Historical sex ratio in fetal mortality in the United States and its impact on the sex ratio at birth*

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1. Introduction

Demographers and public health researchers have generally paid very little attention to historical trends in fetal mortality rates. They have shown greater interest in infant mortality as a more orthodox indicator of changes in human survival. Although fetal mortality is a very widespread healthcare problem and one of the most common adverse outcomes of pregnancy, it has not attracted the attention of historical public health researchers.

A stillbirth is a delivery after 20 completed weeks' gestation of a fetus showing no signs of life. Stillbirths generally fall into three categories: a) early preterm (20-27 weeks of gestation), b) late preterm (28-36 weeks), and c) those occurring at term (37 weeks or more). The National Center for Health Statistics (NCHS) of the United States recommends that stillbirths at over 20 weeks or with a weight of 350 grams or more (if the gestational age is not known) should be reported through the National Vital Statistics System.

As the years pass, stillbirths have come to account for an increasingly low percentage of all births (alive or dead), but their relative weight as a proportion of all perinatal deaths has risen. The sociological and healthcare implications of this phenomenon mean that the study of mortality in the fetal period is of great sociodemographic importance.

Most studies on fetal mortality in the United States have paid no attention to sex differences, nor have they provided a historical perspective, despite the crucial importance that the length of the study period has for secular trend analyses (Greulich 1931; Ciocco 1938; Teitze 1948; McMillen 1979; Hsieh *et al.* 1997; Ananth *et al.* 2005; Reddy *et al.* 2006; Davis *et al.* 2007; Willinger *et al.* 2009; MacDorman 2011; Rowland Hogue, Silver 2011; MacDorman *et al.* 2015; Gregory *et al.* 2021; Henry *et al.* 2021). Woods (2009, 76) and Schneider (2017) report a large amount of information on the fetal mortality rate in the 20th century, but they fail to address differences related to sex, race and geographical area.

However, we can find various studies that analyze differences in fetal mortality rates according to sex in different European countries (Ruiu *et al.* 2022; Bruckner *et al.* 2019; Fellman, Ericksson 2011; Fellman 2019; Rettaroli, Scalone 2021).

The woman's body is an essential element in human reproduction, and the stillbirth rate is an excellent indicator that can help us to gauge its capacity and

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vitality. Women's bodies reflect the material conditions and distribution of means of subsistence between the sexes, which means that the stillbirth rate can also serve as a potential indicator of inequalities between the sexes (Hart 1998, 215).

The aim of this research is not to examine the causes of the decline in the fetal mortality rate but to analyze the historical sex disparities in late fetal mortality in the two large racial groups that make up the United States population (White and Black)[1]. We have taken into account variables such as the mother's age, place of residence, marital status and socio-economic status, and the gestational age and birth order.

Several researchers have drawn attention to the practice of female-selective abortion among some immigrant groups in the United States (Egan *et al.* 2011; Nandi *et al.* 2015; Howell *et al.* 2018; Duan, Hicks 2020). The conclusions of these studies are based on the idea that the sex ratio at birth (SRB) is a constant biostatistical parameter of around 105-106 in societies where sex-selective abortion is not practiced. Nonetheless, other authors have challenged this conclusion and maintain that this rate fluctuates from time to time (Chahnazarian 1990; Jacobsen *et al.* 1999). For this reason, deeper knowledge of the factors that affect the SRB would be of vital importance. Many studies have analyzed the potential impact of socio-economic, biological, environmental and demographic factors, but so far the influence of fetal mortality has not been investigated in the United States. This is the other main aim of this paper. Some of the conclusions of these studies on sex-selective abortion could be questioned after detailed analysis of the effect of fetal deaths on the SRB.

In the present paper we focus on the sex differences in fetal mortality in the United States. The reasons underlying historical trends, and the racial differences associated with this phenomenon, will be discussed in another paper.

2. Sources

Over the last century, registration of fetal deaths in the United States was somewhat problematic. This is probably one of the reasons why there have been few studies on this demographic phenomenon. The first attempt at registration dates from 1922, but each state had its own rules. The gestational age from which stillbirths had to be registered varied from one state to another. In 1942, the registration of fetal deaths became mandatory, but the huge differences in regulations between states sheds doubt on the quality and consistency of the data (Woods 2009, 75)[2].

One of the most serious problems to be faced when studying fetal mortality over a historical period in any country is the large percentage of under-registration, particularly in rural areas where most births did not take place in hospitals. Even the most recent report by the Division of Vital Statistics of the United States draws attention to the different levels of detail when registering stillbirths in different states (Gregory *et al.* 2021, 2).

Although under-registration can affect comparisons over time and space, it is a less serious issue when the aim of the study is to analyze differences between sexes. We consider that it would be reasonable to assume that there is no sex bias in the registration of fetal deaths in the case of the United States. That is, the same percen-

tage of parents register male and female stillbirths. If this is the case (and we have no reasons to suppose that it is not), the under-registration of fetal deaths reported above would not be a hindrance to examining the sex imbalance.

In some countries, sex-related differences have been found in the birth register. For example, Blanes Llorens (2007, 63) estimates that there is an underreporting of births in the first decade of the 20th century in Spain of 3.1% of males and 7.3% of girls.

In historical times, parents probably had more interest in registering the birth of live male children. However, in the case of stillbirths, we believe that there was probably no particular motivation to register males but not females.

We obtained information about births and fetal deaths from the annual reports of the Vital Statistics of the United States. These reports are available for download at the National Center for Health Statistics Webpage: https://www.cdc.gov/nchs/products/vsus.htm. From 1968 onwards for births, and from 1982 for fetal deaths, we used the Birth and Fetal Death Data Files available at the Vital Statistics Online Data Portal: https://www.cdc.gov/nchs/data_access/vitalstatsonline.htm. For the period 1968-2019, we have 199 million birth registrations, and for the period 1982-2019 we have over 2.2 million stillbirth registrations.

A major limitation of this kind of research is the type of statistical analysis that can be carried out, owing to the restrictions imposed by the publications that provide the aggregated historical data. The various determinants of the sex ratio in fetal mortality are studied almost separately from one another. As far as the published historical data allow, we have tried to control for several variables at a time. Only from 1982 onwards, when the microdata became available on the National Center for Health Statistics Webpage, has it been possible to carry out more sophisticated analyses, controlling for a large number of determining factors at the same time.

3. Historical trends in fetal mortality in the United States

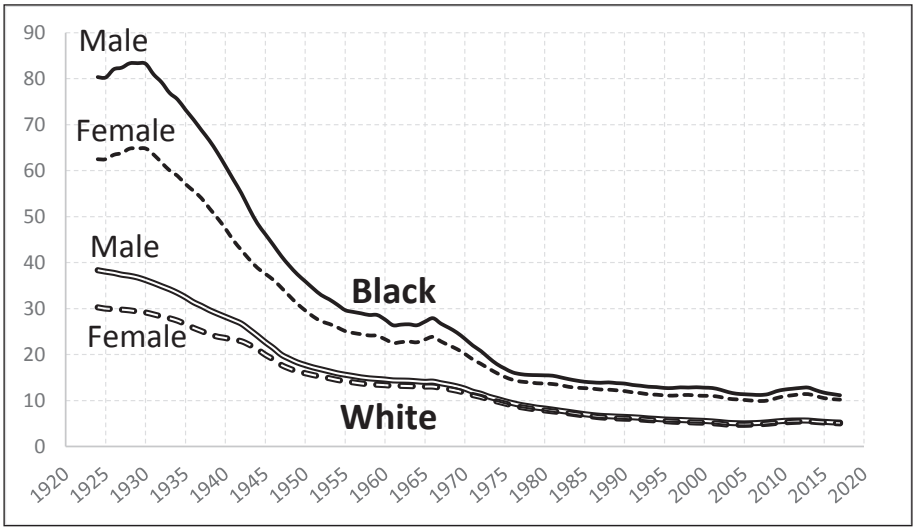
To analyze historical trends in fetal mortality we make use of the fetal death rate (FDR). This rate is calculated as follows:

$$\frac{Stillbirths\ (20 + weeks\ of\ gestation)}{Livebirths + Stillbirths\ (20 + weeks\ of\ gestation)}\ x\ 1{,}000$$

Figure 1 shows us the historical trends in the FDR in the United States for both sexes in the two racial groups analyzed. As it is not possible to classify stillbirths by sex and gestational age before 1945, the FDRs from before this year were calculated by including all the stillbirths registered, without factoring in the gestational age. From 1945 onwards we only took into account those occurring after at least 20 weeks of gestation. Nonetheless, the stillbirths registered at less than 20 weeks generally represent a lower percentage of the total reported. In the period 1922-1936, only 5.9% of those reported were at less than 5 months of gestation.

