



Review Article

The male to female ratio at birth

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Abstract. The factors that influence the male to female ratio at birth are legion. Males are usually born in excess and stress decreases the ratio while wellbeing and good health tends to increase it. This paper reviews the multitudes of factors that have been implicated as affecting this ratio, from historical times to date.

Keywords Sex Ratio - Birth Rate/*trends - Infant, Newborn.

1 The male to female ratio at birth

“The examination of sex distribution in human society constitutes a rather technical, if not abstruse investigation better left to demographers”

(Attané and Guilmoto, 2007).

2 Historical aspects

The male to female ratio of live births is generally expressed as the ratio of male live births divided by total live births (M/F). Although this would be more accurately abbreviated as M/T (male births divided by total births), it is widely (albeit technically incorrectly) abbreviated as M/F, and this will be used throughout.

In ancient times, it was widely believed that an infant’s gender was determined by the degree of heat that a man’s ejaculate was exposed to during insemination.

A statistical study of M/F requires not only raw data but also statistical tools for calculations that provide probabilities of deviation from preset values. The collection of the data from London in the 1600s allowed John Graunt to publish the first descriptive statistical analysis of M/F data (Graunt, 1899).

Graunt’s publication included a detailed description and analysis of annual variation in M/F in London and Romsey. Graunt noted that “that there be more males than females” and that “London is somewhat more apt to produce males than the country”. He based this on the observation that during 1629-1661, 139,782 males and 130,866 females were christened in London, which he approximated as 14:13, a M/F of 0.5164. However, in Romsey, during 1569-1658, 3,256 males and 3,083 females were christened (16:15), a M/F of 0.5136. This is statistically non-significant and Graunt simply speculated that there may be geographic variations in M/F. He also noted secular variation in M/F which is significant with modern day testing.

John Arbuthnott (1667-1735) was a mathematics teacher in London who went on to study medicine (Campbell, 2001). He suggested that “provident Nature, by the Disposal of its wise Creator, brings forth more Males than Females, and that in almost a constant proportion”, noting that male excess is God’s method for compensating for increased male mortality since “polygamy is contrary to the Law of Nature and Justice”.

Arbuthnott’s originality lay in his demonstration that M/F is significantly in excess of 0.5 and this is considered the first use of inferential statistics. His calculations compared annual male and female births in London with the outcome of a number of throws with a two-sided die, a sign test (Campbell, 2001).

The Fisherian explanation is that were male births less common than female, a male would have better mating

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prospects and would sire more offspring. Thus, parents genetically disposed to produce males would have more offspring and this tendency would spread within the community, increasing male births, such that this advantage disappears when an M/F of 0.5 is reached. The converse would apply were there a dearth of females. Hence “it follows that the sex ratio will so adjust itself, under the influence of Natural Selection, that the total parental expenditure incurred in respect of children of each sex, shall be equal” (Fisher, 1930).

While this theory was popularised by Fisher, it must be pointed out that it had already been mathematically expounded by Carl Düsing of the University of Jena in three publications in 1883 and 1884. These investigations comprised the first application of mathematical methods and models to evolutionary biology (Edwards, 1960).

3 Broad epidemiological aspects of human M/F

Random meiosis would lead to a mean (Mendelian) M/F of 0.5, with binomial variation around this value. However, this is based on the following:

1. Males produce equal numbers of X- and Y-bearing sperm in mammalian species.
2. X- and Y-bearing sperm stand equal chances of achieving conception.
3. Equal numbers of male and female zygotes are conceived.

Thus, any M/F variation would be due to sex-selective foetal wastage. However, evidence has been put forward against these conclusions, as will be demonstrated. In humans, M/F exhibits a male excess, and is expected to approximate 0.515 with a range of 0.505 to 0.520 (James, 1997).

The excess of male births may be nature’s compensatory mechanism for increased postnatal male mortality. However, the reason/s and mechanism/s whereby this occurs are uncertain, and several theoretical models have been proposed to explain these variations. This is because a remarkable degree of inhomogeneity in M/F has been demonstrated, both secularly and across regions and the following section will review factors that have been implicated as resulting in these disparities (James, 1997; James, 1987b).

4 M/F physiology

For humans, the gender ratio at birth is determined at the time of conception through genetic control. A review has indicated that there is a consistent and significant

excess of males at fertilisation (Boklage, 2005). However, there is evidence that M/F is partially influenced by a combination of endogenous and exogenous factors.

Although the mechanism/s that produce this effect could theoretically operate at conception or during pregnancy, the latter seems more likely. Indeed, it has been argued that there is no plausible mechanism whereby a species with sets of chromosomes (diploid pairs) could alter M/F at conception (Smits and Maynard-Smith, 1978). Furthermore, it has been pointed out that any maternal control over M/F will be actively opposed by sperm, in that individual sperm that allow themselves to be identified as X- or Y-bearing sperm will not be selected as often as sperm that are able to disguise their gender-selecting material (Reiss, 1987).

