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Arithmetic, reading and writing performance has a strong genetic component: A study in primary school children

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ABSTRACT

Even children attending the same primary school and taught by the same teacher differ greatly in their performance. In the Netherlands, performance at the end of primary school determines the enrollment in a particular level of secondary education. Identifying the impact of genes and the environment on individual differences in educational achievement between children is important. The Netherlands Twin Register has collected data on scores of tests used in primary school (ages 6 to 12) to monitor a child's educational progress in four domains, i.e. arithmetic, word reading, reading comprehension and spelling (1058 MZ and 1734 DZ twin pairs), and of a final test (2451 MZ and 4569 DZ twin pairs) in a large Dutch cohort. In general, individual differences in educational achievement were to a large extent due to genes and the influence of the family environment was negligible. Moreover, there is no evidence for gender differences in the underlying etiology.

1. Introduction

Children differ in their ability to learn the subject material that is taught at school. Some master basic skills, such as reading and arithmetic, and pick up knowledge about science, history and biology much faster than their peers. Low educational achievement is associated with continued low achievement, school dropout and delinquency (Moilanen, Shaw, & Maxwell, 2010). General cognitive ability is the most important predictor of educational achievement (Deary, Strand, Smith, & Fernandes, 2007) and explains about half of the variation (Frey & Detterman, 2004). Most research on educational achievement of children has focused on environmental factors, such as socioeconomic status (SES) of the parents and school characteristics, and on differences between groups of children, for example boys and girls (OECD, 2010). However, even children attending the same school and taught by the same teacher differ greatly in their performance at school. It may be less relevant to look at group differences when differences within a group are much larger. Causes for individual differences between children do not necessarily have to be the same as for average differences between groups. The main reason for mean differences in educational achievement between boys and girls might be environmental whereas the cause for differences in performance between individual children may be largely genetic in nature.

Genetic research can address questions about the causes of individual differences amongst children and disentangle the underlying etiology, i.e. the extent to which the differences in educational achievement between children are explained by their genes or by the environment (Boomsma, 2013; Plomin, Defries, McClearn, & McGuffin, 2008). One of the most often used designs in behavior genetics is the twin study, which is based on the difference in genetic relatedness between identical or monozygotic (MZ) and fraternal or dizygotic (DZ) twins. Monozygotic (MZ) twin pairs are genetically (nearly) identical while dizygotic (DZ) twin pairs share approximately 50% of their segregating genes. If the larger genetic resemblance of MZ twin pairs is mirrored in a larger resemblance for a phenotype the phenotype is being influenced by genetic effects. Genetic effects are the sum of the effects of all additive genetic variants with an influence on educational achievement. When the correlation between MZ twin pairs is higher than between DZ twin pairs, this constitutes evidence for the influence of genetic effects. Environmental effects often are distinguished into common or shared environmental and unique or non-shared environmental effects. Common environmental effects are influences that are shared between twins or siblings who grow up in the same family 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 in the classical twin design will also be detected as common environmental effects (Evans & Martin, 2000). 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

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shared between twins, and make children less similar. When the correlation between MZ twin pairs is not equal to unity the unique environment has an influence. The unique environmental effects also include measurement error.

Numerous studies have demonstrated that genetic effects have a substantial influence on differences between children in general cognitive ability. General cognitive ability is often seen as an aptitude while reading, mathematics and spelling are taught at school and perceived as the outcome of education. Hence, it seems reasonable to expect that heritability of educational achievement is lower than the heritability of general cognitive ability. However, a recent study has shown that the opposite was true for primary school children in the United Kingdom (UK). Literacy and numeracy were significantly more heritable than general cognitive ability at ages 7 and 9, but no longer at age 12 (Kovas et al., 2013). Heritability of general cognitive ability also increases in the Netherlands from low (20%) to moderate (50%) (Bartels, Rietveld, van Baal, & Boomsma, 2002) during primary school, to high (65%) in adolescence (van Soelen et al., 2011) while heritability of educational achievement is already high at the start of primary school (70%) (Calvin et al., 2012) and remains the same until the end of primary school (60%) (Bartels et al., 2002). It has been proposed that the equal opportunities in the relatively homogenous education environment provided in Western societies acts to reduce environmental variation, making differences in educational achievement between children to a greater extent due to genetic differences (Kovas et al., 2013).