In the case of the Black population, we observe a constant decline in the FDR from the 1920s to 1975, with only a brief period of stabilization in 1955-1965. From 1975 onwards, this downward trend continued until the present day, but was much

Fig. 1. *Fetal death rate by sex and race in the USA (5-years-moving-average)*



Note: Before 1945, the figures include all stillbirths, regardless of gestational age. From 1945 only those after at least 20 weeks of gestation are included. In 1950-1978, the data from the Non White population groups are used instead of those for the Black population.

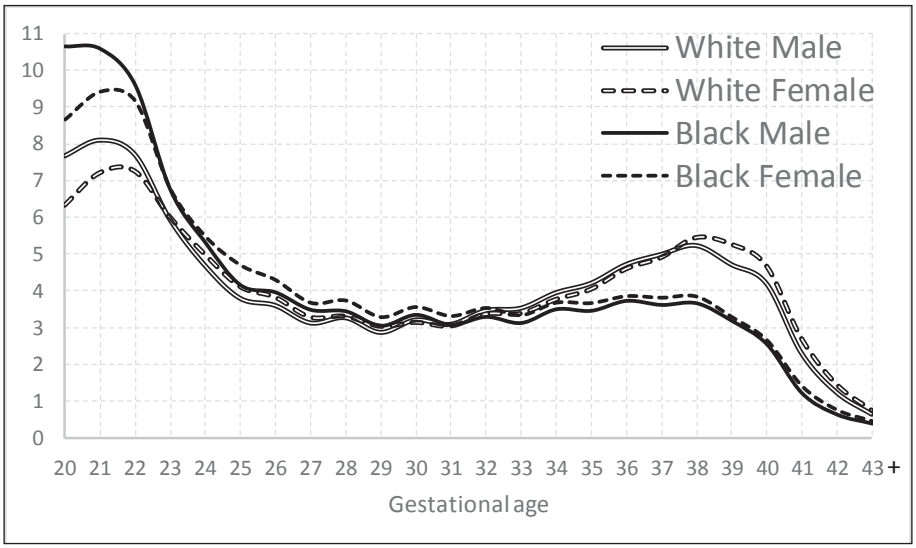
less steep. In the case of the White population, the historical decline has been less dramatic than in the case of the Black population, but has been steady since the 1920s.

Woods (2009, 82) assembles information on fetal mortality in several western countries and concludes that «all examples, regardless of registration conventions, have experienced dramatic decline, and in most cases there is some sign of a considerable turning-point in the late 1930s or during the 1940s […] there are differences of detail in terms of starting level and pace of change, especially in the 1940s and 1950s». The decline in fetal mortality in the United States probably began earlier than in other western countries, since there is evidence that it was already happening in the 1920s.

Figure 2 illustrates the percentage distribution of stillbirths of 20+ weeks of gestation classified by sex and race. We can see that the racial differences are more pronounced than the sex differences. The stillbirths at 20-24 weeks in the White population have a lower percentage weight than those in the Black population. On the other hand, the percentage weight at 34+ gestational weeks is notably higher among the White population. This indicates that stillbirths among the Black population are born at an earlier gestational age than those in the White population (this will be discussed in greater depth below).

The main difference between sexes can be observed in weeks 20-22. Male stillbirths in both racial groups account for more cases in these early weeks than females do.

Fig. 2. *Percent distribution of stillbirths by gestational age (in weeks), USA, 1982-2019*



4. Explanatory variables for fetal mortality inequalities by sex.

To measure the differences in fetal mortality by sex we computed the sex ratio of stillbirths (SRSB), which is calculated as follows:

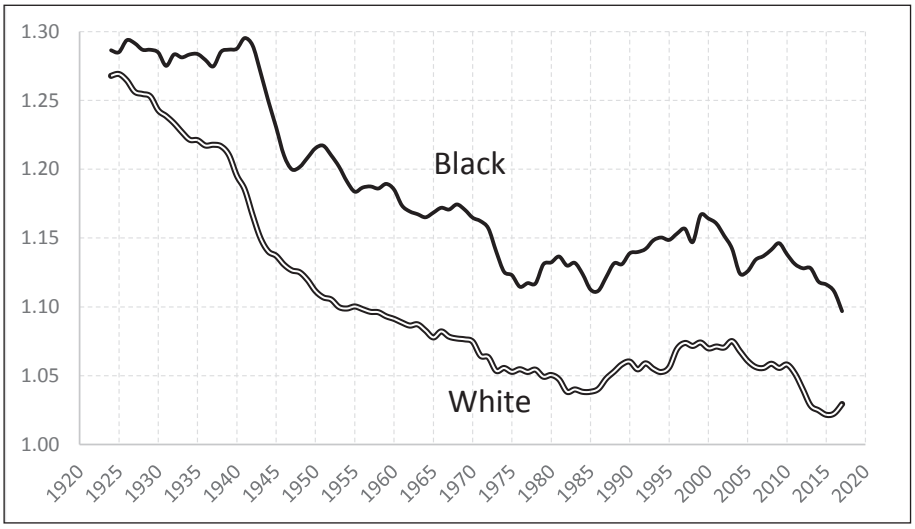
$$\frac{Male\ stillbirths\ (20 + weeks\ of\ gestation)}{Female\ stillbirths\ (20 + weeks\ of\ gestation)}\ x\ 100$$

We should recall that, as explained above, the historical under-registration of fetal deaths is irrelevant if our aim is to compare differences in fetal mortality between sexes, since we can assume that there was no sex bias in the United States as far as the reporting of stillbirths was concerned. The ratios showing the proportions of male and female stillbirths are therefore highly reliable when it comes to assessing fetal mortality by sex.

The first point to be emphasized is that, as the FDR declined (see Figure 1), the sex differences in fetal mortality also decreased (Figure 3). While in the 1920s the mortality for male fetuses was 26-28% higher than for females, in 2019 it hardly reached 3% (White) or 10% (Black). As time passed, there was a process of homogenization in fetal mortality as far as sex was concerned in both racial groups.

The sharp reduction in male fetal mortality that occurred in parallel to the decrease in the FDR is a phenomenon that has been detected in other western countries (Teitelbaum 1970; Rettaroli, Scalone 2021).

Fig. 3. *Sex ratio of fetal death rates by race (5-years-moving-average)*



Note: In the period 1950-1978, the data correspond to the Non White population rather than the Black population as such.

What factors account for the sex imbalance in fetal mortality in the United States?

4.1. Mother's age

Figure 4 shows us how the effect of the mother's age on the sex ratio of stillbirths (SRSB) has varied greatly over time and reveals a different pattern among the White and Black population.

For 1922-1936, we only have data for the population as a whole. During those years, the SRSB declined slightly as the mother's age rose. From 1942 onwards, we can calculate the rate by race, and the following points emerge:

a) In all age groups, there is a sharp decline as time passes (although the course of this downward tendency is more uneven for the Black population).
b) Values for the White population have always been lower than for the Non White population in all age groups. This is logical because, as we have already seen, the SRSB is always higher where fetal mortality is higher.
c) In the White population, the SRSB has been higher among mothers aged under 20 years; the rate declines sharply for mothers aged 20-24 years, then rises until the 35-39 age group. Values for mothers aged 40+ are slightly lower than for those aged 35-39.
d) The pattern observed for the Black population is slightly different from that described in the White population. The rate declines as the mother's age rises, but the drop in the groups aged 20-24 and 25-29 is not as marked as for their White counterparts even by the end of the study period.

It is very important to take into account the variations in the SRSB in relation to the mother's age, since the mean age of motherhood in the United States has risen continually over the last 50 years (Mathews and Hamilton 2002; 2016). Women are having children later in their lives. Whereas in 1968 the mean age at motherhood was 25.1 for the White population and 23.6 for the Black population, in 2019 the equivalent values were 29.2 and 28, respectively.

4.2. Gestational age

The trajectory of the human sex ratio from conception to birth has been poorly characterized. The first researchers to address this subject in the United States were Greulich (1931), Ciocco (1938) and Tietze (1948). Figure 5 shows how the sex differences in gestational age of stillbirths are slight (less than one week) in both racial groups. On average, female stillbirths are slightly more advanced in gestation than male ones. Although historical trends are very similar in both races and for both sexes, the differences increased from 1950 up to the 1980s. From then until now, they have declined.

