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Educational attainment of same-sex and opposite-sex dizygotic twins: An individual-level pooled study of 19 twin cohorts

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ABSTRACT

Comparing twins from same- and opposite-sex pairs can provide information on potential sex differences in a variety of outcomes, including socioeconomic-related outcomes such as educational attainment. It has been suggested that this design can be applied to examine the putative role of intrauterine exposure to testosterone for educational attainment, but the evidence is still disputed. Thus, we established an international database of twin data from 11 countries with 88,290 individual dizygotic twins born over 100 years and tested for differences between twins from same- and opposite-sex dizygotic pairs in educational attainment. Effect sizes with 95% confidence intervals (CI) were estimated by linear regression models after adjusting for birth year and twin study cohort. In contrast to the hypothesis, no difference was found in women ($\beta = -0.05$ educational years, 95% CI -0.11, 0.02). However, men with a same-sex co-twin were slightly more educated than men having an opposite-sex co-twin ($\beta = 0.14$ educational years, 95% CI 0.07, 0.21). No consistent differences in effect sizes were found between individual twin study cohorts representing Europe, the USA, and Australia or over the cohorts born during the 20th century, during which period the sex differences in education reversed favoring women in the latest birth cohorts. Further, no interaction was found with maternal or paternal education. Our results contradict the hypothesis that there would be differences in the intrauterine testosterone levels between same-sex and opposite-sex female twins affecting education. Our findings in men may point to social dynamics within same-sex twin pairs that may benefit men in their educational careers.

1. Introduction

There are well-established sex differences in educational attainment. These differences have changed over the cohorts born during the 20th century: educational level was higher in men than in women in the cohorts born before the World War II, but thereafter the sex difference disappeared and then in the most recent cohorts women tend to be more educated than men (OECD, 2015). The twin study design offers a natural experiment, which can shed more light on the background of these sex differences in educational attainment. Differences in testosterone levels during fetal life can have permanent effects on brain development and behavior, which is demonstrated by more masculinized behavior of girls with congenital adrenal hyperplasia and also supported by a large body of evidence based on experimental studies of non-human mammals (Hines, 2020). Gonadal hormone transfer between fetuses has been suggested to lead to higher testosterone exposure of females with a male rather than a female co-twin (Ahrenfeldt et al., 2020). This is known as the Twin Testosterone Transfer (TTT) hypothesis suggesting that comparisons of same-sex (SS) and opposite-sex (OS) twins can inform the effects of prenatal testosterone exposure on psychological and behavioral traits, including educational attainment. However, even when the hormonal transfer between fetuses has been shown in other mammals, the direct evidence in humans is still lacking (Tapp et al., 2011). Postnatal factors, such as socialization, may also contribute to the differences between SS and OS pairs and are difficult to exclude in observational studies (Loehlin and Martin, 2000).

Some studies of SS and OS twins have supported the TTT hypothesis for cognition, whereas the evidence for other traits has been less consistent (Ahrenfeldt et al., 2020). There are a few previous studies testing the differences between OS and SS twin pairs in educational attainment. A Danish study did not find any differences between SS and OS twins in academic performance at 15–16 years of age, while the expected sex differences favoring males in mathematics and females in languages were found (Ahrenfeldt et al., 2015). A Swedish study found that both SS male and female twins had, on average, slightly better academic performance at the age of 15–16 years and a higher probability of university education as compared to their OS counterparts (Hjern et al., 2012). A study of Norwegian female twins found that those having a male co-twin had a higher rate of failing to graduate from high school or completing college as compared to SS female twins (Bütikofer et al., 2019). Thus, the previous evidence may suggest that twins from SS pairs, at least in females, have some academic advantage as compared to OS twins.

