WHY ARE MORE BOYS BORN THAN GIRLS?

Every year across the world, more boys are born than girls. This means that the sex ratio of boys:girls is greater than 1 – but why? There are many factors that affect the sex ratio throughout development, including biological and environmental factors. In my essay I study these factors from conception to birth to understand which are most significant. I also examine historical fluctuations in the sex ratio, which allows me to get more insight into the environmental factors. I found that the most significant differences occur during conception of the embryo, and not because of unequal foetal death during development. In particular, differences in the ability of X and Y sperm to fertilise eggs, and coital rate likely play important roles. I anticipate my findings to help understand natural sex selection and embryonic development, with potential applications in helping infertile couples conceive.

1. INTRODUCTION

Unknown to many, the ratio of male to female births each year is not 1:1. Worldwide, the sex ratio is around 105 male births for every 100 female births (Richie & Roser, 2019) and, since records began in 1838, more boys than girls have been born in England every single year. For example, in 2017 there were 348,071 male and 331,035 female live births in England and Wales (BBC, 2018). However, this is not just limited to humans, unequal sex ratios are also seen in many other animals, including most mammals (Clutton-Brock & Iason, 1986). This simple observation raises fundamental questions about the nature of sex, human development, and most interestingly, why and how does this inequality occur in nature?

FALLEN SOLDIER EFFECT

Many people will have of heard of the phenomenon called the fallen soldier effect, where an increased number of male babies were born after the ends of World War 1 (WW1) and WW2 (Figure 1). During this period, the sex ratio was >1.06 (UK government, 2023). However, this phenomenon is not limited to the World Wars and it has occurred multiple times in history when a country is in celebration – for example, in 1982 in England and Wales after the birth of Prince William, and in South Africa after their football World Cup success in 2010 (James & Grech, 2018). Furthermore, the opposite has also been seen and in times of extreme hardship the sex ratio falls, so that it is almost 1:1. A study (Schacht et al., 2019) conducted in Utah from 1918-1939 showed that 51.90% of babies born were male over the entire period. However, during the Spanish flu the proportion dropped to 51.12%, and during the Great Depression to 51.19%. In the joy of the "roaring 20s", it increased to 53.10%. Although the variation in these numbers may seem small, it is by no means random as the sample sizes were very large, meaning that lots of additional male babies would have to be born to increase the sex ratio by only 1%. Evidence linking harsh economic and social times to a lower sex ratio and prosperous times to a higher sex ratio have been seen many times in many different studies.

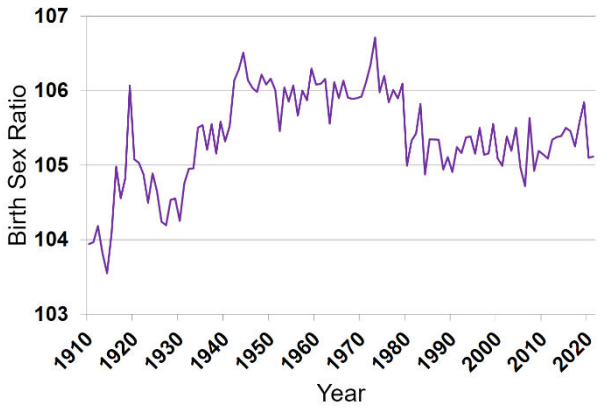


Figure 1 – the variation in birth sex ratio over time in England (UK government, 2023)

Two interesting questions can be asked about these data: Why does the sex ratio vary like this? Why is the baseline sex ratio not 50%? In my essay, I explore both of these questions through examining multiple lines of scientific evidence and in the context of existing hypotheses.

2. WHAT IS THE EVOLUTIONARY ADVANTAGE OF AN UNEQUAL SEX RATIO?

In general, traits evolve in biology through natural selection and evolution, and for this to happen, those traits must be advantageous to the species in some way. This raises the question of why humans would have evolved to have an unequal sex ratio at birth? Does it give us an advantage or is it a by-product of another biological mechanism?

TRIVERS-WILLARD HYPOTHESIS

The Trivers-Willard hypothesis (Trivers & Willard, 1973) is a proposed explanation for why there is variation in the sex ratio at birth. It is based on the idea that it is beneficial to maximise the number of grandchildren per woman, therefore maximising population size. A female of reproductive age will produce an average number of children, despite her condition. However, a male who is in 'fit' condition will produce far more children than a male in 'poor' condition. This is because, evolutionarily, males compete for female mates so a 'poor' male will simply be outcompeted. If it is assumed that the condition of the mother is the same as the condition the child will be in when of reproductive age, in order to maximise grandchildren, males are born to mothers in 'fit' condition, whereas females are born to mothers in 'poor' condition (Grech, 2022; James & Grech, 2018; Trivers & Willard, 1973).