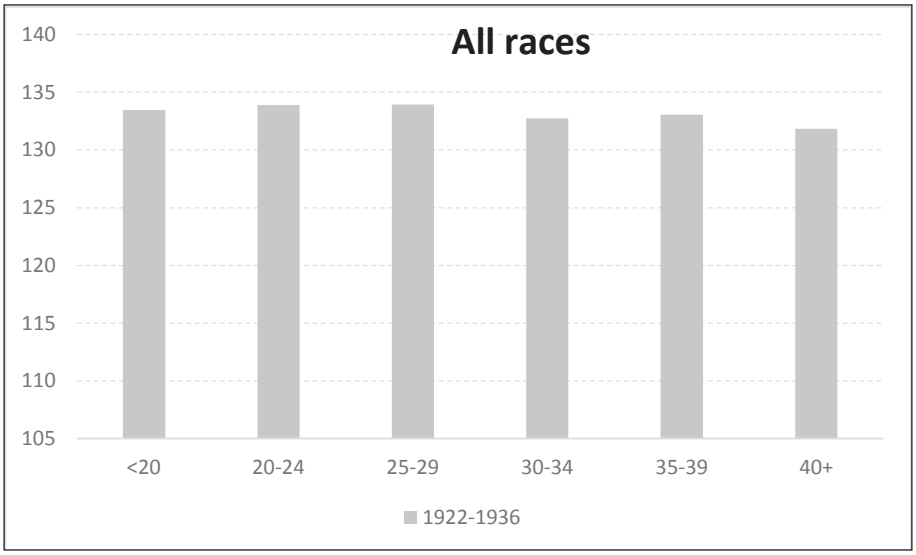
The SRSB by gestational age is shown in Figures 6, 7 and 8. Gestational age is expressed in months in Figure 6 because this is the only information available for the period 1922-1936. The figures suggest that in the first weeks of life there is a sharp increase until months 2-3 of gestation. In the period 1922-1936, for every female stillbirth at 2-3 months of gestation there were nearly 4 male stillbirths. In 1982-2019 (Figure 7), the male fetal hyper mortality reached a peak at 16 weeks of gestation. At this point, for every female stillbirth there were nearly 3 male ones. From week 16 onwards[3], the SRSB declined notably for both racial groups.

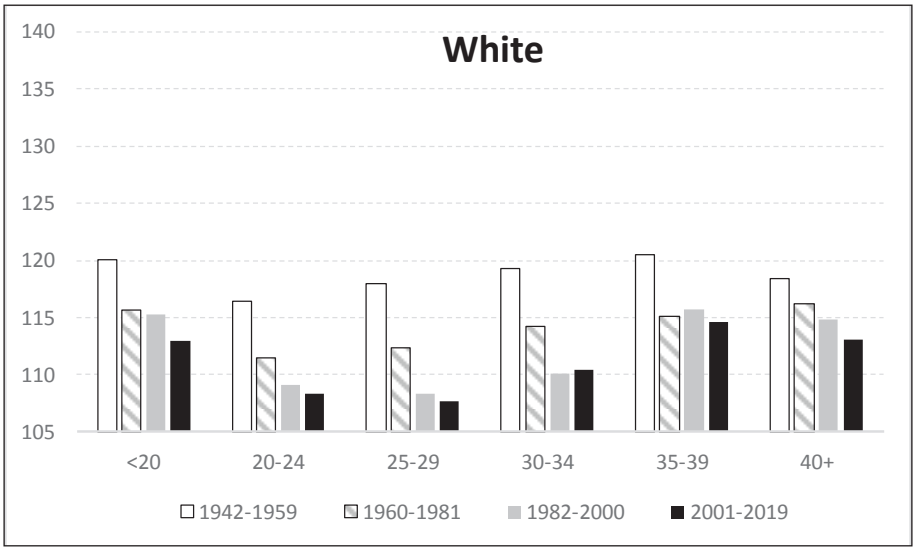
The major differences between the two racial groups come to light in week 36 of gestation in 1950-1981 and in weeks 37-39 in 1982-2019 (Figure 8). At these weeks of gestation, while the SRSB drops noticeably in the White population, it is stable or even increases in the Black population. In 1982-2019, it is important to stress that for the White group, from week 40 onwards, female stillbirths outnumber male ones. This is the first time such a trend has been documented in the US.

There is an interesting debate concerning the primary sex ratio, that is, the sex ratio at the time of fertilization. On one side we find experts who, by taking into account the sex ratio at birth (SRB) and the higher proportion of male stillbirths, estimate that the primary sex ratio ranges from as low as 107 to as high as 170 males to 100 female conceptions (McMillen 1979; Pergament *et al*. 2002). However, new estimates of selection in utero derived from a large dataset challenged this classical hypothesis. Orzack *et al*. (2015, E2102) assert that «the sex ratio at conception is unbiased […] and total female mortality during pregnancy exceeds total male mortality». According to these authors, mortality is higher for female fetuses than for male ones in the early stages of pregnancy.

In the case of the United States, the official statistics do not provide information about the SRSB during the first 7 weeks of pregnancy. From week 8 onwards, we have been able to show that mortality for males was much higher than for females (particularly between weeks 11 and 22). If the thesis of Orzack *et al*. that the sex ratio at conception is unbiased is true, this would imply that the mortality rates for

Fig. 4. *Sex ratio of stillbirths by mother's age, USA 1922-2019*

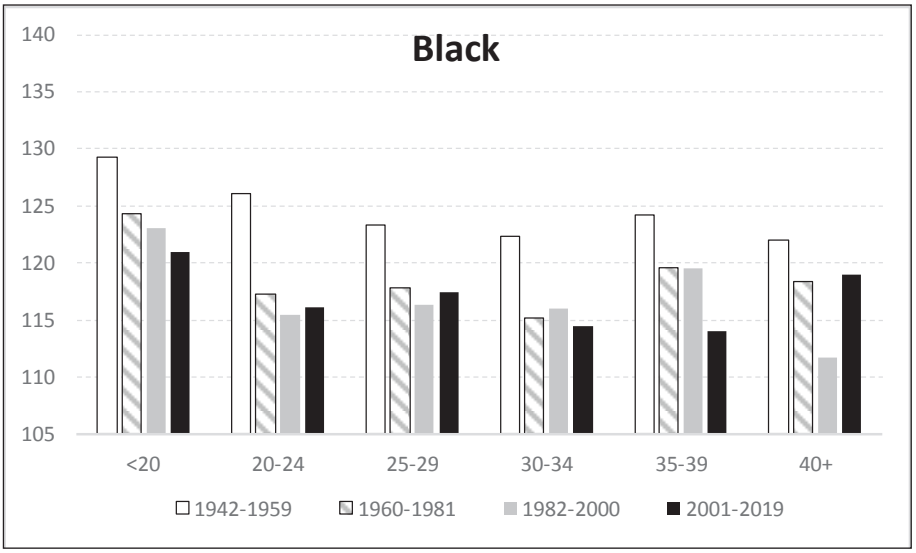




female fetuses in the first 7 weeks of gestation must be exceptionally high in comparison with that for males so that the sex ratio at birth could reach an approximate value of 105-106.

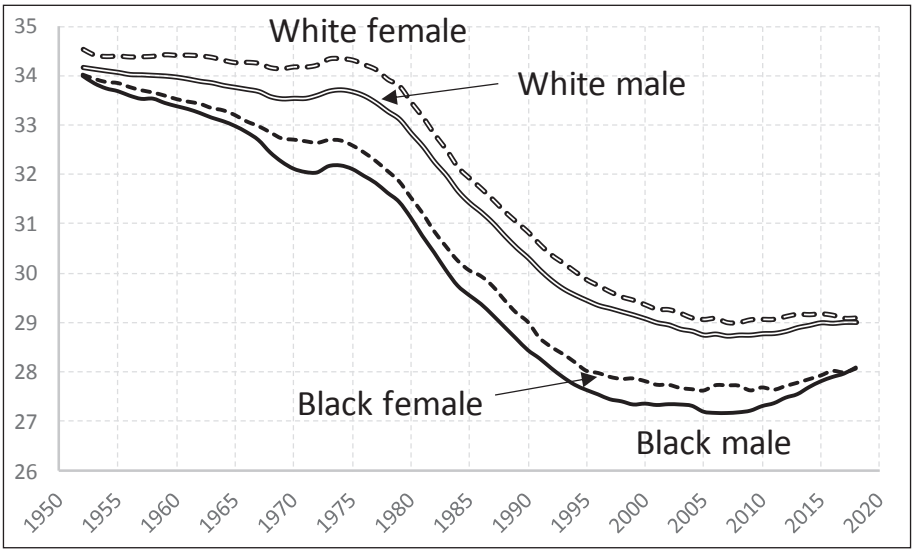
4.3. Birth weight

Figure 9 shows that, if we control for race, there is hardly any difference between sexes in the mean weight of stillbirths. The historical decline in this value seems



Note: From 1942 to 1981, the data are for the Non White rather than the Black population.

Fig. 5. *Trends in mean age of gestation (in weeks) of stillbirths (20+ weeks of gestation), USA (5-years-moving-average)*



Note: For the period 1950-1981, the data are for the Non White population, instead of the Black population as such. We had to estimate the mean gestational age during the period 1950-1981 since the available published data are grouped into different age categories. These are the mean ages that are used for each of the gestational age groups: 20-27 weeks (23.8), 28-31 (29.9), 32-35 (32.9), 36 (36.5), 37-39 (38.5), 40 (40.5), 41+ (41.9).

