



Research Article

Meta-analysis of twin studies highlights the importance of genetic variation in primary school educational achievement

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ABSTRACT

Children differ in their ability to learn what is taught at school. Evidence from twin studies suggests that genetic effects contribute to such differences. The aim of the present study was to systematically review the existing literature, including 61 studies from 11 cohorts, on twin studies of educational achievement in primary school children. The meta-analysis estimated heritability, based on up to 5330 MZ and 7084 DZ twin pairs, at 73% for reading, 49% for reading comprehension, 57% for mathematics, 44% for spelling, 64% for language and 66% for educational achievement. The importance of genetic effects on educational achievement differed between countries. Heritability was consistently high in the Netherlands across educational domains, while this was not always true for the USA and the UK. It can be concluded that genetic variation is an important contributor to the individual differences in educational achievement, with some indication for interaction with country.

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1. Introduction

Educational achievement in children can be defined as the extent to which a child has achieved the educational goals corresponding to his or her grade level. Lower educational achievement has an adverse effect on access to higher education and is negatively related to numerous other outcomes later in life, including earnings [1] and health and wellbeing [2]. Research towards the causes of individual differences between children has tended to focus on environmental factors, such as parental educational level, socioeconomic status (SES) and quality of education. Yet, even children from a similar background and attending the same school can differ greatly in their performance at school. This introduces genetic effects as an important additional source of variation in educational achievement. Moreover, parts of the child's environment, like parental educational level, can themselves be influenced by genes [3,4]. In keeping, general cognitive ability is the most important predictor of educational achievement [5], explaining roughly half of the variation [6]. A major role for genetic effects on general cognitive ability has already been well recognized [7] and is characterized by an increase during childhood [8,9]. Here we systematically review twin studies on educational achievement of children in primary school, aiming to provide, based on the existing literature, an

estimate of the heritability and the influence of the environment by meta-analyzing the twin correlations.

Twin studies are the most often used design to analyze the causes of variation in complex phenotypes, such as educational achievement [10]. Monozygotic (MZ) twin pairs are genetically (nearly) identical while dizygotic (DZ) twin pairs share approximately 50 per cent of their segregating genes [11]. If the larger genetic resemblance of MZ twin pairs is mirrored in a larger resemblance for a phenotype, i.e. when the correlation between MZ twin pairs is higher than between DZ twin pairs, this observation is consistent with the phenotype being influenced by genetic effects. Genetic effects are the sum of the additive effects of all genetic variants with an influence on educational achievement. Environmental effects often are distinguished into common environmental and unique environmental effects. Common environmental effects are influences that are shared between twins or siblings who grow up in the same environment and enhance their similarity beyond the similarity due to shared genes. There are other effects that also make offspring from the same parents more similar, including the effects of assortative mating, the similarity between spouses, which will in the classical twin design also be detected as common environmental effects [12]. When the correlation between DZ twin pairs is more than half the correlation between MZ twin pairs there is an indication for the influence of the common environment. Unique environmental effects are influences that are not shared between twins, and make children less similar. When the correlation between MZ twin

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pairs is not equal to unity the unique environment has an influence. The unique environmental effects also include measurement error.

The twin method assumes that MZ twins are more similar in educational achievement than DZ twins because of their larger genetic resemblance and not because MZ twins are treated more alike than DZ twins. The equal environment assumption can be violated if similarity in treatment relates to similarity in a phenotype. However, MZ twins may be exposed to more similar treatment because of their larger genetic resemblance. For instance, if children that learn easily get treated differently than children that struggle more at school, the higher genetic resemblance in educational achievement of MZ twins causes them to experience more similar environments than DZ twins, as a secondary effect of the genetic effects on educational achievement. In contrast, when there is a similar environment unrelated to the genetic make-up of the twins, e.g. MZ twins are dressed more alike than DZ twins this could lead to a violation of the assumption, but only if similarity in appearance relates to similarity in the outcome. Such violations of the equal environments assumption have been tested by empirical approaches in large scale studies [13–15] which show that the assumption holds for, amongst others, educational achievement.

In order to generalize the outcome of twin studies to the general population, twins should be representative of the general population for the phenotype of interest. With regard to most characteristics, this assumption will be met as twins are born in all strata of society [16]. Nonetheless, twins differ from singletons with regard to birth conditions. Twins are born, on average, 3–4 weeks prematurely and have ~1 kg lower birth weights [17]. These differences dissipate fairly early on, however, and, already in childhood, twins and singletons have very similar body composition [18] and educational achievement [19], especially when birth order within family is taken into account [20,21].