A drawback of these previous studies is that since they are based on register data, they were not able to make the distinction between same-sex dizygotic (SSDZ) twins and monozygotic (MZ) twins. This is a limitation because dizygotic (DZ) twins have, on average, slightly lower education than MZ twins (Silventoinen et al., 2017). Thus, pooling MZ and SSDZ twins may have biased the results of such studies. Further, all previous studies represented Nordic countries and included twins born in 1967 or later. Thus, it is not known how universal these findings are and whether the changing sex differences in education during the 20th century have affected these differences. To analyze this question in-depth, we conducted a large international study of twins. Our data cover 11 countries and birth cohorts over 100 years as well as information on parental education for sub-cohorts, permitting the analyses according to macro-level societal factors and family environment. We hypothesize that if the TTT hypothesis is correct for education (i) there should be differences between SSDZ and opposite-sex dizygotic (OSDZ) female twins in education; (ii) these differences should have changed over the birth cohorts when the sex difference in education reversed favoring women; and (iii) the education should be similar in SSDZ as OSDZ male twins.

2. Material and methods

The data were derived from the international CODATwins database targeted to gather together all twin cohorts in the world having information on height and weight (Silventoinen et al., 2015; Silventoinen et al., 2019). In this study, we analyzed those cohorts having additional information on one's own education at 25 years of age or older and including both SSDZ and OSDZ twins (at least 50 twins in each group). The original educational classifications were transformed as educational years as described in detail elsewhere (Silventoinen et al., 2017). Together, we had data from 19 twin cohorts including 88,290 individual DZ twins (55% women and 39% OSDZ twins). In these twins, we had information on maternal education for 24,417 twins and paternal education for 23,687 twins. Zygosity was mainly assessed by validated questionnaire methods, and in a minority of cases by genetic testing (Silventoinen et al., 2015).

The data were analyzed by linear regression models using Stata statistical package (version 14.2) and using the cluster option to adjust for lack of statistical independence of the co-twins, when the primary sampling unit is the twin pair (StataCorp LP; College Station, TX, USA). This adjustment provides correct standard errors and confidence intervals (CI) when twins are analyzed as individuals. We adjusted the results for birth year and twin study cohort to take into account the secular increase in educational level as well as differences between educational level and the educational classifications used in each twin study cohort. To analyze the heterogeneity between the twin study cohorts in effect sizes, we conducted a meta-analysis using a maximum likelihood random-effects estimator with the "metan" command in Stata. The effect sizes in twin study cohorts were adjusted for birth year. The heterogeneity was measured by I^2 estimating the proportion of effect size variation due to between-cohort variation. The values of 25–49% have been suggested to indicate low, 50–75% moderate and >75% high heterogeneity (Higgins et al., 2003).

3. Results

Table 1 shows how the difference in educational attainment between women and men measured as years of education has changed over the birth cohorts during the 20th century. In the cohorts born between 1910 and 1939, men had slightly higher education than women. After that the sex differences reversed and in the cohorts born after 1940 women had higher education than men. The largest difference was found in the latest birth cohort where women had, on average, 0.59 years higher education compared to men. The standard deviations were somewhat greater in the earlier compared to the later birth cohorts. When analyzed in more detail, this was because of a larger proportion of those having very limited education in the earlier birth cohorts (data not shown but are available from the corresponding author).

We then analyzed the effect sizes of educational attainment among SSDZ twins as compared to OSDZ twins (Table 2). In the pooled data, no difference between SSDZ and OSDZ twins in women was found (−0.05 educational years; 95% CI −0.11, 0.02). However, men from SSDZ pairs had slightly greater educational attainment than OSDZ men (0.14 educational years; 95% CI 0.07, 0.21). The interaction between own sex and the sex of the co-twin was statistically significant ($p < 0.0001$). When stratified by birth cohorts, differences between women from SSDZ and OSDZ pairs were inconsistent, having either a positive or a negative sign. In contrast, the point estimates in men (except for one cohort) showed an educational advantage of SSDZ twins as compared to OSDZ twins. In both men and women, only one of these birth-cohort stratified estimates was statistically significant.