Fig. 6. *Sex ratio of stillbirths according to months of gestation (USA, 1922-1936)*

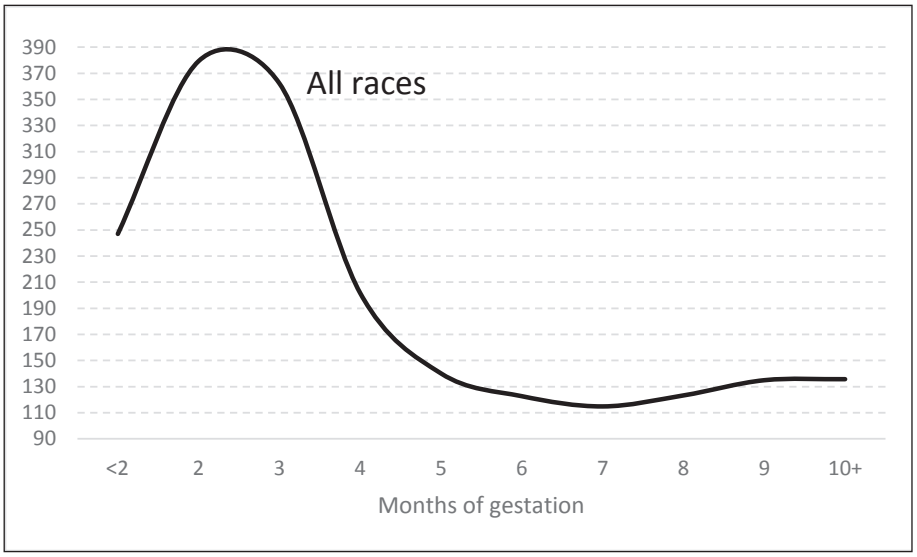
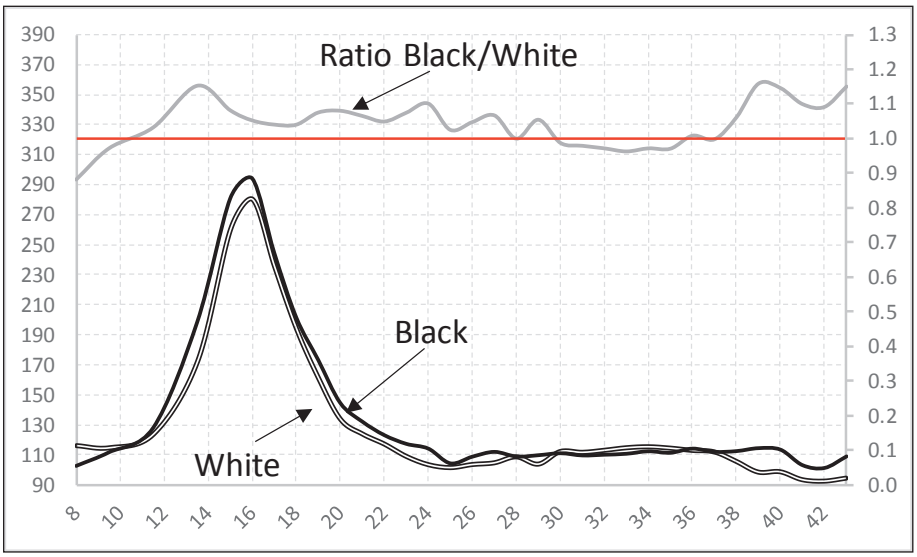


Fig. 7. *Sex ratio of stillbirths according to weeks of gestation (left axis) and Black/White ratio (right axis) (USA, 1982-2019)*

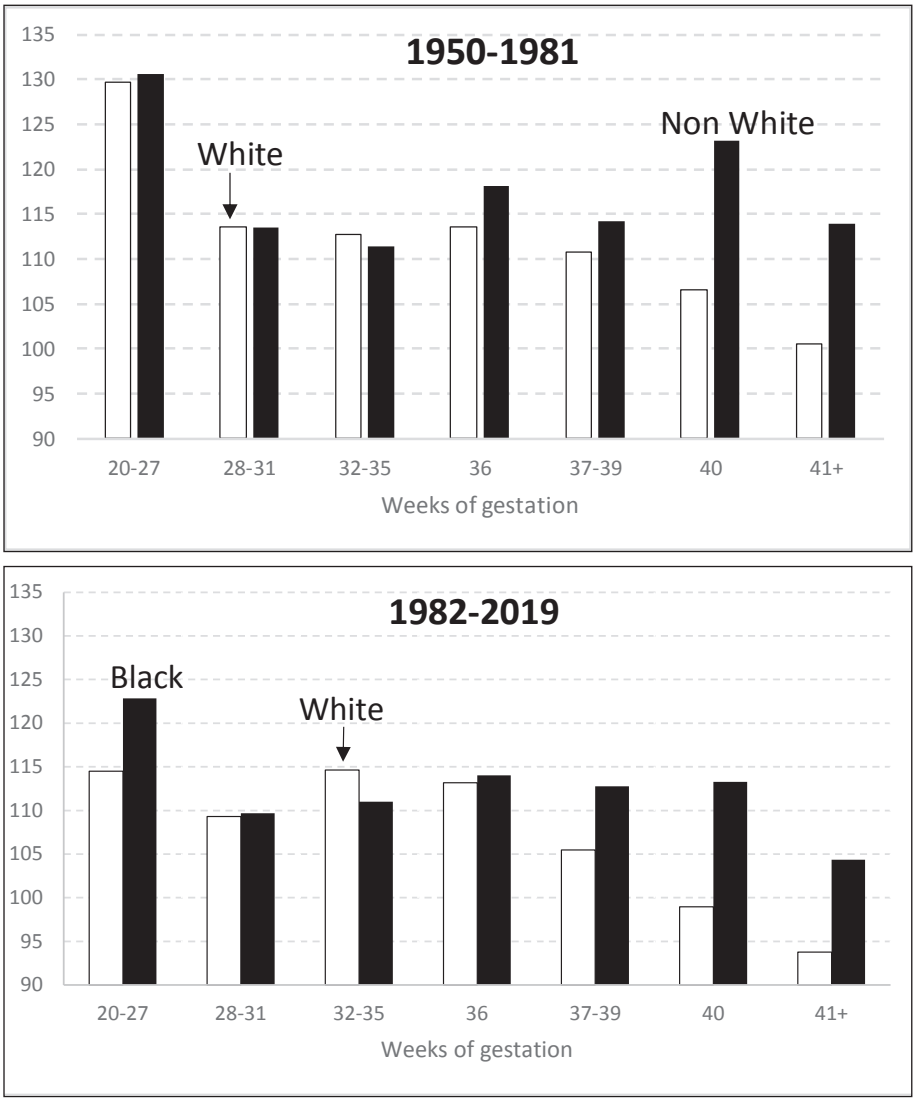


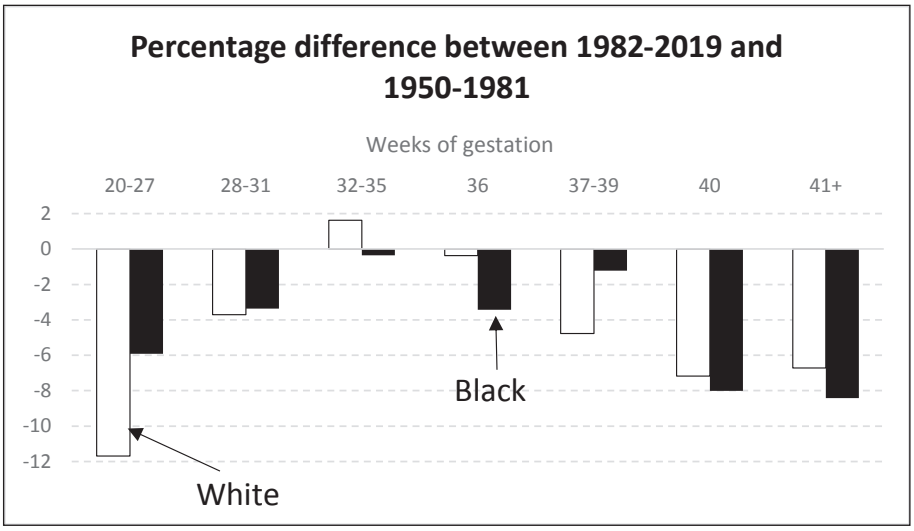
to have affected males and females to the same extent. Figure 10, however, draws our attention to certain differences in the mean birth weight of stillbirths according to sex after week 28 of gestation. These differences are perceptible in both racial groups. Live birth weight has consistently been shown to be higher

in boys than in girls (Kramer 1987). Everything suggests that there is a genetic basis for this, which means that males gain more weight than females during the fetal period.