Recent studies that rely on the biochemical detection of pregnancy reveal that around 73% of natural singleton conceptions fail to survive beyond six weeks of gestation. This implies that pregnancy is an opportunity not only for gestation but also for selection and/or culling, and that significant wastage occurs before maternal or clinical recognition of pregnancy - 90% of the survivors go on to reach term (Boklage, 1989).

It is also believed that multiple pregnancies may constitute over 12% of all natural conceptions, but only approximately two percent reach term as live twin births, and 12% of these result in single births. In all of the above situations, the attrition described can be modelled with a simple equation for exponential decay (Boklage, 1989).

The sex ratio at conception in humans may be 0.545, with the highest sex ratio of fetal deaths in the second trimester, decreasing in the third trimester, and peaking again at term. This data also suggests that late fetal deaths may be postponed to early infancy (McMillen, 1979).

Evolutionary theory proposes that mutations produce some individuals who may be fitter in a given environment and who are therefore likelier to survive and procreate, dispersing their advantageous genes. One such adaptation could be the ability of the individual to influence M/F outcomes in conceptions.

In polygynous species, only the fittest males reproduce. For this reason, parental investment in a “good quality” son may yield greater numbers of descendants than an equivalent investment in a “good quality” daughter. It may therefore be advantageous for a mother to produce sons when she has sufficient resources to give them a better than average edge that will then give them a greater chance to reproduce, and daughters when she does not. This is known as the Trivers-Willard hypothesis (Trivers and Willard, 1973).

5 Factors known to influence M/F

Three mathematical models have been proposed as potential explanations, individually or in combination/s, to elucidate the probability p of a male birth within and across sibships (Edwards, 1960; James, 1997).

Markov variation assumes that p varies within couples depending on the gender of previous births. Markov variation is said to be positive when p increases with previous male births, and vice-versa.

Poisson variation assumes that p varies within couples from one pregnancy to the next, irrespective of the gender of previous siblings, and has the same overall mean across couples. Poisson variation is “chaotic” if p varies in a random manner within couples. It is called “systematic” variability when p varies from one pregnancy to the next in parallel across all mothers, such as, for example, a birth order effect.

This is complicated by a so-called “stopping rule” of which there are two types. Type I occurs when families desire one or more children of one sex, and cease reproducing when their wish is satisfied. Type II occurs when families desire both sexes among their offspring, and cease reproducing when their wish is satisfied (James, 1997).

Some form of variation probably operates on M/F as it has been shown, for example, that M/F of sibs of male-male, male-female and female-female twin pairs differ significantly, with values of 0.536, 0.523, and 0.508 respectively (Turpin and Schutzenberqer, 1952). Overall, it appears that the evidence for either Lexis and/or Markov variations exist and this will be briefly alluded to in the next sections (James, 1997).

While the physiological basis for the influences of external factors on M/F are not understood, alterations in parental sex hormone level/s and/or differential gender-based survival modulated by stress during embryogenesis have been proposed as likely mediators.

The hormonal theory is heavily subscribed to by William H. James, the foremost expert in the field (James, 2004). Indeed, a hormonal explanation by this same author will be noted for almost all of the factors that are known to influence M/F. More recently, this same authority has also acknowledged the effect of stressors on M/F during pregnancy, as will be outlined.

Population/physiological differences - Lexis variation The male excess has been historically shown to be significantly less in Black populations when compared to Caucasian populations (Ciocco, 1938; Visaria, 1967), and significantly higher in Asian populations

(James, 1997; Visaria, 1967). A more recent study in the United States confirmed the Black-Caucasian difference and also demonstrated a low Hispanic M/F (Branum et al., 2009).

This difference persists even when races co-exist such as in South Africa and the West Indies (Visaria, 1967) and in England and Wales (James, 1997). It has been speculated that this may be due to innate minor physiological differences (Ciocco, 1938; Visaria, 1967). With regard to hormones, the evidence to date seems to indicate that mammalian (including human) M/F is causally related to periconceptual parental hormone levels. For example, differences in the levels of maternal gonadotrophins have been implicated, with higher levels causing a lower M/F (James, 1984). In addition, elevated levels of testosterone and oestrogen increase M/F (James, 1986b) while progesterones decrease M/F (James, 2004).

The luteal surge in the middle of the menstrual cycle has therefore been proposed to be the cause of the excess conception of females noted in the fertile part of the cycle (James, 2004). Interestingly, it has been noted that right-sided ovulation is associated with a higher M/F than left-sided ovulation (Schoner, 1927). Furthermore, serum estradiol and testosterone concentrations are higher in right-sided than left-sided ovulation (Fukuda et al., 2000). It has been speculated that the former may be due to the latter (James, 2004).

Physiological changes in normal hormone profiles may also occur with maternal age, such that a shift in maternal age, for example, to older mothers, may also potentially influence M/F (James, 1984). It has been speculated this may be due to the increasing circulating gonadotrophin levels present in older mothers that favour a lower M/F (James, 1980b).

Furthermore, births to younger fathers and births of lower orders appear to be likelier to be male, increasing M/F (Chahnazarian, 1988). This is particularly relevant since family size has significantly decreased in many countries (Festy, 1984).

