarus, 2002). In order to incorporate the effects of these factors on offspring sex, it was necessary to examine whether a woman's height and weight were related to the likelihood of an individual offspring being a male, i.e., multiparous women had multiple observations, with logistic regression model. To account for a potential non-independence of observations within mothers, maternal identity was treated as a random factor (Krackow and Tkadlec, 2001). Generalized linear mixed model was thus used, fitted with binomial errors and logit link function, and Satterthwaite's formula was used to determine the denominator degrees of freedom of fixed effects (Littell et al., 1996). The analysis also controlled for the effect of a woman's educational level (elementary school, secondary school, or university/college degree) on offspring sex. I also included the second-order interactions between maternal height and weight with educational level, offspring birth order and maternal age at delivery.

Note that Kanazawa (2005) examined the effects of parental height and weight on the numbers of sons and daughters born in separate models, probably because the height and weight of an individual are likely to covary, leading to collinearity problems (this issue was not, however, formally examined or discussed). Therefore, he was unable to contrast the effects of parental height and weight simultaneously. Here, the collinearity between maternal height and weight was assessed with variance inflation factors and tolerance values. The largest variance inflation factor was 1.1 and the lowest tolerance value 0.9, indicating that the standard errors of regression coefficients were unbiased. Hence, I was able to reliably contrast the effects of maternal height and weight on offspring sex simultaneously. Likewise, the collinearity between birth order and maternal age at delivery was negligible (variance inflation factor = 1.03 and tolerance value = 0.98, estimated between the number of births and average maternal age at reproduction to avoid multiple observations within mothers). Model reduction of non-significant interactions and predictors, excluding maternal height and weight, by backward stepwise elimination using F-tests was applied to obtain a final model (Wilson and Hardy, 2002). The Pearson residuals showed no values exceeding 3 and the dispersion parameter was 0.95, indicating a good fit of the final model. A total of 234 women having 480 offspring were included in the analysis, which was conducted with SAS version 9.1 (SAS Institute Inc. Cary, NC, USA).

The results are shown in Table 1. Among the women studied, maternal height was not related to offspring sex. The effect of maternal weight on offspring sex depended on the birth order of the offspring and on maternal age at delivery. Heavier mothers reproducing at an older age tended to be more likely to deliver a son, whereas heavier mothers having had many previous births were more likely to deliver a daughter. Comparable results were found when the body mass index (BMI, a measure of body fat, calculated as weight (kg)/height (m^2)) of women was used instead of their height and weight, as the mothers with higher BMI (i.e., heavier women considering their height) who reproduced at an older age tended to be more likely to deliver a son (odds ratio = 1.009, 95% CIs = 0.999–1.019, $F_{1,474} = 2.96$, $p = 0.086$), while the mothers with higher BMI having had many previous births were more likely to produce a daughter (odds ratio = 0.932, 95% CIs = 0.873–0.996, $F_{1,474} = 4.35$, $p = 0.038$). The educational level of the mother, used in many studies as a proxy of maternal condition and/or status, was unrelated to offspring sex and it did not mediate the effects of height and weight on offspring sex.

The current findings are partly in agreement with those of Kanazawa (2005), as the weight of the mothers seemed to be more closely related to offspring sex than their height. Note that

Table 1
Effects of a woman's height and weight on the sex of offspring born (probability of being a male)

Predictor	$df_{num,den}$	F	p	Odds ratio (95% CIs)
Height	**1, 230.4**	**0.22**	**0.64**	**0.991 (0.952–1.031)**
Weight	**1, 473**	**1.72**	**0.19**	**0.994 (0.978–1.010)**
Birth order	**1, 473**	**3.96**	**0.047**	**0.984 (0.736–1.314)**
Age at delivery	**1, 473**	**3.57**	**0.059**	**0.983 (0.939–1.028)**
Weight × Birth order	**1, 473**	**3.92**	**0.048**	**0.976 (0.953–0.999)**
Weight × Age at delivery	**1, 473**	**3.11**	**0.079**	**1.003 (1.000–1.007)**
Educational level	2, 226.1	0.36	0.70	–
Weight × Educational level	2, 227	1.04	0.36	–
Height × Birth order	1, 468	0.75	0.39	1.022 (0.973–1.073)
Height × Educational level	2, 223.1	0.17	0.85	–
Height × Age at delivery	1, 465	0.00	0.99	1.000 (0.991–1.010)

Variables given in bold case are included in the final model. Odds ratio estimates, which measure effect size, are given with 95% confidence intervals (CIs). Odds ratios for categorical variables and their interactions are omitted for simplicity. Maternal identity, fitted as a random factor, explained a significant proportion of variance in offspring sex at birth (estimate = 0.295, 95% CIs = 0.096–0.495).