Stillbirth rates began declining in several Western countries simultaneously at the beginning of the 1940s (Vallgårda 2010). The rates of overall, term, all preterm, very preterm and moderate-to-late preterm stillbirth decreased from 1982 to 2017 in the United States (Dongarwar *et al*. 2020). Sánchez-Barricarte and Sánchez-Arlegui

Fig. 8. *Sex ratio of stillbirths according to weeks of gestation, USA*





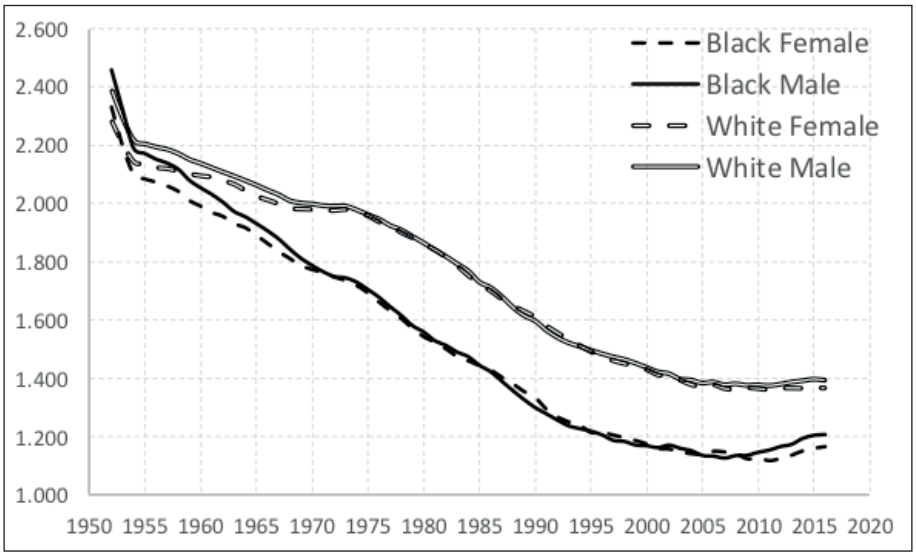
(2023) found a major relationship between developments in low birth weight and the decline in fetal mortality. They found that the surprising historical increase in the incidence of low birthweight in Spain can be explained by the improvement in fetal mortality rates. As more fetuses of lower gestational age are born alive, cases of low birthweight also increase. It is important to highlight those improvements in medical technology mean that we can save children at risk of stillbirth to a much greater extent than was possible in the past. Thus, it is not surprising that stillborn children are younger and lighter today than in the past.

4.4. Blood level of vitamin D

Various epidemiological studies suggest that male fetuses have more complications during pregnancy as a result of maternal inflammation (Goldenberg *et al.* 2006). The studies by Purdue-Smithe *et al.* (2019a; 2019b; 2021) suggest that vitamin D may mitigate maternal inflammation that would otherwise be detrimental to the implantation or survival of male conceptuses in utero. According to these researchers, «among women attempting to conceive, vitamin D sufficiency versus insufficiency during preconception is associated with higher probability of carrying and giving birth to a live-born male infant […] No associations were observed for vitamin D status and female live birth, suggesting that sufficient preconception levels of vitamin D may ameliorate an inflammatory process that is disproportionally harmful to male conceptuses» (Purdue-Smithe *et al.* 2021, 3).

Vitamin D is synthesized in the skin from cholesterol thanks to a chemical reaction that is naturally activated by type B ultraviolet light (UVB) from sunlight. According to the United States National Solar Radiation Data Base, the states in the South East and South receive the most Global Horizontal Irradiance (Senguptaa *et al*. 2018). To test for the potential influence of solar radiation intensity (and thus for

Fig. 9. *Mean birth weight in grams of stillbirths (20+ weeks of gestation) by race and sex, USA (5-years-moving-average)*



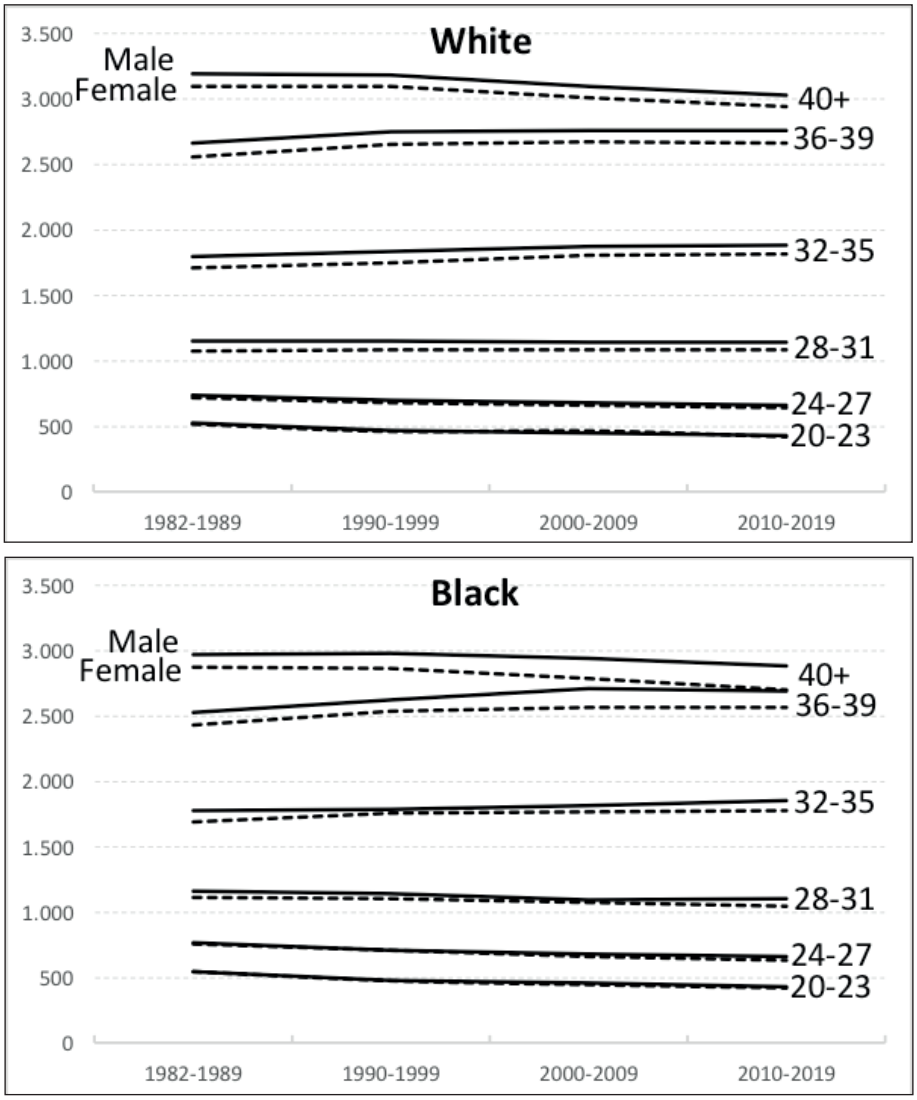
blood vitamin D levels) on the survival of male fetuses, we contrasted the figures for the two groups of states with lowest and highest solar irradiation:

1. Northern states: Alaska, Maine, Michigan, Minnesota, Montana, New Hampshire, New York, North Dakota, Pennsylvania, Vermont, Washington and Wisconsin.
2. Southern states: Arizona, California, Florida, Nevada, New Mexico and Utah.

Table 1 shows that over the last 100 years, the southern states with higher solar radiation (and where women of reproductive age can therefore be assumed to have higher vitamin D levels in the blood) do indeed have a much lower SRSB than the northern states. That is, solar irradiance seems to have a protective effect on the life of the fetus, and very specifically, the male fetus, as Purdue-Smithe *et al.* (2021) indicated. These north/south differences are particularly striking in the Black population. This can be explained by the fact that people with a dark skin tone require six times the amount of exposure to the sun needed by White people to generate the same amount of vitamin D. Adults with darker skin tend to have a higher prevalence of vitamin D insufficiency (Tangpricha *et al.* 2020).

Using the information gathered in the Fetal Death Data Files of the Vital Statistics, it is possible to calculate the SRSB from 1982 onwards in terms of the month prior to conception. It is important to use the month before, and not the month when conception occurred, because the mother's body requires several weeks of exposure in order for the levels of vitamin D in the bloodstream to

Fig. 10. *Mean birth weight in grams of stillbirths (20+ weeks of gestation) by sex, race and weeks of gestation, USA*



increase in response to solar irradiance. In Table 2 we can see that the male fetuses for whom the month prior to conception fell in the period May-August (the months with the highest solar irradiance across the whole of the United States) have a higher survival rate than those with pre-conception months in November-February.

Tab. 1. *Sex ratio of stillbirths (20+ weeks of gestation) by place of residence and mother's race, USA*

		1922-1930	*1982-1993*	*1994-2004*
White	South	110.6	107.4	110.3
	North	121.6	112.1	114.1
	Difference South - North	*-11.0*	*-4.7*	*-3.8*
Black	South	116.0	114.2	115.4
	North	136.3	119.5	126.1
	Difference South - North	*-20.3*	*-5.3*	*-10.7*

Note: The data for 1922-1930 also include stillbirths of under 20 weeks of gestation.