However, studies between races, such as Scotland for the period 1975-1988 (549048 1st – 5th order births in 330088 women) have failed to demonstrate Lexis variation (Maconochie and Roman, 1997).

Moreover, it has been shown that the M/F of offspring of women who have never had a spontaneous abortion is very close to that of the surviving offspring of women who have had a spontaneous abortion, further arguing against Lexis variation (Boldrini, 1937; Colombo, 1957).

6 Family planning, birth order, polygamy and multiple pregnancy

Birth order has been shown to be negatively correlated with M/F (Garenne, 2008), being highest among first-born children and declining asymptotically with increasing numbers of offspring (Russell, 1936), a form of systematic Poisson variation.

However, gender preference may potentially influence M/F. For example, couples with a male preference may stop trying to have children if the first birth or the first several births are male, a stopping rule (Goodman, 1961). Indeed, it has been shown that M/F declines with increasing birth order. Moreover, M/F decreases with increasing paternal age (James, 1987a), and (to a lesser extent) with increasing maternal age (Ulizzi and Zonta, 1995). The latter is attributed to increasing circulating gonadotrophin levels present in older mothers that favour a lower M/F (James, 1980b). The former has been attributed to decreasing coital rates (James, 1980a) and to declining male androgen levels with increasing paternal age (Punifoy et al., 1981).

Additionally, the decreased M/F seen with increasing birth order and with increasing paternal age are almost identical, and may be caused by the same factor/s (Novitski and Sandler, 1956).

Interestingly, yet another study has not only shown that maternal age correlates negatively with M/F (40-49 years), but also that very young mothers (12-19 years) also have a low M/F (Garenne, 2008).

Matters are complicated by the fact that consistency between studies is not always present. For example, a large study showed a decline in M/F with paternal age and with number of siblings per plural birth, with no influence from maternal age or birth order (Jacobsen et al., 1999).

In addition, coital rates after marriage have been shown to approximately halve in the first year of marriage and halve again over another twenty years (James, 1983). The relation between M/F and coital rates is confirmed by the finding that M/F declines according to month of conception over the first year of marriage (Bernstein, 1958).

Moreover, twin births (Bulmer, 1970) and multiple births have lower M/F than singleton births (Pollard, 1969), and this has been attributed to the increased male mortality in such multiple pregnancies (Zahalkova, 1978). This is complicated by the fact that periconceptual high levels of maternal gonadotropin predispose to dizygotic twinning (Bulmer, 1970).

In addition, the three main races exhibit different dizygotic twinning rates. Blacks have higher rates than caucasians, who in turn, have higher rates than orien-

tals (Bulmer, 1970). There is also evidence that gonadotrophin levels vary consistently across these three races (Milham, 1964), further influencing M/F.

7 Warfare and time of coitus in menstrual cycle

Marked increases in M/F in the range of 1-2% have been noted during and after warfare in England, Wales and France in relation to the First and Second World Wars (James, 1987a).

WW1 A rise in M/F was noted in Austria, Belgium, Bulgaria, England, France, Germany, Hungary, Italy, Romania, and South Africa (Russell, 1936; Bernstein, 1958).

WW2 In England and Wales, M/F was higher in 1941-1946 than in any years previously recorded, with registrations dating back to 1841 (Lowe and McKeown, 1950). Similar findings were noted for Belgium, France, Germany and the Netherlands (Graffelman and Hoeksrtra, 2000), as well as in Finland (Vartiainen et al., 1999). This effect was smaller or absent in neutral countries (Russell, 1936), and absent in the United States where the percentage of the population in the armed forces at any one time was less than 4%, compared to 15-22% in the principally affected European countries (Anon, 1939).

Warfare related alteration in M/F has been attributed to coital frequency. In times of war, an adult sex ratio imbalance prevails, with more males being away from their homes. This results in sexual excesses, "actions [that] were viewed as understandable responses to the Frauenuberschuss," the excess supply of women (Moeller, 1993). It has been mooted that in wartime, nonprogrammed copulation and high coital rates co-exist, with more conceptions occurring early or late in menstrual cycle, increasing M/F (James, 1980a).

This is due to the fact that M/F follows a U-shaped regression on cycle day of insemination, suggesting that female conceptions result most often from conceptions around ovulation, with male conceptions occurring more frequently at the beginning and end of the menstrual cycle (Guerrero, 1974; Harlap, 1979). These findings have been confirmed by more recent meta-analysis (Gray, 1991).

This U-shaped regression is confirmed by the higher M/F that is depicted after the failure of rhythm methods of birth control since such failures would theoretically, on average, occur earlier or later in the menstrual cycle (James, 1987b).

It has been noted that coital frequency may be related to individual age, and therefore secular changes

in parental age composition could produce M/F shifts. However, these wartime rises could not be entirely accounted for by changes in fetal death rates, maternal age, parity or birth interval (MacMahon and Pugh, 1953).

Conversely, brief episodes of belligerence decrease M/F. For example, the very short war in Slovenia (26 June-7 July, 1991) reduced M/F to 0.504 in Slovenia and to 0.483 in Ljubljana, 6 to 9 months later. A decrease in sperm motility was also noted, from 56% just before the war to 52% after (Zorn et al., 2002), and this will be further amplified later.