the results of Kanazawa (2005) have been criticized to be of improper statistical approach (Gelman, 2007), and later re-analysis of a subset of the original data by Denny (2008) using a similar approach as applied here found neither parental height nor weight to be associated with offspring sex. Nevertheless, in these Finnish women, the effect of weight was mediated by the age of the mother at delivery and how many previous births a mother had had. To the best of my knowledge, no previous study has reported that maternal weight with an interaction of her age or parity might be related to offspring sex. The reason(s) why heavier mothers who were older were more likely to deliver a son than a daughter remain, however, unclear. In general, older women, and particularly older men, are found to be more likely to produce a daughter than a son (Lazarus, 2002). Despite this, the finding may be compatible with life-history theory, which predicts that since older mothers approaching menopause lose rapidly their residual reproductive value, they should increase their reproductive effort (Charlesworth and Leon, 1976). Since having a son is energetically more demanding for the mother than having a daughter due to sons' faster intra-uterine growth rate, heavier birth weight, and larger birth size (Hindmarsh et al., 2002; Loos et al., 2001; Marsál et al., 1996), older and heavier mothers delivering a son may indicate that only these mothers had still sufficient physiological resources to produce and nurture a son.

The opposite was found for offspring birth order, as heavier mothers having had many previous births were more likely to deliver a daughter. Although high parity has generally been related to increased likelihood of female birth (Chahnazarian, 1988; Lazarus, 2002), we do not currently know the reason for this. Family planning and the increased mortality of male foetuses are perhaps the most prominent candidates. Therefore, the result that the effect of birth order on offspring sex was mediated by maternal weight is hard to interpret.

Compared to maternal weight, similar results were found when the BMI of women was used instead of their height and weight. Gibson and Mace (2003) have previously shown that in rural Ethiopia mothers with high BMI were more likely to deliver a son than a daughter in their previous birth. These results have not, however, been supported by larger national data from Ethiopia (Stein et al., 2004). Moreover, high maternal waist-to-hip ratio (WHR), another proxy of elevated fat deposition in women, has been related to male-biased offspring birth sex ratio (Manning et al., 1996; Singh and Zambarano, 1997).

Although one of the assumptions of Kanazawa's *generalized* Trivers and Willard's hypothesis, a high heritability of human

body size, may well hold, the assumption that men but not women gain fitness benefits from high stature may not be that straightforward. This is because taller women may also accrue fitness benefits through increased offspring number and survival, higher probability of multiple births and longer lifespan (Allal et al., 2004; Basso et al., 2004; Kemkes-Grottenthaler, 2005; Liljestrand et al., 1985; Martorell et al., 1981; Sear et al. 2004). Therefore, it may not be in order to assume that parents of large body size should bias their offspring sex ratio towards sons.

In addition, apart from the fact that this study relied on a self-reported measure of maternal weight, an inability to use the pre-conception weight of women in the analyses (as done in most current studies except in Cagnacci et al., 2004) may introduce problems. This is because, in contrast to height, the weight of mothers may potentially show a great degree of age-dependency. The weight of mothers may thus vary markedly between the subsequent pregnancies, making the results based on a single estimate of maternal weight hard to interpret. Furthermore, causality can also go from pregnancies to maternal weight, as both the increased and decreased weight of mothers with increasing parity have been reported (Tracer, 2002). If such effects are further related to the sex of offspring born, they may further confound the association between a woman's weight and her offspring birth sex ratio.

It is also interesting to note that some mothers were more likely to produce sons while others were more likely to produce daughters, as indicated by the statistically significant effect of maternal identity on offspring sex (Table 1). This finding is rather surprising, since generally the heterogeneity of secondary offspring sex ratio between couples is believed to be very low (Edwards, 1970; Curtsinger et al., 1983). The current analysis cannot distinguish whether this effect was due to maternal or paternal influence, or shared family environment. Since we do not have information on the paternity of the offspring born, maternal influence may seem to be more likely here. However, paternal influence may also play a role, since in vertebrates sperm motility and the proportion of viable spermatozoa have been suggested to bias offspring birth sex ratio (Fukuda et al., 1996; Gomendio et al., 2006).

In sum, there is currently mixed evidence that body size, or some component of it, is related to offspring sex ratio in humans. It remains an unanswered question what measure(s) should be used to describe (heritable) body size in humans that can be used to predict parental sex allocation as described by Trivers and Willard (1973). Strong interrelations between the different body size/condition measures may make the statistical assessment of their unique effects hard to quantify. Moreover, it is important to separate their effects from other parental attributes that may potentially be related to a Trivers–Willard effect.

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