Fig. 1 presents the forest plot of the effect sizes by twin study cohort in women and Fig. 2 in men. The cohorts were ordered so that the first nine cohorts shown are from Europe followed by six cohorts from the USA, two cohorts from Australia and individual cohorts from Sri Lanka and China. There was moderate heterogeneity between the twin cohorts in the effect sizes: $I^2 = 71\%$ for women and 65% for men. In women, the results were mixed, such that in 8 of 19 cohorts the point estimates showed advantage for SSDZ twins over OSDZ twins. In men, 14 of 19 cohort-specific point estimates showed educational advantage for SSDZ twins over OSDZ twins. In the only East-Asian cohort from China, the zygosity difference differed from the other cohorts, showing higher education in SSDZ women and OSDZ men; however, the interaction effect between own sex and the sex of the co-twin was not statistically significant in this cohort ($p = 0.28$).

Finally, we tested, in a sub-cohort, whether parental education modifies the difference in educational attainment between SSDZ and OSDZ twins. We found no evidence for an interaction effect between the sex of the co-twin and maternal or paternal education, either in women ($p = 0.40$ and 0.58, respectively) or in men ($p = 0.90$ and 0.49, respectively).

4. Discussion

In this large study of data originating from twin cohorts from 11 countries, we found that in women the sex of co-twin was not associated with educational achievement. However, in men, educational achievement was slightly higher if they had a male co-twin than when they had a female co-twin. This association in men was systematically found in different European countries, the USA and Australia, and thus seems to be universal within the Western cultural context. The difference (0.14 educational years) is relatively small. In comparison, the sex difference in education (0.59 years, at largest, found in the latest cohorts born in 1980–1989 years) is more than four times as large as this difference between same versus opposite sex male twin pairs. Further, we did not find evidence that the associations have changed over birth cohorts during the 20th century or that it is modified by parental education. The consistency of results across birth cohorts is especially interesting, because the sex difference favoring men in the earlier birth cohorts reversed in the later birth cohorts where women had higher education.

Table 1
The number of twin individuals, the descriptive statistics and sex differences of educational years by birth cohort.

Birth cohort	Men			Women			Sex difference[a]		
	N	Mean	SD	N	Mean	SD	β	Confidence intervals	
								LL	UL
1900–1909	248	8.1	4.56	502	8.3	4.43	0.20	−0.67	1.06
1910–1919	1052	10.3	4.56	1656	9.9	4.27	−0.44	−0.84	−0.04
1920–1929	3141	10.4	4.55	3781	10.2	4.20	−0.22	−0.47	0.01
1930–1939	5579	10.6	4.59	5695	10.5	4.29	−0.07	−0.25	0.11
1940–1949	10,940	11.4	4.47	11,944	11.6	4.22	0.21	0.09	0.33
1950–1959	10,100	12.8	3.85	12,092	13.1	3.68	0.27	0.15	0.39
1960–1969	4142	14.0	2.88	5782	14.0	2.82	0.05	−0.07	0.17
1970–1979	3456	14.2	2.81	5086	14.7	2.69	0.56	0.43	0.68
1980–1989	1337	14.1	2.72	1757	14.7	2.65	0.59	0.40	0.78

[a] Educational years in women minus educational years in men.

Table 2
The differences of educational years of same-sex dizygotic twins compared to opposite-sex dizygotic twins by sex and birth cohort.[a]

Birth cohort	Men			Women			*p*-value of sex interaction
	β	Confidence intervals		β	Confidence intervals		
		LL	UL		LL	UL	
All	0.14	0.07	0.21	−0.05	−0.11	0.02	<0.0001
1900–1909	1.16	−0.77	3.10	0.90	−0.38	2.18	0.742
1910–1919	0.23	−0.40	0.85	−0.18	−0.65	0.29	0.710
1920–1929	0.09	−0.26	0.45	−0.12	−0.42	0.19	0.754
1930–1939	0.13	−0.12	0.37	−0.05	−0.29	0.18	0.886
1940–1949	0.27	0.13	0.41	0.13	0.00	0.26	0.135
1950–1959	−0.05	−0.20	0.09	−0.13	−0.25	−0.01	0.674
1960–1969	0.06	−0.11	0.23	0.02	−0.13	0.16	0.455
1970–1979	0.14	−0.06	0.34	−0.03	−0.19	0.13	0.099
1980–1989	0.17	−0.13	0.47	−0.01	−0.28	0.25	0.241

[a] Educational years of same-sex dizygotic twins minus educational years of opposite-sex dizygotic twins.