8 Stress and socioeconomic status

This hypothesis implies that natural selection has developed mechanisms by which pregnant females subjected to environmental stressors manipulate M/F by culling male fetuses that are least likely to eventually sire grandchildren. Males are specifically selected for abortion as a male in poor condition is likelier to die before reaching reproductive age than a female in similar condition, despite receiving a greater maternal investment - a socio-economic paradigm. Mammalian demographic studies support this theory since, as the maternal condition deteriorates, females produce less male offspring (Trivers and Willard, 1973). However, overall, the evidence for this hypothesis is mixed. Reviews have shown that 89 tests of the hypothesis on primates (including man) have only supported it half of the time. Furthermore, some test results went contrary to this hypothesis (Brown and Silk, 2002; Lazarus, 2002).

Male vulnerability is manifest in premature births, as well as in term babies, with higher morbidity and mortality rates that persevere into early childhood. It has therefore been suggested that postnatally, malnutrition, interacting with infection, is a precipitant for male loss. Furthermore, because of this innate male vulnerability, despite advances in medical care, male loss always exceeds female loss (Wells, 2000).

Natural selection may have favoured the female ability to manipulate M/F since females without such mechanisms would produce fewer grandchildren due to the loss of weaker male infants. Moreover, women who fail to abort male foetuses in times of stress reduce their own odds of survival due to the higher metabolic requirements necessitated by the gestation of a male baby to term. Conversely, a female who aborts a male baby under stressful circumstances fails to invest heavily in what would potentially result in a frail son, and makes herself available to potentially bear a daughter, or a robust son (Wells, 2000).

Indeed, male attrition in pregnancy under stressful

conditions may be an inevitable physiological consequence since women who gestate a male embryo require a 10% higher daily energy intake than women who gestate a female embryo, consuming on average 8% more protein, 9.2% more carbohydrates, 10.9% lipids of animal origin and 14.9% lipids of vegetable origin. Male embryos may therefore be more susceptible to energy restriction and therefore more likely to be aborted spontaneously (Tamimi et al., 2003).

This is supported by the fact that M/F is positively correlated with maternal socio-economic status (Shapiro et al., 1968). Dietary calorie intake alone has also been shown to influence M/F, with high intakes increasing M/F (Mathews et al., 2008).

These findings are confirmed by a study that examined various African populations which showed that short maternal stature was also independently related to a lower M/F (Andersson and Bergstrom, 1998). Conversely, big and tall parents have been shown to have a higher M/F (Kanazawa, 2007).

Dwelling ownership has also been shown to affect M/F in a Ugandan sample, with the M/F of mothers who live in owned dwellings at 0.502, as compared with non-owners at 0.458 (Wallner et al., 2012).

However, several large studies have failed to confirm these findings (Erickson, 1976) (Rostron and James, 1977). This discrepancy has been attributed to the relatively short duration of some of the above events since the fetus is very efficient at extracting calories in short-term periods of deprivation (Hyttén, 1983). The effect of a population's health on M/F has also been shown on a global scale. It has been shown internationally that M/F is positively correlated with life expectancy and healthy life expectancy. This was demonstrated to hold true for all indicators including individual mortality rate, maternal mortality ratio, under-five mortality rate, adult mortality rate and averaged mortality indices including life expectancy and healthy life expectancy (Dama, 2011).

It has been postulated that socio-economic effects are even more complex, giving rise to an inverted response with a M/F reversal - a so-called *dose-response fallacy*. This hypothesis suggests that M/F increases from low to high as a family's socioeconomic level rises, due to decreasing rates of periconceptual mishaps, resulting in more male survivors. With further rises in socioeconomic conditions, M/F decreases to a more equal gender proportion due to optimal conceptions of both genders (Jongbloet et al., 2001).

Several studies have shown a decreasing M/F in association with surrogates of socioeconomic status, such as "descent in the social scale" (Russell, 1936). More recently, in the US population, women married to men listed in various Who's Who volumes have a high M/F

while those listed in social registers have a lower M/F (Mackey and Coney, 1987). This is also quite noticeable at the extreme end of the spectrum, with male billionaires listed in *Forbe's* having more children with a higher M/F than female billionaires. Furthermore, women married to billionaires had higher M/F than self-made female billionaires (Cameron and Dalerum, 2009).

Interestingly, a study of Caucasian mothers between 1983-2001 that included 48 million births found that married, better educated and younger mothers had a higher M/F, and infant deaths were likelier to be male if the mother was unmarried and young, supporting the Trivers-Willard hypothesis. This is because while younger mothers tend to be healthier, their socio-economic characteristics are often worse than older mothers, and this latter characteristic overwhelms the former (Almond and Edlund, 2007).

Furthermore, it has been shown that working women with higher-earning occupations have a higher M/F and that women working in more traditionally masculine occupations have a higher M/F (Bernstein, 1958). Thus, greater female participation as part of a nation's workforce may potentially influence M/F (Grant and J.T., 2001). Dominant women have also been shown to have higher testosterone levels (Grant and J.T., 2001) and it has been suggested that this may also result in higher M/F ratios in their offspring (James, 2004).