Tab. 2. *Sex ratio of stillbirths (20+ weeks of gestation) according to month prior to conception, USA 1982-2019*

	White	*Black*
May-August	110.33	116.49
November-February	111.23	117.7
Difference	*-0.9*	*-1.21*

Many experts are now alerting us to the increase in the percentage of people with vitamin D deficiency, not only in the United States, but across most of the world (van Schoor, Lips 2017; Lips *et al*. 2019; Irandoust *et al*. 2020; Tangpricha *et al*. 2020). This vitamin deficiency, which has become widespread over the last few decades, might have impacted on the survival of male fetuses, and could be one of the reasons why the sex ratio at birth has dropped in the United States population as a whole since 1945.

4.5. Maternal marital status

For some decades now, many obstetric researchers have pointed to the influence of maternal stress on fetal survival, and particularly, on the survival of male fetuses. Numerous studies have confirmed that natural abortions increase (particularly of male fetuses) when mothers are subject to various forms of stress (such as massive layoffs, terrorist attacks, wars, earthquakes, financial recessions, Ramadan fasting, famines, mother's employment situation, epidemics) (Ruckstuhl 2010; Catalano *et al.* 2012; Catalano *et al*. 2013; Grech 2018; Catalano 2021).

Cortisol is known to be the hormone responsible for stress, as our organism produces it in «emergency» situations so that we can confront problems that arise. Romero-González *et al.* (2021) found significant differences in maternal hair cortisol levels in the first trimester based on the sex of the baby they had given birth to: the concentration of the hormone was higher if the baby was a girl than if it was a boy.

It is reasonable to assume that unmarried pregnant women are subject to higher stress levels: they may well have more socioeconomic difficulties since the income of their family unit is lower, more of them are obliged to carry on working for most of the pregnancy, they have less help when it comes to carrying out everyday tasks as they do not have the support of a partner, etc. If this hypothesis is true, we would expect the SRSB among married women to be lower than that for their unmarried counterparts. The data presented in Table 3 would appear to confirm this hypothesis in both racial groups. These results are completely aligned with those observed in previous studies (Luo *et al.* 2004; Raatikainen *et al.* 2005).

Tab. 3. *Sex ratio of stillbirths (20+ weeks of gestation) according to mother's race and marital status, USA*

		1982-2000	*2001-2019*
White	Married	109.8	109.4
	Not married	113.6	113.6
	Difference	*-3.8*	*-4.2*
Black	Married	115.3	115.0
	Not married	118.1	117.3
	Difference	*-2.8*	*-2.3*

Since some women have their first child when single and then marry and have more children when they are older, it could be objected that the data shown in Table 3 might be distorted by the different ages of motherhood found among married and unmarried women. However, Table 4 shows us that, even when we control for the mother's age, in general, married women have a SRSB that is lower than that for unmarried women. Although ratios follow similar patterns for both races, non-married mothers (both races) in the first age-group (15-19 years old) record the highest of all ratios. However, the most distinctive point is for black married women between 25-29 years old, who present higher sex ratios than their un-married counterparts.

In recent years, there has been an increase in the number of couples in the United States that live together and have children without being legally married. It would be reasonable to think that when women in this situation become pregnant they have the same stress levels as married women, that is, that the differences observed in Tables 3 and 4 in the SRSB values would certainly be higher if we were able to classify women into the following two groups: women with the support of a stable partner and women without (regardless of whether they are married or not).

4.6. Birth order

Birth order is another factor to be taken into consideration when it comes to analyzing the SRSB (MacDorman 2011). Figure 11 shows that as time passes, the White population group has come to have a stable U-shaped pattern. That is, the

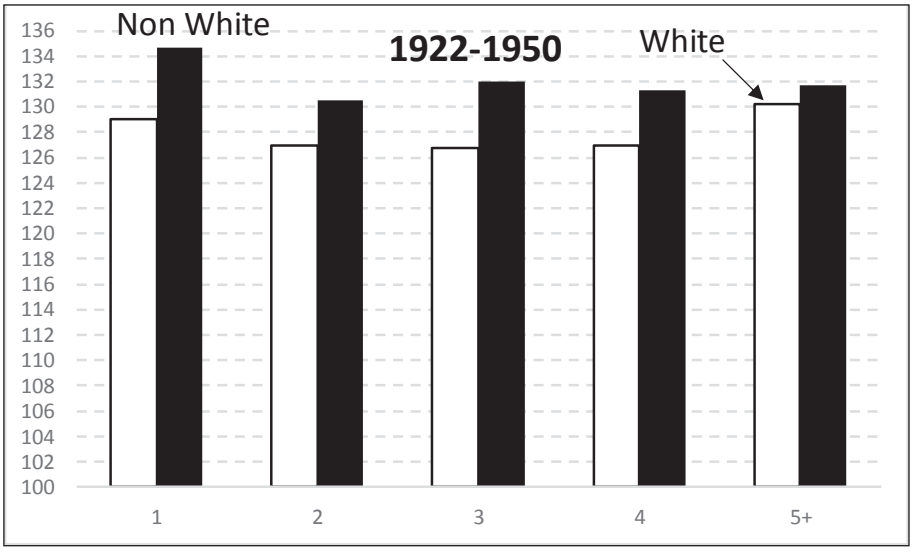
Tab. 4. *Sex ratio of stillbirths (20+ weeks of gestation) according to mother's race, age and marital status (USA, 1982-2004)*

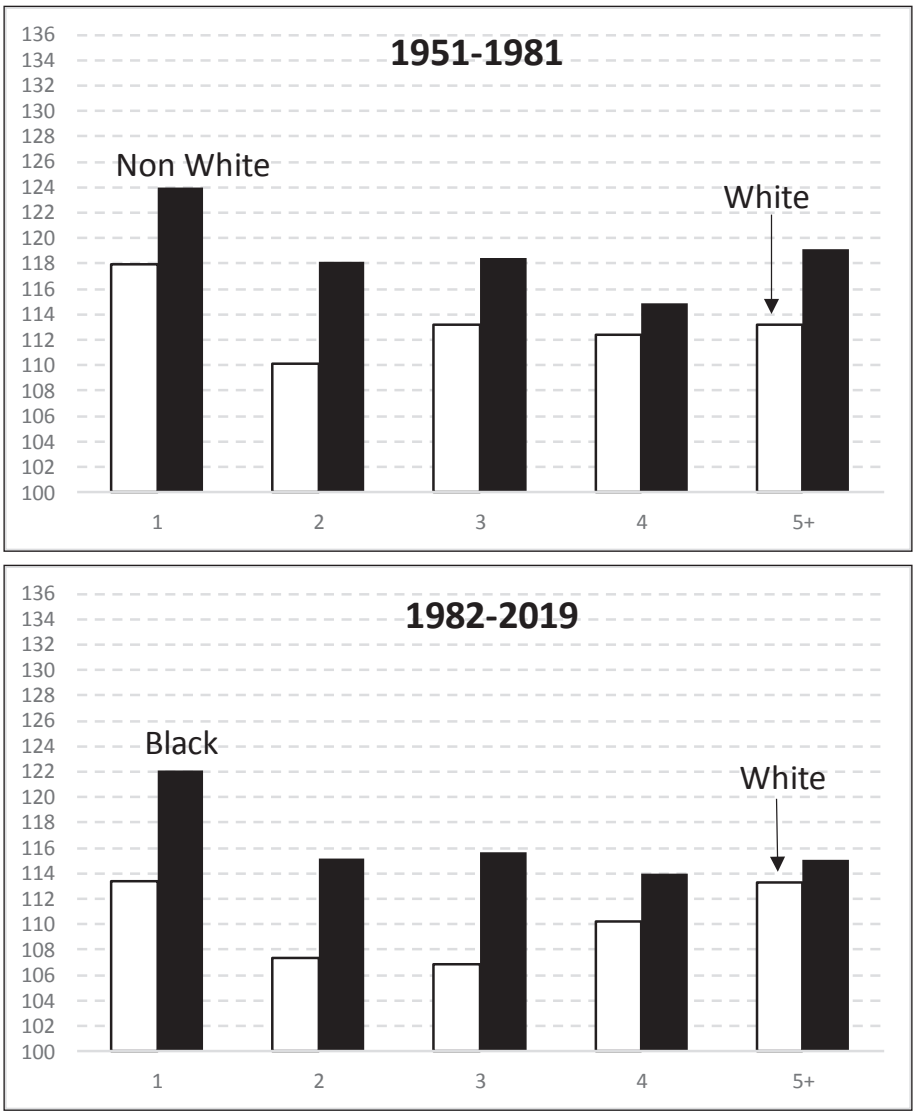
		15-19	*20-24*	*25-29*	*30-34*	*35+*	*All*
	Married	112.2	107.9	107	109.6	115.5	109.7
White	Not married	117	109.9	114.4	116.4	112.2	113.6
	Difference	*-4.8*	*-2.0*	*-7.4*	*-6.8*	*3.3*	*-3.9*
	Married	116.4	112.6	117.6	113.1	116.8	115.2
Black	Not married	123.6	115.5	114.9	116.8	117.0	117.8
	Difference	*-7.2*	*-2.9*	*2.7*	*-3.7*	*-0.2*	*-2.6*

SRSB is high for the firstborn, and then falls for subsequent births, only to rise again with the third or fourth pregnancy. The SRSB for the first pregnancy is highest in the Black population in all the periods analyzed since 1922, but no increases in the SRSB are found with the third pregnancy or beyond. In this population group there is thus no U-shaped pattern.