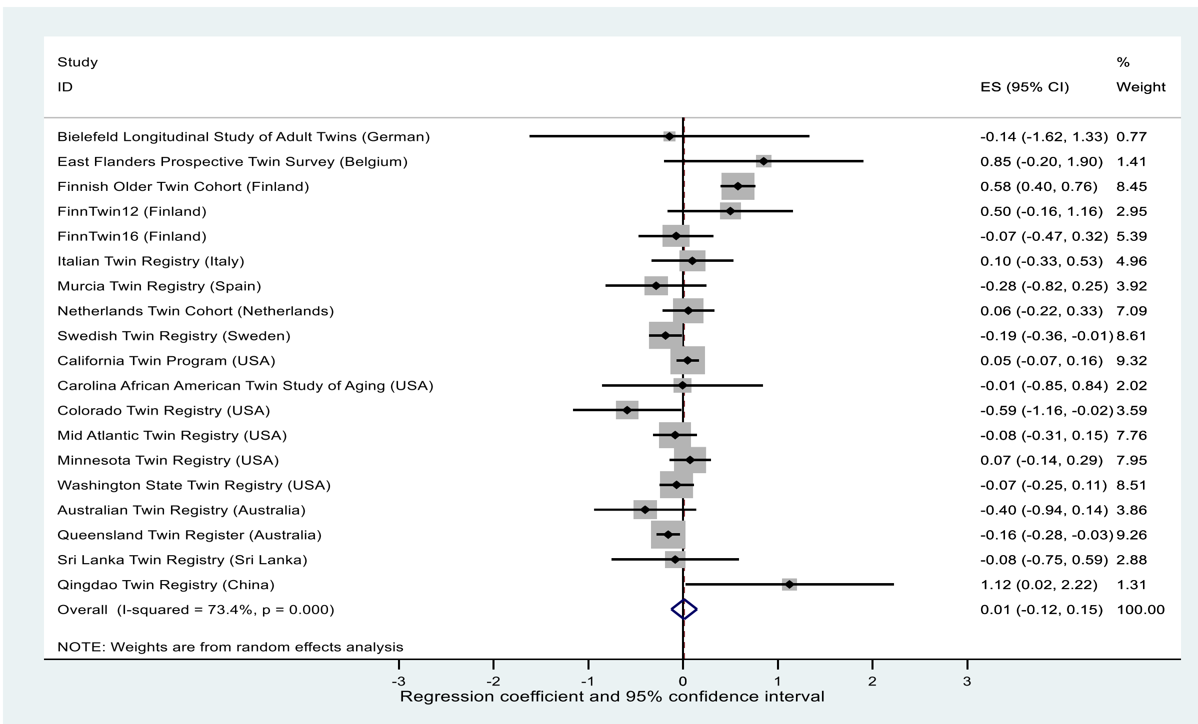

Fig. 1. The difference in educational years of same-sex dizygotic twins as compared to opposite-sex dizygotic twins by twin cohort in women.

In our only East-Asian cohort from China, the results differed from the other cohorts, and education was higher in SSDZ women and in OSDZ men. This result should be treated with caution since the interaction between own sex and the sex of co-twin was not statistically significant, but it may suggest differences between cultural contexts. It is noteworthy, however, that we did not find any evidence for discrimination of girls in this Chinese cohort for education since educational level was slightly higher in women (10.8 educational years) than in men (10.0 educational years).