As a consequence, in good times, more mothers will be in 'fit' condition and therefore will have more sons. Assuming the conditions are still good by the time the son is of reproductive age, the son will have more children than a daughter would have, as males have more children than females when both are in 'fit' conditions. On the other hand, in times of hardship, more mothers will be in 'poor' condition, meaning they have more daughters who, if times are still 'poor', will have more children than sons would.

The Trivers-Willard hypothesis would explain the fallen soldier effect as, after the wars, people were very happy, and times were generally good. Therefore, more mothers would be in 'fit' condition and so would have male children to maximise grandchildren. Furthermore, in the US, race is the biggest indicator of socio-economic status, with white Americans often being much wealthier than African Americans. A wealthy person is considered to be in better condition than a poorer person as they have lower stress levels and better access to healthcare. As expected by the Trivers-Willard hypothesis, the sex ratio at birth is lower for African American babies: 1.0162 compared with 1.0244 for white Americans (Grech, 2022). This shows the applicability of the hypothesis in multiple situations, providing support for its validity.

However, a number of studies have challenged the Trivers-Willard hypothesis and raised concerns regarding whether it provides an adequate explanation for the sex ratio. Firstly, the terms 'fit' and 'poor' are never properly defined, this is a big limitation of the theory as it leaves this important distinction open to interpretation. Furthermore, data were examined from 1749-1991 in Sweden (Wu, 2021) comparing stress and the sex ratio at birth. It would be expected that the sex ratio would be lower during stressful periods as more women would presumably be in 'poor' condition and would therefore have daughters. However, the link between the stress and sex ration was found to be 'weak or even non-existing', the opposite to what the hypothesis had predicted.

If this hypothesis is correct, it is completely unclear how the biological practicalities of such a system would be implemented. The mother's body would need to detect the sex of the foetus and reject some based upon their sex, but how the body knows to terminate or not is difficult to explain. Additionally, there is no known period from conception to birth when there is higher rate of female foetus loss compared to male foetuses (James & Grech, 2017). It is possible that that the foetus loss could occur extremely early on in pregnancy (in the first couple weeks) when it is too early to detect the loss, but this would also be very early for the mother's body to detect the sex as the foetus is simply a clump of cells. Overall, these issues raise questions about how the Trivers-Willard hypothesis would work in practice and therefore question its' validity. Also, the Trivers-Willard hypothesis doesn't address why the sex ratio is always above 1, as presumably it would predict that in average times the sex ratio would be 1. Additionally, in bad times, it would be beneficial for more female than male babies to be born as this would maximise grandchildren. However, a time with more female births has never occurred (BBC, 2018). Together, these points mean that there are likely some other factors influencing the sex ratio.

MALE DEATH LATER IN LIFE

Males are much more likely to die in childhood than females. Even today, per 1000 live births, 4.4 males die before adulthood, compared with 3.5 females (Wolfe et al., 2014). It has been argued that more males are born so, by age 25, the sex ratio is equal (Figure 2) (BBC, 2018; Humby, 2016). If the sex ratio at birth were equal, by reproductive age, there would be more women than men. There would be so many women that not all of them would be able to have a stable partner to assist with raising children, which could cause the child to suffer. In turn, this would decrease the total population size – which isn't good for a species, showing the benefits of an unequal sex ratio at birth. However, sex ratio is a factor that affects the entire population, rather than a trait that can evolve through 'survival of the fittest'. This means that it is hard to explain how this evolution would have occurred.

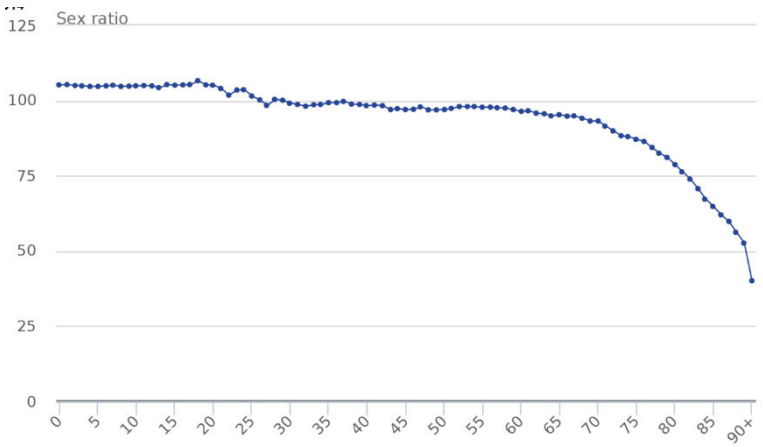


Figure 2 – the number of males per 100 females at different ages (Humby, 2016)