This effect is evident even when social class is taken into consideration (Bernstein, 1958). For example, M/F is increased in royal families (Norton, 1940). Conversely, M/F is lower in men who perform personal services, such as domestic servants, inn-keepers, barmen, waiters, hall porters, barbers and cleaners (McDowall and Britain, 1985).

Furthermore, it has been shown that a stressed parent is likelier to produce a child of the opposite sex (Schuster and Schuster, 1973). This might be due to the fact that anxiety lowers gonadotropin levels in potential mothers (Peyser et al., 1973) and the androgen levels of potential fathers (Kreuz et al., 1972).

Matters are compounded by the opposing hormonal responses to stress of the two sexes. Males lower testicular androgen levels while females increase adrenal androgen levels (Christiansen, 2004). Thus, if both parents are exposed, the hormonal effects on M/F counter each other and may attenuate or even completely nullify any potential effects on M/F (James, 2004).

There are also indications that the Trivers-Willard effect may extend across generations. For example, it has been shown that the reproductive success of individuals born to mothers who had previously had sons is lower than in those who had previously had girls, a Markov variation (Rickard et al., 2007).

Explanations of these findings fall into two broad

groups outlined hereunder: the male foetal death mechanism and the reduced male conception theory. The latter is further subdivided into two potential mechanisms: less frequent coitus and poorer sperm quality.

9 Male foetal death

This hypothesis contends that population stressors result in endocrine changes in females that induce the spontaneous abortion of small or weak male fetuses (Forchhammer, 2000; Owen and Matthews, 2003). This accedes to the notion that under such conditions, female offspring are likelier to reach reproductive age and reproduce than male offspring (Trivers and Willard, 1973).

A corollary of the excess male death theory is that males lost due to maternal stress would have been at risk of premature delivery and very low birthweight (<1500g) in the absence of stress. This is confirmed by the finding that the risk of prematurity and very low birthweight increases with maternal stress, and that M/F in such babies is elevated (Hall and Carr-Hill, 1982).

The stress hypothesis is supported by studies that followed up the effects of stressful events on populations. For example, M/F fell in New York City three months after the terrorist attacks of September 11, rather than seven or more months later as would be the case were male conceptions to have been reduced by this event (Catalano et al., 2006).

Similar findings were noted for the same time period, following the above mentioned terrorist attack, in California (Catalano et al., 2005) suggesting that witnessing harm befalling on others induces biological responses that resemble those in the persons harmed (Singer et al., 2004).

Thus, male mortality is higher than female mortality during gestation. Improved socioeconomic conditions and medical care have been shown to be associated with a lowering of prenatal mortality rates. The amelioration of gestational conditions and a reduction in factors that predispose to spontaneous abortion will therefore spare more male than female births, increasing M/F.

This is evidenced in developed countries where the decline in stillbirth rates has been drastic, with, for example, the ratio of stillbirths to live births dropping from 30-40/1000 in the late 1800s in Sweden and Belgium to 10/1000 in the 1970s. This was paralleled by a decline in M/F of stillbirths (Schtickzelle, 1981).

10 Reduced coital rates

One of the defining characteristics of stress in humans is reduced libido, and hence coital rates (Segraves, 1998). Reduced coital rates inevitably reduce the chances of conceptions early in the menstrual cycle. Since it has been shown that conceptions on most fertile days yield

a M/F of approximately 0.492, with a ratio of around 0.536 on other days (James, 1999), reduced coital rates will decrease M/F.

11 Reduced sperm quality

Another effect may be that of the lowering of sperm quality, as already alluded to (Fukuda et al., 1996). This is attributed to the fact that Y-bearing sperm have greater mucosal penetrability, an advantage that is attenuated if motility is reduced, thereby reducing M/F (Pyrzak, 1994).

Life events also affect sperm quality. For example, the recent death of a close family member was associated with a reduction in progressively motile sperm (Fenster et al., 1997).

Natural disasters have similar effects. This was shown one month following the Kobe earthquake in Japan (January 1995), with sperm motility recovering two to nine months after the event (Fukuda et al., 1996).

Factors that influence sperm quality and M/F are complex. Mild stress appears to have overall positive effects on sperm characteristics (Poland et al., 1986). However, high levels of stress negatively influence sperm quality. Stress has been shown to increase prolactin production (Gerhard et al., 1992) and decrease serum testosterone levels (Francis, 1981), and both hormonal changes may interfere with spermatogenesis.

These findings are reinforced by studies demonstrating that soldiers have a lower urinary excretion of testosterone, androsterone, and etiocholanolone prior to combat (Rose et al., 1969). Furthermore, in the early and more stressful part of officer training, plasma testosterone was shown to be suppressed when compared with levels in the later and less stressful part of the course (Kreuz et al., 1972).

Semen volume and normal sperm morphology have been shown to be negatively correlated with levels of psychological stress and low adaptability to stress (Giblin et al., 1988). Work related stress along with stress related to family dynamics or those at the workplace have also been associated with lower sperm morphology and vitality (Gerhard et al., 1992).