Our results differ from previous studies from Sweden and Norway reporting higher education in SS female twins as compared to OS female twins (Bütikofer et al., 2019; Hjern et al., 2012). A factor which may explain these differences as compared to our results is that in these previous studies MZ twins were pooled with SSDZ twins, and MZ twins have slightly higher educational attainment than DZ twins (Silventoinen et al., 2017). The reason for this zygosity difference is unknown, but could be associated with the higher maternal age of DZ twins. This can affect the education of offspring because of the number of older siblings, a family structure known to be associated with lower educational attainment in younger siblings (Black et al., 2005; Brooth and Kee, 2009). Thus, the mixture of SSDZ and MZ pairs in previous studies may explain why differences have also been found between SS and OS pairs in females.

The lack of difference in educational achievement between SSDZ and OSDZ pairs in women is not compatible with the TTT hypothesis for educational achievement. This negative result raises the question of how plausible the TTT hypothesis is in general in humans. The most evidence for the TTT hypothesis in humans concerns cognition, whereas there is little support for the TTT hypothesis for other traits (Ahrenfeldt et al., 2020). However, even for spatial ability showing consistent sex differences (Peters et al., 2006), the evidence for the TTT hypothesis is inconsistent and there are studies supporting (Heil et al., 2011; Vuoksimaa et al., 2010) and not supporting the expected difference between SS and OS female twins (Toivainen et al., 2018). It is also noteworthy that while there is solid evidence for the TTT hypothesis in litter-bearing mammals, the direct evidence for humans is lacking (Ryan and Vandenbergh, 2002). There are major physiological, molecular and structural differences of the placenta between human and rodent

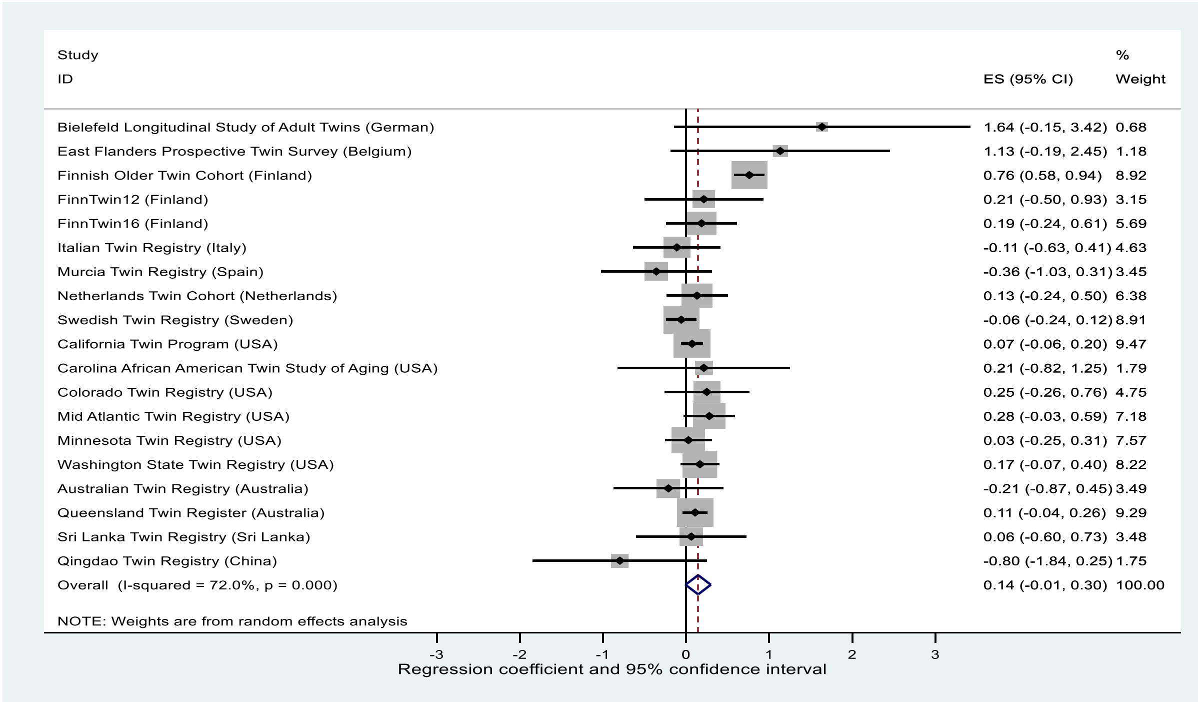

Fig. 2. The difference in educational years of same-sex dizygotic twins as compared to opposite-sex dizygotic twins by twin cohort in men.