SUMMARY

Overall, neither the Trivers-Willard hypothesis nor male death later in life provides a convincing argument for why humans would have evolved to have an unequal birth sex ratio. Whilst both hypotheses provide a theoretical rationale, neither has scientific evidence to support their real-world application. In the next section, I discuss alternative biological mechanisms that could explain the unequal sex ratio.

3. HOW IS AN UNEQUAL SEX RATIO CREATED AND AT WHAT POINT DOES THIS OCCUR?

Regardless of the evolutionary reasons for an unequal sex ratio, there must be some mechanism for sex determination or sex selection of foetuses that creates an unequal sex ratio. It is well accepted that the sex ratio of sperm produced during meiosis is 1:1 (He et al., 2022), creating the question – at which stage of embryonic development is the sex ratio first unequal and how is this inequality created? I will go through the foetal life from conception to birth to try to gain insight into this.

X VS Y SPERM

During conception, the sperm enters the uterus, through the vagina, where it then needs to find and fertilise the egg. The first sperm to do this is the sperm that provides half of the foetal DNA, and therefore determines the sex of the foetus. Previously it had always been thought that the X and Y sperm had equal chances of fertilising the egg but, if the Y sperm had a small advantage, it could explain the difference in sex ratio as slightly more fertilised eggs would be male.

Whilst X and Y sperm are very similar, there are some structural differences. Due to the X chromosome being longer, X sperm carry 2.8% more DNA than Y sperm, causing them to have larger and longer heads in order to fit the extra genetic material (He et al., 2022). The impact of differences in head shape has not been studied so it cannot be excluded as a reason for the unequal sex ratio. The head of the sperm has to get inside the egg's outer casing by digesting it to fertilise the egg. A bigger head could mean that the X sperm have to make a slightly larger hole in order to fit, which takes a little more time and therefore gives the Y sperm a small advantage in the race to conception. A slight advantage for the Y sperm during fertilisation could be enough to shift the sex ratio.

Furthermore, Y sperm may be faster and so be able to reach the egg first. They have a higher expression of proteins involved in metabolism than X sperm (He et al., 2022). This means that they produce more ATP, which is crucial for powering movement. If the Y sperm have more ATP, they can likely contract their flagella more quickly, which would cause them to move faster (He et al., 2022). Although the first sperm to reach the egg is not always the sperm that fertilises it, it has an advantage (Sheikh, 2023), which could be enough to shift the sex ratio.

Another reason for differences in conception could be the survival of sperm within the uterus. X sperm are more robust – surviving better at lower pH and lower temperature (22 °C). However, in simulated in vitro extracts, Y sperm showed much better survival rates (He et al., 2022). Although X sperm are better adapted to a bigger range of conditions, in reality, no uterus will ever be under very extreme conditions as the variation of uterine conditions within the population is not very large. For example, having a uterus at 22 °C would mean that the core body temperature would have to be around 22 °C, which is too low for survival. As sperm take around 24 hours to fertilise an egg (Sheikh, 2023), being able to survive is important, suggesting that the fact that Y sperm are better adapted to uterine conditions could be the advantage that shifts the sex ratio.

Notably, a very interesting study (James & Grech, 2017) showed that the sex ratio in babies conceived by ICSI (intracytoplasmic sperm injection) is much lower than in IVF (in vitro fertilisation) babies. In ICSI, the sperm are injected directly into the egg, whereas in IVF the

sperm have to penetrate the egg themselves (University Hospitals Coventry & Warwickshire, n.d.). This suggests that the sperm reaching the egg and penetrating the egg outer casing is likely a source of differences within the sex ratio. It would explain why the sex ratio is not 50% as Y sperm could be slightly faster (due to higher ATP) and fertilise the egg more efficiently (due to smaller heads). Whilst it does not explain why the sex ratio varies, as X and Y sperm do not change due to certain events, differences between sperm are a very convincing reason for an unequal sex ratio.

COITAL RATE

In order for a woman to become pregnant, she must have sex with a man during her fertile window. During joyous times, people have more sex and more male babies are born. Although this is not necessarily causative, the correlation is too strong to not explore as an option.