Furthermore, it has already been pointed out that stress may reduce the frequency of sexual activity. Since it has also been shown that sexual abstinence may result in a higher proportion of X-bearing sperm (Hilsenrath et al., 1997), all of these factors further predispose to female conceptions.

Overall, sperm motility appears to be the factor most affected by stress (Bigelow et al., 1998). For example, in infertile couples undergoing *in vitro* fertilisation, sperm motility declined at the time of oocyte retrieval, ostensibly due to the perception of the importance of producing an adequate semen sample for the fertilisation process

(Clarke et al., 1999).

All of this is compounded by studies that show that sperm motility is secularly progressively decreasing. For example, sperm volume, concentration, count and total sperm motility was unchanged for the period 1988 to 1996, while rapid progressive sperm motility decreased by a mean of 0.95% per annum (Zorn et al., 1999).

12 Other man-made stress

The reunification of Germany in 1990 resulted in the temporary economic collapse of the East German region in 1991, and this was associated with a significant decline in M/F (Catalano, 2003).

The unemployment rate was specifically used as a surrogate for ambient economic stressors less extreme than collapsing national economies, and was also shown to induce an excess of male fetal deaths (Catalano et al., 2005).

13 Miscellaneous parental influences

M/F is decreased in mothers with anorexia nervosa and bulimia nervosa, while binge eating disorders increased M/F (Bulik et al., 2008).

It was indirectly shown as far back as 1932 that male preference was associated with increased M/F (Winston, 1932). This was confirmed by the fact that in response to the question "what sex for the neonate do you prefer" a significant correlation was found between sex preference and the gender of newborn (Emamghorashi et al., 2011).

Handedness also affects M/F. M/F is lower in the offspring of left-handed parents than in that of right-handed people (James, 1986a). Parental attractiveness has also been shown to be negatively correlated with M/F (Kanazawa, 2007).

Two-parent care has also been shown to increase M/F, a finding that was first noted in 1874 (Darwin, 1874). Moreover, in polygynous arrangements, when co-wives co-habit in a harem, M/F is increased whereas when co-wives have separate dwellings and are visiting by their husband, M/F is reduced (James, 1995).

Time to achieve pregnancy also influences pregnancy. A longer interval to achieve a pregnancy increases M/F, and this is in accordance with the hypothesis that poorly penetrable cervical mucus reduces fertility and increases the chance of a smaller and faster Y-bearing sperm achieving conception (Smith et al., 2005).

14 Seasonal variation

Cold weather is an environmental stressor, acting directly on those who do not have adequate access to shelter. Such conditions also influence indirectly, stressing

populations by disrupting economies (Catalano et al., 2008).

It has also been shown that cold weather exacerbates the effect of other stressors, particularly in unseasonably cold summer months, since such conditions mitigate against restorative behaviours (Catalano et al., 2008). According to the Trivers-Willard hypothesis, both direct and indirect mechanisms may cause pregnant females to abort frail male fetuses, lowering M/F. Indeed, European data for the period 1865-2003 shows an increase in M/F in warm years (Helle et al., 2009).

More cogently, a study of the Sami people (the only indigenous Scandinavian race) showed that a 1°C increase in mean temperature yielded 1% more sons annually (Helle et al., 2008). Interestingly, in this same population, annual mean temperature and birth rate seem unrelated (Helle and Helama, 2007).

Temperature influences on M/F may have long-term effects. It has been shown not only that M/F is influenced by ambient temperature, but also that males from cold-stressed cohorts who have experienced cold weather *in-utero* could have, on average, longer life expectancies. This has been calculated as an average decrease in male life-span by 14 days per 1°C increase from one year to the next among those who survived to one year of age (Catalano et al., 2008).

15 Environmental toxins and occupations

A plethora of environmental toxins have been implicated as affecting M/F with parental exposure, but only a representative sample will be outlined hereunder.

Decreasing M/F The industrial accident that occurred in Seveso (Italy) in 1976 exposed a large population to dioxin (2,3,7,8-tetrachlorodibenzo-p-dioxin), widely considered the most toxic man-made substance. Among many other local effects (Bertazzi et al., 1998), M/F declined significantly with paternal exposure, even in births in 1996 (Mocarelli et al., 1996), in a dose-effect relationship (Mocarelli et al., 2000).

Polychlorinated biphenyl (PCB) compounds (banned in 2001) were widely used as coolant fluids and dielectrics in industry prior to this time. The parental consumption of PCB contaminated rice oil (del Rio Gomez et al., 2002) and the maternal consumption of contaminated fish (Weisskopf et al., 2003) has been shown to decrease M/F.

Pesticide exposure has similar effects, including the paternal exposure to the nematocide 1,2-Dibromo-3-chloropropane (Goldsmith, 1997), pesticide applicators (Garry et al., 2003) and hexachlorobenzene (Jarrel, 2002). It has been speculated that these effects may be

hormonally induced (James, 1987b). For example, it has been shown that exposure to the above nematocide increases paternal gonadotrophin levels (Whorton et al., 1979), which would in turn lower M/F.