Twin studies have mainly focused on reading and, more recently, mathematics. Most studies are from English speaking countries, such as the USA, the UK and Australia. Studies from other countries with different educational systems are relatively scarce [22–24]. Studies are characterized by differences in age, sample size, cohort and measurement instrument. Therefore, it is difficult to draw clear conclusions regarding the relative contribution of genetic and environmental influences on educational achievement. Here we aim to provide a review of all studies that addressed the heritability of educational achievement in primary school and carry out a meta-analysis of the correlations within MZ and DZ twin pairs. This review does not include twin studies of selected samples (low or high performance) or of learning disabilities, such as dyslexia and dyscalculia, as there are excellent recent reviews describing twin studies (e.g. [25–28]) and molecular genetic studies (e.g. [29,30]).

2. Methods

A search of the published literature was conducted in PubMed to find all relevant papers describing twin studies on the heritability of educational achievement in primary school children published before September 2014. Searches were performed to find any paper in English that contained the words genetics, heritability or twin study combined with educational achievement, educational attainment, school achievement, academic achievement, scholastic achievement, school performance or academic performance or combined with reading, mathematics, arithmetic, spelling, language or science in its title, key words, abstract or main text. Abstracts of these search results were evaluated and relevant full text articles were retrieved from the internet. The reference lists of all these papers were examined to identify additional studies that had not been located in the initial database search and searches on names of authors who previously

published twin studies on educational achievement were performed. Criteria for inclusion were determined a priori and assessed. Only original research reports published in peer-reviewed journals were included in the review. Twin studies including a sample of primary school aged children (6–13 years) were selected. Studies were included when they contained information on heritability estimates for a measure of educational achievement in a specific educational domain, for example, reading or mathematics, or a measure of general educational achievement. Studies were selected when they used standardized tests or teacher assessments to measure educational achievement. Studies reporting on estimates from univariate analyses as well as studies containing univariate estimates from multivariate analyses were included. Only twin studies from unselected genetically sensitive samples were included. From each study, when available, the first author, year of publication, country, cohort, age, sample size, measurement instrument, educational domain and heritability estimates were extracted.

A meta-analysis of studies that provided sample size, separate for MZ and DZ twin pairs, and twin correlations was conducted for both educational achievement in specific educational domains and general educational achievement. The meta-analysis was carried out to estimate heritability across multiple datasets when at least two independent studies from different cohorts were available. The decision which study to select and include in the analysis when studies reported twin correlations from the same cohort was based on the largest sample size. The educational domain science was only available for one cohort which made meta-analyzing the results not possible.

A variance decomposition model was fitted to the twin correlations, weighted by sample size, to estimate the influence of genetic and common environmental effects [31–33] on educational achievement using the structural equation modeling program Mx [34]. With Mx it is possible to analyze the twin correlations from multiple studies in a multi-group analysis and obtain a maximum likelihood estimate of heritability across all studies. It was tested whether the heritability estimate could be constrained to be equal across studies. The difference in goodness of fit between the nested models was assessed with hierarchic chi-squared tests. The difference in the χ^2 -statistic is evaluated with the difference in the number of estimated parameters between the nested models as degrees of freedom. A p -value smaller than .01 was considered significant.

3. Results

The PubMed search retrieved 61 studies that were published between 1991 and 2014. Table S1 summarizes the characteristics and results of these twin studies from 6 different, mostly English speaking, countries (mainly Northern Europe, the UK and the US, but also Australia and China). The studies include heritability estimates for a number of specific educational domains or for general educational achievement. Table S1 also gives an overview of the heritability estimates as reported by the included studies. Studies providing separate estimates for the heritability in boys and girls did not report any gender differences [35–40]. Some studies took into account that the members of a twin pair could be assessed by the same or different teachers and reported separate heritability estimates for these groups [41,42]. Studies used teacher assessments, standardized tests taken at school or tests that had been administered by the researchers through the internet, telephone or during a home-visit. Teacher assessments were based on the evaluation by the teacher of the overall proficiency of a student or on criteria that are listed in national guidelines stating what a student should be able to do or know with respect to a certain educational domain.

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