Nulliparity is known to be a risk factor for stillbirth (Henry *et al*. 2021). Some studies present the view that the odds ratio for nulliparous deliveries appears to be similar across racial groups (Willinger *et al*. 2009), but in Figure 11 we can observe that the sex ratio of nulliparous stillbirths has always been somewhat higher in the Black population than in the White, which casts doubt on the supposed similarity across racial groups.

Fig. 11. *Sex ratio of stillbirths (20+ weeks of gestation) according to race and birth order, USA 1982-2019*

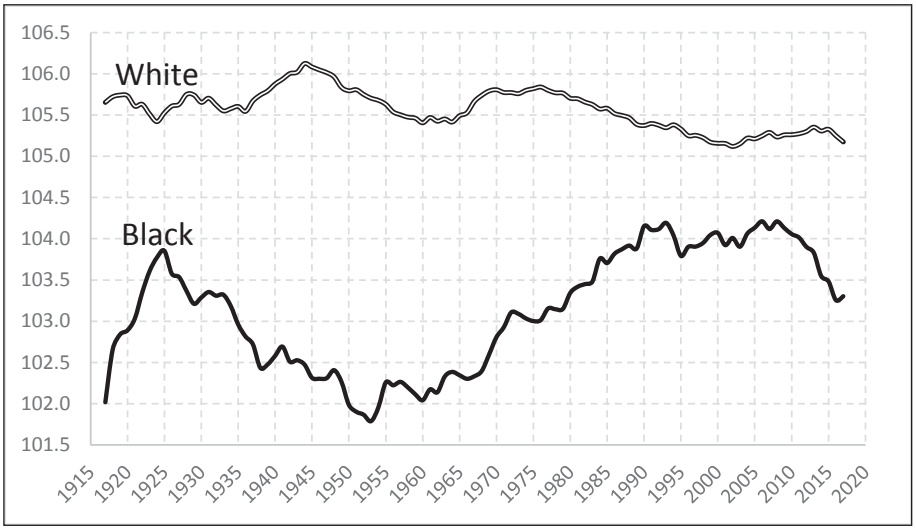




5. Impact of fetal mortality on the sex ratio at birth

The sex ratio at birth (SRB) is the relationship between the number of male and female infants born live, expressed as a percentage. Some authors consider that this ratio is constant at around 105-106 (Livi Bacci 1993; Caselli, Vallin 2001; Ein-Mor *et al*. 2010). On the basis of the supposed stability of this biostatistical parameter, many researchers have used it to detect or even estimate the number of sex-selective abortions (Bongaarts 2013; Guilmoto 2015). Several studies have made use of this parameter to censure this practice in certain immigrant communities in the United

Fig. 12. *Sex ratio at birth by race group in the USA (5-years-moving-average)*



Note: From 1978 for the White population, this shows the SRB of live newborns whose two parents are White Non-Hispanic. From 1968 for the Black population, this shows the SRB of live newborns whose two parents are Black.

States (Egan *et al.* 2011; Nandi *et al.* 2015; Howell *et al.* 2018; Duan, Hicks 2020). However, other researchers have challenged the idea that the SRB is constant and maintain that it fluctuates from time to time (Chahnazarian 1990; Jacobsen *et al.* 1999).

Figure 12 sheds light on the different trends in the SRB within the White and Black populations over the last 100 years in the United States. While the SRB in the White group has decreased slightly, that of the Black group has undergone major fluctuations (particularly the decline observed between 1920 and 1952 and the rise from the early 1950s until 1990).

Dozens of factors have been proposed as having an influence on the SRB: biological factors (e.g., aspects of sperm, women's hormone levels at the moment of conception, parental age, race, ethnicity), behavioral factors (e.g., coital frequency, stress level, smoking), environmental factors (e.g., solar irradiance, pollutants in the water supply) (James, Grech 2017; Chahnazarian 1988; Fellman 2019; Long *et al.* 2021). None of the factors analyzed to date in the United States has been sufficient to explain the striking fluctuations in SRB values among the Black population.

In several studies on European countries the historical decline in fetal mortality has been linked to the reduction in sex differences, which in turn resulted in an increase in the sex ratio at birth (SRB) (Fellman, Ericksson 2011; Fellman 2019; Rettaroli, Scalone 2021). Figure 13 provides a diagram of how the historical decline in the fetal death rate (FDR) could result in an increase in the SRB. It is important to take into account that this effect is limited to historical moments at which the

fetal mortality rate is high. Once the FDR values have been reduced and fetal deaths represent a very small percentage of all births (live and dead), the effect of the FDR on the SRB is marginal.

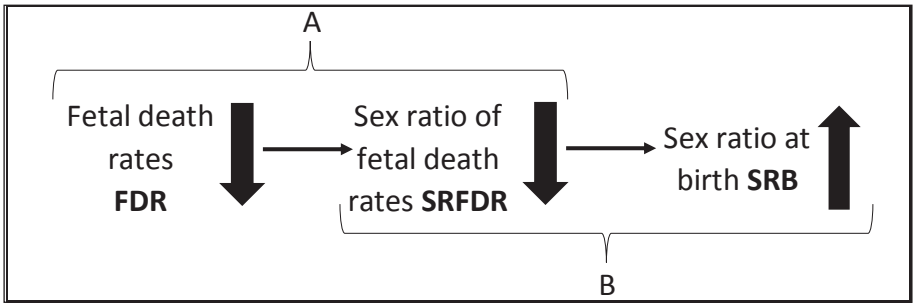
Figure 14 does indeed indicate that the decline in the fetal death rate (FDR) went hand in hand with a reduction in male hyper mortality, which is reflected in a pronounced decrease in the sex ratio of fetal death rate (SRFDR)[4]. This process whereby the fetal mortality rate reaches a similar level for both sexes can be observed in both the White and Black populations. This adjustment of the two variables is very noticeable until the point at which the FDR reaches very low values, around 1985, when the SRFDR fluctuates as a result of other variables. We can therefore state that our intuition is confirmed, and that relationship A represented in Figure 13 is borne out. The reasons why the SRFDR values in the Black population remained stable even though the FDR values declined notably during the period 1925-1940 are not known.

Did the decline in the SRFDR affect changes in the SRB? For the case of the Black population, we can safely associate the sharp increase in the SRB in the period from the early 1950s to 1990 with a drop in the SRFDR, as reflected in relationship B in Figure 13.

In the case of the White population, the decline in the SRFDR was not accompanied by the expected increase in the SRB. There are five possible explanations:

a. The first is that the historical fetal mortality rates in the White population have been much lower than those in the Black population, and that their effect on the
b. The second is related to the decline in fertility rates, particularly among the White population. As Figure 11 shows, the SRSB varies with birth order (it is highest for the firstborn). With the historical decline in the number of births among White women (which is steeper than for Black women), the SRSB for the firstborn takes on greater importance when it comes to influencing the SRB. Since more male fetuses die during the first pregnancy, the greater decline in total fertility rates among the White population could push down the sex ratio at birth.
c. Thirdly, we should take account of the fact that the above-mentioned delay in the mean age at motherhood affects the White population more than the Black. As Figure 4 shows, during the period 1942-2019, the SRSB increases from the 20-24 age group onwards. As the proportion of women giving birth at more advanced ages increases (implying higher SRSB rates), the values of the SRB are pushed down.
d. The fourth reason may have something to do with the changing ethnic composition of the White population. It is well known that the Hispanic population has increased enormously in the United States. In 1960 the Hispanic population accounted for 3.5% of the total population of the United States, but by 2020 it had risen to 18% (Flores 2017; Funk, Hugo López 2022). Before 1990, Hispanic deliveries were included in White or Non White and not separately reported. The vast majority of women of Hispanic origin is reported as White. MacDorman and Gregory (2015, 5) show that, at least since 1995, fetal mortality has been higher among the Hispanic population than for the White Non-Hispanic. It is quite possible that the growing proportional weight of people of

Fig. 13. *Outline of possible impact of historical evolution of fetal death rates on sex ratio at birth*



Hispanic origin within the White racial group explains why the sex ratio at birth failed to increase as the SRFDR values declined.

e. Finally, the growing percentage of United States population with vitamin D deficiency may also have brought down the SRB values among the White population.