Methylmercury contamination of Minemata bay in Japan in 1955 to 1959 and the resultant maternal exposure to contaminated fish was also shown to reduce M/F (Sakamoto et al., 2001)

Parental exposure to air pollution from incinerators (Williams et al., 1992) and cigarette smoking (Fukuda et al., 2002) also decreases M/F. Smoking reduces maternal oestrogen levels (MacMahon et al., 1982) and this has been attributed to lower M/F (James, 1987b). However, a more recent study showed that maternal smoking increased M/F, more so in primiparous mothers (Beratis et al., 2008).

The paternal exposure to chemicals in the carbon typesetting occupation (Milham, 1993); the maternal exposure to clomiphene citrate in infertility treatment (Jarrel, 2002); the paternal exposure to high voltages and the maternal exposure to non-ionising radiation (James, 1997) have all been implicated as decreasing M/F. Males in these occupations have been shown to have low testosterone levels (Grajewski et al., 2000), and it has been speculated that the latter may cause the former (James, 2004).

Male exposure to lead, alcohol (Dickinson and Parker, 1994), boron (Chang et al., 2006), vinclozolin (James, 1997), dibromochloropropane (Potasjnik and Yanai-Inbar, 1987), non-Hodgkin's lymphoma (Olsson and Brandt, 1982), children of men who later go on to contract prostatic cancer (Hill et al., 1985) and the development of insulin-dependent diabetes mellitus (Rjasanowski et al., 1998) have all been shown to decrease M/F.

These factors would all seem to suggest that industrially (or otherwise) contaminated environments reduce M/F. Indeed, in Japan, the male/female ratio of fetal deaths (after 12 weeks) was reported to be increasing from the 1970s: this trend suggests a particular prenatal vulnerability of the male fetus in the face of adverse prenatal conditions (Mizuno, 2000).

However, in Finland a study over the period 1751 to 1997 has demonstrated that the decline in M/F preceded the onset of industrialization and the introduction of pesticides and hormonal drugs (Vartiainen et al., 1999).

HLA markers may also affect M/F. It has been shown that men with rheumatoid arthritis and HLA B15 had the lowest M/F (Astolfi et al., 2001) and the lowest testosterone levels (Ollier et al., 1988), and it has been speculated that the latter may mediate the former (James, 2004).

Certain occupations may also affect M/F. Male

drivers have been shown to have poor sperm quality and low testosterone levels and this has been linked with a low M/F (Dickinson and Parker, 1994). Divers also have low M/F (Rockert, 1977, Lyster, 1982) and they have also been shown to have lower testosterone levels (Rockert and Haglid, 1983). Similarly, pilots of high-performance aircraft and spacecraft also exhibit low M/F (Snyder, 1961) and low testosterone to gonadotrophin ratios (Strollo et al., 1998). It has been suggested that low M/F in all of these associations is related to low testosterone levels (James, 2004).

Increasing M/F An increase in M/F was noted in localities close to a steel foundry (Lloyd et al., 1984), close to natural gas (Saadat et al., 2002) and to the petrochemical industry (Yang et al., 2000).

The overall effect of a toxin is probably modulated by a number of factors, which include parental age at the time of exposure, the total level of exposure and whether the exposure was maternal or paternal (Mackenzie et al.,).

Exposure to ionising radiation has been shown to elevate M/F. Radiation increases the incidence of lethal malformations, affecting female pregnancies more

than male pregnancies. Hence, when both parents are equally exposed, fertility decreases while skewing birth rate in favour of males (Scherb and Voigt, 2011).

16 Placental pathology

M/F is increased in pregnancies with abruptio placenta, placenta praevia, fatty liver and toxemia of pregnancy. On the other hand, M/F is decreased in pregnancies with placenta accreta and ectopic pregnancy.

A review of such placental pathology postulated that M/F deviations are caused by abnormal hormone concentrations periconceptually, which persist and are partially responsible for the abovementioned pathologies (James, 1995).

17 General temporal trends

Non-random, slight but highly statistically significant secular trends in M/F were first described in 1955 (Gini, 1955). Due to the non-trivial numbers usually invoked, relatively small changes, when appropriately tested, yield high significance levels. A large sample of the available reported national datasets are listed in table 1.

Table 1: Historical studies of secular trends in M/F.

(Chahnazarian, 1990)	Japan	1950-70	Increasing
(Schtickzelle, 1981)*	Belgium, Sweden, England and Wales	1900-90	Increasing
(Chahnazarian, 1990)	Taiwan	1945-90	Increasing
(Ulizzi, 1983; De Bartolo, 1985)	Italy	1930s-90	Increasing
(Chahnazarian, 1990)	England, Wales, US Caucasians, Japan	1970-90	Decreasing
(Aubenque, 1989)†	France	1800-90	Decreasing
(Chahnazarian, 1990)	Australia	1900s	No trend
(Chahnazarian, 1990)‡	Sweden	1750-00	Increasing
(Moeller, 1993)	Denmark	1951-95	Decreasing
(van der Pal-de Bruin et al., 1997)	Netherlands	1950-94	Decreasing
(Allan et al., 1997)	Canada	1930-90	Decreasing
(Allan et al., 1997)	USA	1970-90	Decreasing
(Feitosa and Krieger, 1992)	Uruguay, Chile, Argentina, Brazil, Bolivia, Peru, Paraguay, Ecuador, Venezuela, Colombia, and Costa Rica	1967-86	Decreasing
(Imaizumi and Murata, 1981)	Japan	1900-78	Increasing
(Ulizzi and Zonta, 1995)	Italy	1930-90	Increasing
(Vartiainen et al., 1999)	Finland	1751-20	Increasing
(Vartiainen et al., 1999)	Finland	1920-97	Decreasing