A study (W.H., 2008) has shown that the probability of the zygote being male decreases linearly over the fertile period from 57% to 45%. It could be because of the luteal surge in the middle of the fertile window (Grech, 2022), but it is not clear how that changes the sex ratio. However, despite the reason why, the decrease in male babies over the period means that, as the coital rate increases the number of male babies increases. This is because women are having more sex so are more likely to get pregnant earlier in their fertile period (W.H., 2008) when the chance of a male baby is highest. This fits with the variation of sex ratio seen after important events. For example, after WW1 and WW2 people were celebrating the return of their loved ones and therefore the coital rate was higher, and so was the sex ratio. Additionally, with every year of marriage, the coital rate decreases and so does the sex ratio (James & Grech, 2018), further supporting the link between coital rate and sex ratio.

On a slightly different note, it has been proven (James & Grech, 2018) that sex increases testosterone levels in men and oestrogen levels in women. Also, a link between high testosterone/oestrogen levels and male births has been shown. This suggests that the variation of hormones caused by coital rate is partially responsible for the changing sex ratio.

Overall, coital rate is a good explanation for variation in the sex ratio, however the mechanism of why boys are more likely to be conceived at the start of the cycle or when there are higher hormone levels is unknown.

FETUS DEATH

Some studies (Orzack et al., 2015) claim that the sex ratio at conception is equal, however, this is a big point of contention within the field as no one has been able to prove whether or not this is true. If the sex ratio at conception is equal, more female foetuses must die during foetal development to shift the sex ratio.

A study (Jarvis, 2017) estimated that 40-60% of embryos die between conception and birth, mostly during the first 4 weeks as only an estimated 12-24% of babies alive at 4 weeks post gestation die before birth. However, accurate estimates for foetal death in the first couple weeks of pregnancy are difficult to obtain because most women don't notice they are pregnant until a missed period two weeks after conception (Jarvis, 2017). Furthermore, even if a woman does know she is pregnant, the foetus is too small to take a genetic sample safely. This means that

death in the first few weeks of pregnancy could be mostly female, which would cause the sex ratio at birth to be unequal. There is currently no way of collecting data to verify this hypothesis. In the future, circulating foetal DNA could be extracted from the mother's blood and tested to determine the sex as a small amount of foetal DNA ends up in the maternal blood even from very early on in the pregnancy (Lo, 2022). This technique is not widely used, especially very early in pregnancy, but advancements could make this possible in the future.

Chromosomal abnormalities are a common reason for foetal death, however only 3 chromosome pairs are affected by sex - chromosomes 15, 17 and the sex chromosomes themselves (Orzack et al., 2015). This means that chromosomal abnormalities that would affect one sex more than the other would have to occur on these chromosomes. However, abnormalities on these chromosomes are more common in male foetuses than female (Orzack et al., 2015), the opposite to what causes the shift in the sex ratio in the direction that is ultimately significant. Additionally, abnormalities on these chromosomes occur in less than 1% of foetuses, and most foetuses don't die from these abnormalities (Orzack et al., 2015). Therefore, chromosomal abnormalities aren't enough to shift the sex ratio in a significant way either direction and so can be excluded in relation to my question.

It is known that foetus death in late pregnancy is mostly male (Orzack et al., 2015). This slightly shifts the sex ratio the other direction but very few babies are affected so it has little impact across an entire population.

Overall, foetus death in very early pregnancy is a possible explanation for the shifted sex ratio but this cannot be verified with current technology and the reason for potentially more female foetus death is unknown.

FRAIL MALES

Whilst foetal death cannot explain why the baseline sex ratio is unequal, it could explain fluctuations. It has been shown that, for unknown reasons, male foetuses need a 10% higher daily energy intake compared to female foetuses (Grech, 2022). This means that in times of hardship, male foetuses will suffer more. As mothers face starvation and illness, the amount of energy that they can provide to their foetus decreases and, considering that males need more energy, the decrease will affect them more than female foetuses.

This has been seen during important historical events for example, the great Chinese famine from 1959-1961 caused the sex ratio to decrease drastically with far more female babies being born than normal (Schacht et al., 2019). As mothers starved, they could not give their foetuses the same nutrients and metabolic products as normal. This meant that, in general, more foetuses died, however male foetuses were more affected, causing the shift in the sex ratio. Although, it is worth noting that the sex ratio has never became female biased (BBC, 2018), which it should during hardship according to this theory. This suggests that, whilst the fragility of male foetuses may be a cause for changes in the sex ratio, it is not the reason that it is not normally 50%.