So the fact that we observe no growth in the SRB among the White population does not necessarily invalidate relationship B in Figure 13.

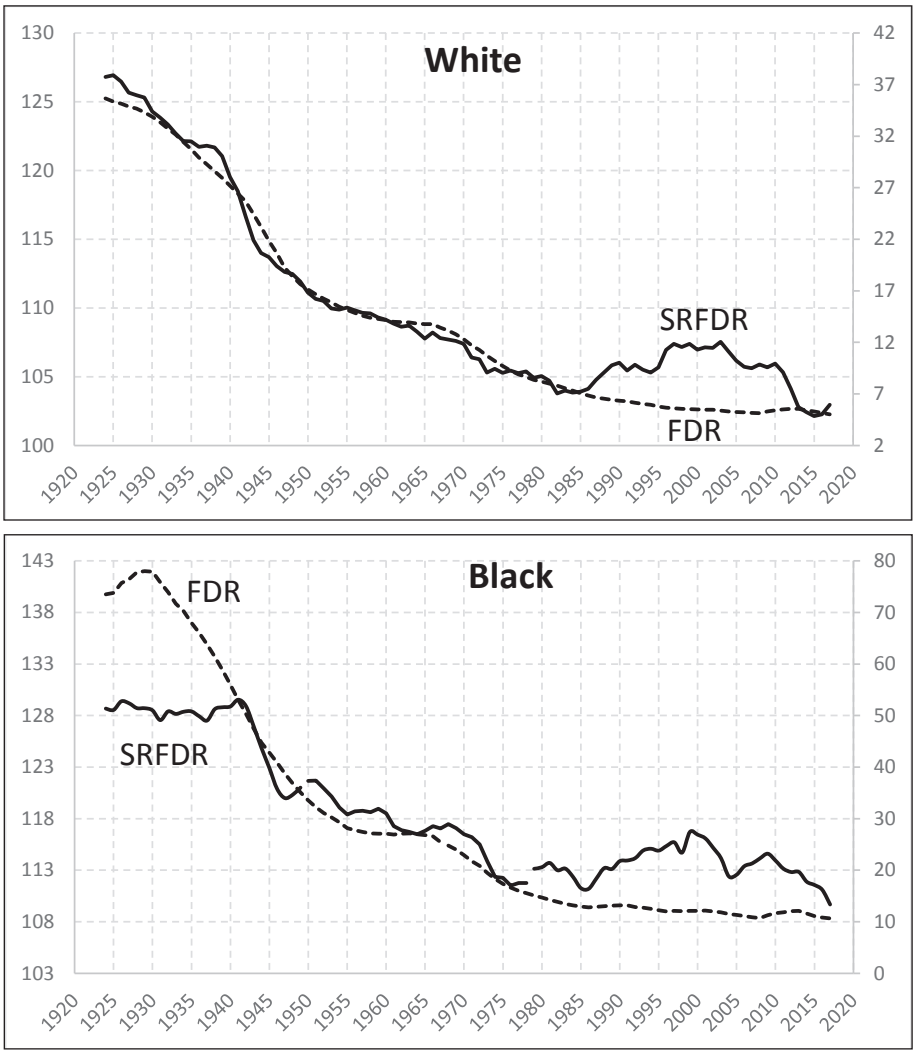
6. Conclusions

The limitations of the official statistics as regards under-registration have not prevented us from performing a detailed analysis of differences between the sexes in fetal mortality. We have been able to confirm that fetal mortality affects males more than females in both racial groups. Nonetheless, over time, male hyper mortality has decreased considerably, particularly among the White population.

We have analyzed variables that may influence the sex differences in fetal mortality: mother's age, gestational age, blood levels of vitamin D, maternal marital status and birth order. Although there appear to be certain differences between races, we have generally found that the older the mother, the greater the proportion of male fetuses that fail to survive. Male fetuses are particularly vulnerable in weeks 13-19 of gestation. At the same time, mothers who live in the south of the United States and therefore receive higher doses of solar radiation (and can thus be assumed to have higher blood levels of vitamin D) are less likely to lose their male fetus (particularly if they are Black).

The mother's stress levels have a major impact on fetal survival (particularly male fetal survival). We have analyzed the impact of maternal stress and have been able to show that the greater stress resulting from being unmarried leads to higher mortality among the weaker fetuses, that is, males. We have also confirmed that birth order influences survival in a sex-specific way: in the first pregnancy, males have a higher fetal mortality rate. In the White population, male fetuses in pregnancy 4+ also have higher mortality.

Fig. 14. *Sex ratio of fetal death ratio (SRFDR) (left axis) and fetal death ratio (FDR) (right axis) in the USA (5-years-moving-average)*



Note: For the FDR, the data up to 1968 are for the Non White population. For the SRFDR, the data for 1950-1978 are for the Non White population.

Lastly, we have provided evidence showing the important effect of the fetal mortality rate on the sex ratio at birth (SRB). We have confirmed that the surprising growth in the SRB values in the Black population registered from the mid-20th century until the 1990s can be attributed to the sharp decline in fetal mortality in this population group. Detailed analysis of the variables affecting sex differences in

fetal mortality has helped us to tease out the reasons why the sex ratio at birth in the White population has dropped slightly since 1945 instead of rising.

Disclosure statement
The author reports there are no competing interests to declare.

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[1] For the periods for which no data are available for the Black group, we have used the data for the Non-White group as a proxy variable. Historically speaking, the differences between the values for the Black population and those for the Non-White group are negligible, since the former account for a very high percentage of the latter. In the period 1922-1949, 97.3% of the Non-White stillbirths were Black . In the period 1979-2000, it was 88%. This information allows us to deduce that in the period 1950-1978 (for which we only have information on Non-White stillbirths) that percentage was also very high.

[2] Woods (2009, 74-75) discusses some possible limitations of the US official statistics: «Gestational ages of 4, 5, and 6 months were regularly used, although Indiana specified 'seven months and over' and Connecticut used 'not less than 28 weeks'. From the start there was a clear recognition that the race was an important factor, with fetal mortality apparently twice as high among the non-white compared to the white population […] The early published reports on US vital statistics also tended to combine the numbers of registered fetal deaths from states regardless of definition, to use the term 'stillbirth' to refer to fetal deaths regardless of gestational age, and to report fetal deaths per 100 live births as the stillbirth ratio».
For more details on the registration problem see Shapiro *et al*. (1965).

[3] In the United States, a miscarriage is defined as loss of a baby before the 20th week of pregnancy. Figure 7 shows all the fetal deaths at less than 20 weeks of gestation.

[4] The sex ratio of fetal death rate (SRFDR) is calculated as follows:

$$\frac{\textit{Male Fetal Death Rate}}{\textit{Female Fetal Death Rate}}$$

A value equal to 1 means that the FDR values in both sexes are the same. A value greater than 1 indicates that it is higher for males. And a value lower than 1 indicates that the mortality rate is higher for females.

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Summary

Historical sex ratio in fetal mortality in the United States and its impact on the sex ratio at birth
This paper presents a detailed historical study of several variables (mother's age, gestational age, blood level of vitamin D, maternal marital status and birth order) that may influence the sex ratio in fetal mortality in the United States. The analysis goes from 1922 to the present. We analyze the impact of each of these variables in two major racial groups (White and Black). We also provide evidence on how the historical decline in fetal mortality rates affected the sex ratio at birth, particularly among the Black population, confirming the results obtained in various European countries. The detailed analysis of the variables affecting sex disparities in fetal mortality helps us to understand why the sex ratio at birth developed differently in the White population.

Sommario

Trend storico nel rapporto di mortalità fetale per genere negli Stati Uniti e suo impatto sul rapporto tra sessi alla nascita
Il presente studio usa dati storici per analizzare dettagliatamente diversi fattori (età della madre, periodo gestazionale, livello ematico di vitamina D, stato civile della madre, ordine di nascita) che possono aver influito sul rapporto tra sessi nella mortalità fetale negli Stati Uniti. Il periodo storico considerato va dal 1922 ai giorni nostri. Tale analisi viene condotta anche distinguendo tra popolazione bianca e nera. Confermando risultati precedentemente ottenuti per alcuni paesi

europei, si mostra che il calo della mortalità fetale ha influito sul rapporto tra sessi alla nascita (in particolar modo per la popolazione nera). L'analisi condotta sulle variabili che influenzano le differenze di genere nella mortalità fetale aiuta anche a capire perché il rapporto tra sessi alla nascita nella popolazione bianca si sia evoluto in maniera differente.

Keywords
Stillbirth; fetal death rate; United States; vitamin D; sex inequalities; maternal age; gestational age; birth order; mother's stress level.

Parole chiave
Natimortalità; tasso di mortalità fetale; Stati Uniti; vitamina D; ineguaglianza tra sessi; età al parto; periodo gestazionale; ordine di nascita; stress materno.