*This study also failed to find trends for Australia and the United States.

†This study showed that the variation noted was more closely associated with a variation in the male birth rate than in the female birth rate.

‡No trends for the period 1900-1990.

Overall, the most striking findings have been a decline in M/F over the second half of the 20th century in vari-

ous industrialised countries (Davis et al., 1998).

A few papers have reported aggregate country

datasets. The largest prior to this author's publications summarised secular trends in M/F five populations: United States Caucasians and Blacks, Australia, Japan and Taiwan during this 20th century and for a few countries (Sweden, France, England and Wales), for even longer periods (Chahnazarian, 1988).

However, a study from Malta was the first to identify secular trends using continent-wide data from a World Health Organization (WHO) dataset. Grech et al. studied secular trends in gender ratios for live births over the second half of the 20th century. These included 12,7034,732 North American and 15,7947,117 European live births.

This study showed a highly significant overall decline in male births in both Europe and North America ($p < 0.0001$), particularly in Mexico ($p < 0.0001$). Interestingly, in Europe, male births declined in North European countries (latitude > 40 degrees, $p < 0.0001$) while rising in Mediterranean countries (latitude congruent with 35-40 degrees, $p < 0.0001$). These trends produced an overall European male live birth deficit 238,693 and a North American deficit of 954,714 for the period under study (total male live birth deficit 1,193,407). This study concluded that there were no reasonable explanation/s for the observed, and the causes for these trends may well be multifactorial (Grech et al., 2003).

18 Latitude gradients in M/F

The same Maltese group were also the first to note a latitude gradient in M/F. Annual data was obtained for European countries from official WHO publications and manually input into a spreadsheet for the period 1990-1995.

European countries were banded by latitude. Southern countries (latitude 35 – 40°) included Bulgaria, Greece, Italy, Malta, Portugal, and Spain. Central Europe (40–55°) included Austria, Belgium, Czech Republic, France, Germany, Hungary, Ireland, Luxembourg, Netherlands, Poland, Romania, Switzerland, and the United Kingdom. Nordic countries ($> 55^\circ$) include Denmark, Finland, Iceland, Norway, and Sweden.

Analysis of European births showed a much higher ratio of male births in the south of Europe than in the north ($p < 0.0001$). At this stage, the authors speculated that M/F might be somehow influenced by a factor related to latitude, such as temperature (Grech et al., 2000).

The same authors acquired annual data on male and female live births from WHO for the North American continent for 1958-97 and for European countries for 1950-99 (courtesy of Mie Inoue from WHO). Overall less than 3% of data were missing.

European countries were banded as above (Grech et al., 2000). North America was divided by latitude

into Canada ($> 50^\circ$), the United States (30 – 50°), and Mexico ($< 30^\circ$).

Significantly, more boys were born in southern countries than in central Europe ($p < 0.0001$) or the Nordic countries ($p = 0.003$) countries (1950-99), confirming the first study (Grech et al., 2000). Trend analysis was highly significant ($p < 0.0001$). All had a M/F < 0.515 , with a resultant male birth deficit of 12744 in the Mediterranean, 212,780 in central Europe, and 13169 in the Nordic countries (a total deficit of male births 238,693).

However, the converse latitude gradient was evident in the North American continent. A low M/F was found in Mexico, a higher ratio in the United States, and an even higher ratio in Canada (trend analysis $p < 0.0001$). All had a M/F < 0.515 , with a resultant male birth deficit of 21,993 in Canada, 410,932 in the United States, and 521,789 in Mexico (total deficit 954,714). In the two continents, the total male birth deficit was 1,193,407 live births (for the years 1958-97).

In summary, in Europe, significantly more male babies were born in southern latitudes than in northern latitudes, whereas the reverse was found in North America. The authors were unable to explain these findings, which do not support a latitude related effect (Grech et al., 2002).

19 Conclusion

A veritable plethora of factors influence M/F in order to finally reach a value that approximates 0.515. It is therefore very true to say that “the persistent, exactly equal difference in this proportion at birth, and even its relatively small variations have provided food for thought for theologians, mathematicians, social scientists and biologists ever since the first calculations were made, even up to the present day” (Brain and Jaisson, 2007). Indeed, the factors that influence M/F are dynamic areas of research with over a thousand published papers to date. Doubtless, many more factors that influence M/F will be found through the utilisation of ever larger and pooled datasets with longer time frames.

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