pregnancies, which make extrapolation of results from rodent studies to humans uncertain (Schmidt et al., 2015). Since the evidence is lacking whether there can even be a transfusion of gonadal hormones between human fetuses, it is impossible to say whether our negative results suggest that testosterone levels in the uterus do not affect education level or whether there are no any differences between SS and OS female twins in their intrauterine testosterone exposure levels.

The reasons for our findings that educational level was higher in SSDZ than in OSDZ men are not clear. Low birthweight is found to be associated with less education (Breslau et al., 2004). However, birthweight is lower in SSDZ than in OSDZ male twins and thus cannot explain this association (Jelenkovic et al., 2018). It is possible that the reasons may be related to post- rather than prenatal life. There is some evidence that parents may financially support the education of their sons more than their daughters (Raley and Bianchi, 2006). However, if this kind of sex discrimination exists, it should rather benefit sons with a twin sister more than a twin brother. Finally, it is possible that the social dynamics of SS male twins may facilitate their educational career. For instance, a male counterpart in SS twin pairs may serve as a model or as a competitor, motivating educational advancement. However, this is all speculative and more research on the internal dynamics within twin pairs is needed to shed more light on this finding. It is, however, noteworthy how universal this effect is, at least within the Western social context.

Our data have major strengths but also limitations. Our main strength is that we utilized a very large pooled dataset from 19 independently collected twin cohorts representing 11 countries and birth cohorts over 100 years. The need for the replication of results and the problem of publication bias are well-recognized in psychology (Laraway et al., 2019), and these problems may be especially important in this type of study testing a specific hypothesis when there can be a publication bias against results not supporting a priori hypothesis. Our study can answer both problems by replicating the analyses in multiple twin cohorts and publishing the estimates irrespective of effect sizes, statistical significance or whether they support the previous hypothesis or not. It is also a clear advantage that we can distinguish MZ pairs from SSDZ pairs, which may have biased the results found in previous studies on this topic. However, for most twin participants in this study, the zygosity was not confirmed by DNA. Since education is somewhat higher in MZ as compared to DZ twins (Silventoinen et al., 2017), possible misclassifications of MZ and SSDZ twins may have contributed to the higher education in SSDZ twins as compared to OSDZ twins in men. However, this cannot explain our main finding, i.e., the lack of difference in education between OSDZ and SSDZ twins in women. Our main limitation is that we only had information on educational attainment and not academic performance or IQ as a possible determinant of education, which could help to study this effect in more detail. Additionally, our data are based on surveys instead of register data and are thus prone to non-response bias. The proportion of OSDZ twins is generally somewhat lower in twin surveys than the proportion of SSDZ twins, indicating a lower response rate (Silventoinen et al., 2015). It is further known that low education is typically associated with lower response rates (Reinikainen et al., 2018). However, we assume that this bias should rather increase the level of educational attainment in OSDZ twins if those having lower education have disproportionally not participated in the surveys. More studies are also needed to investigate the social dynamics within SS and OS twin pairs, which may help to explain our findings for men. Further, we had limited data on non-Western populations. More twin studies conducted in non-Western societies are needed to study whether the results can be generalized outside the Western cultural context.

In conclusion, our results do not support the hypothesis that there would be differences in the intrauterine testosterone levels between OSDZ and SSDZ female twins affecting education. Men having a same sex co-twin have slightly greater educational attainment than men with an opposite sex co-twin. This difference is universal within, at least, the Western cultural context and is not modified by birth cohort or parental education. Whereas we cannot exclude a prenatal biological explanation, we find it more plausible that postnatal socialization of male twins may create the differences, and this hypothesis should be considered in future research.

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