Additionally, poor conditions seem to need to occur over an extended period of time to have an impact on the sex ratio. For example, the Dutch hunger winter lasted a couple of months in 1944-1945 but had no impact on the sex ratio – this is likely because it was simply too short and

so didn't have the same effect on mothers and foetuses. This does not disprove the frail male theory as it is not unreasonable that the conditions have to be prolonged.

This theory fits with the finding that foetal death in late pregnancy is slightly more common for males. However, the number of babies that die at this stage, even in times of hardship, is not significant or in the relevant direction. This means that coital rate is a more convincing argument for why there are variations in the sex ratio.

INFANTICIDE

Across the world the sex ratio differs – in Asia, there is the highest sex ratio with >110 male babies per every 100 female (Richie & Roser, 2019). This huge disparity is thought to be because of infanticide – where the mother lets the foetus die through lack of nutrition – or sex selective abortion. Whilst this explains why the sex ratio in Asia is so high, it does not explain why the sex ratio is unequal in other countries; the UK government has said that 'analysis of birth ratios did not offer evidence of sex selection occurring in the UK' (Department of health, 2014). This means that there must be another factor that causes the baseline sex ratio to be unequal, even if sexism causes it to be more unequal in some countries.

GLUCOSE, MATERNAL AGE, GESTATION LENGTH

Finally, there are a few additional factors that affect sex ratio for unknown reasons.

High maternal glucose levels during pregnancy are associated with a higher sex ratio, with more sons being born (Schacht et al., 2019). This is because male foetuses cannot survive in low glucose environment. Although the reason for this is unknown, the increased metabolic needs of male foetuses is a possible explanation. The link between glucose and males is supported by the fact that women who develop gestational diabetes (and therefore have high glucose) often have sons. However, high levels of maternal stress have been shown to increase glucose levels, but also to decrease the sex ratio, with more females being born. This suggests the link between glucose levels and sex ratio is complex and there are other factors involved that warrant further investigation.

In an analysis of sex ratios in England and Wales by the government, it was found that the sex ratio does not vary by birth order – whether it is a first child, second child, etc (Department of health, 2014). However, a different study (James & Grech, 2017) suggested that, when looking over multiple countries, sex ratio does vary by birth order. This disagreement is likely because the studies were conducted over different scales, and, when you look worldwide, it becomes much more complex as purposeful foetal death, and poor records impact the data. Overall, it seems likely that birth order has no real impact on sex ratio, at least in England and Wales.

Maternal age, paternal age, race, and social class also all have a link to sex ratio with the most male babies being born to young, white, middle/upper class parents (James & Grech, 2017). The mechanism for this link is unknown, however, and these factors are less important as their effect is small compared with other factors.

4. CONCLUSIONS

LIMITATIONS OF REASEARCH

My research has been difficult due to the lack of knowledge of when the sex ratio becomes unequal. Knowing the sex ratio at the 20-week scan, when it is first available (NHS England, 2020), could be helpful, however, any foetal death after this is rare so it is highly likely that the sex ratio is already unequal at this stage. Therefore, being able to establish the gender of the baby as early as possible – preferably at conception – would be very important for solving my question. As discussed earlier, collecting foetal DNA from maternal blood could be the best way to investigate, but this approach is not yet standard.

IMPORTANCE

Understanding the unequal sex ratio could provide fundamental insights into reproduction and development. Furthermore, as we make scientific advancements that give us more control to select the characteristics of our babies, it is important to understand the mechanisms of natural sex selection. This could give us insight into the sex chromosomes and their role in foetal development as well as potentially helping infertile couples conceive (especially in cases of sex chromosome-linked problems).

CONCLUSION

In conclusion, there are many factors that could affect the baseline sex ratio throughout the time from conception to birth. The main debate within the field is whether the sex ratio at conception is equal. If the sex ratio is equal at this point, then female foetal death during development must cause it to become unequal by birth. If it is already unequal at this point, then it must be due to differences during conception, likely due to differences in X and Y sperm.

Overall, it seems that the baseline unequal sex ratio and fluctuations in the sex ratio are caused by different factors. Given the available evidence, it seems that the natural sex ratio is likely unequal from conception, due to differences in X and Y sperm. This is supported by the difference in sex ratios in ICSI and IVF. Fluctuations in the natural sex ratio are also best explained at conception, due to changing coital rates. This was particularly evident in the fallen soldier effect. More research into conception and early foetal development will provide more insight into these fundamental biological questions.

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