Twin studies have mainly focused on the educational domain of reading and, more recently, mathematics, while less is known about the etiology of other educational domains, such as, science. Most studies have used teacher assessments or tests that had been administered by the researchers through the internet, telephone or during a home-visit while only a few used standardized tests administered at school. Even though teacher assessments are correlated with standardized tests they might be less reliable measures of educational achievement. Furthermore, teacher ratings may be subject to rater bias when twins are taught in the same classroom and their educational achievement is rated by the same person. Each teacher has his or her own perception on educational achievement, which can make children seem more similar when they are assessed by the same teacher (Kan, van Beijsterveldt, Bartels, & Boomsma, 2014; Simonoff et al., 1998).

Most twin studies on educational achievement have primarily included English speaking children from the USA and the UK. Studies from other countries with different educational systems and languages are scarce (Byrne et al., 2009; Chow, Ho, Wong, Waye, & Bishop, 2011; Samuelsson et al., 2008). The question addressed in this study is whether the same pattern of the relative contribution of genetic and environmental effects on the variation in educational achievement exists in the Netherlands. Calvin et al. (2012) found genetic effects to be an important cause of variation in achievement in the educational domains language (43–74%) and arithmetic (36–73%) at ages 8, 10 and 12 in Dutch primary school children. However, they used a population cohort without information on zygosity and estimated the resemblance between monozygotic and dizygotic twin pairs from the proportion of same-sex and opposite-sex twin pairs, which is a much less powerful design than when zygosity is known.

In the Dutch educational system, the majority of primary schools use a pupil monitoring system that includes standardized tests assessing educational achievement (Cito, 2014a; Vlug, 1997). Tests are available for all grades and all important educational domains. The tests are independent of teaching methods and can be used to monitor a child's educational development in comparison to peers and across grades and educational domains. Tests measuring arithmetic, word reading, reading comprehension and spelling are, according to an inventory amongst teachers, the most informative with regard to the educational development of children (Polderman et al., 2011). A standardized nation-wide educational achievement test is available for the last grade, measuring what a child has learned during all primary school years (Cito, 2002). Together, these data provide a unique opportunity to give an overview of the underlying etiology of differences in educational achievement on different educational domains across primary school grades.

Differences in average educational achievement between boys and girls could be due to differences in the etiology of educational achievement. Quantitative gender differences are present if one gender is affected to a greater extent by the same genetic or environmental effects. Qualitative gender differences exist when different genetic or environmental effects have an influence on boys and girls. Very few studies have examined differences between boys and girls in the etiology of educational achievement, probably due to small sample sizes. One large study utilizing teacher ratings to determine the level of educational achievement in language, reading, mathematics and science found no gender differences in the causes underlying differences between children (Kovas, Haworth, Dale, & Plomin, 2007). Gender differences were also absent in another study using a standardized test to measure the reading level of children (Harlaar, Hayiou-Thomas, & Plomin, 2005).

The aim of the current study is to identify the impact of genes and the environment on educational achievement, i.e. arithmetic, word reading, reading comprehension and spelling, in primary school in a large cohort of Dutch twins and to explore possible gender differences.

2. Methods

2.1. Participants

The Netherlands Twin Register (NTR) was established around 1987 by the Department of Biological Psychology at the Vrije Universiteit Amsterdam and registers approximately 40% of all multiple births in the Netherlands. The parents of twins participate in longitudinal data collection and receive a survey about the development of their children every 2 to 3 years up until the twins are 12 years old. Details about selection and response rates are described elsewhere (Bartels et al., 2007; Boomsma et al., 2002; Boomsma et al., 2006; van Beijsterveldt et al., 2013). In 1999 the NTR started asking parents for their consent to approach the teacher(s) of their children attending primary school. Each year the parents of twins aged approximately 7, 9 and 12 years have been approached with this request. After parental consent, a survey is sent to the primary school teacher(s) of the twins and their siblings with questions about behavioral and emotional problems, functioning at school and educational achievement. In the Netherlands, a widespread pupil monitoring system is developed with standardized tests to monitor a child's educational progress in primary school ('LeerlingVolgSysteem' in Dutch) (Cito, 2014a). Since 2008 teachers are systematically asked to submit copies (usually a print-out) of the results on the pupil monitoring tests administered during the primary school period. Teachers were asked to provide information on the results of the tests administered in the current and previous grades. Approximately one third of the teachers who returned the teacher survey also send in a student report with the pupil monitoring test results. A final educational achievement (EA) test is administered at the end of the last grade of primary school (Cito, 2002). Because the results of the EA test become available at the end of the last school year, both the parents as well as the children themselves instead of the teachers are asked to report the scores on this EA test. Results on the EA test at the end of the primary school period have already been collected since 2000.

Data on at least one of the pupil monitoring tests (cohorts 1995–2006) or on the EA test (cohorts 1987–2001) were available for 16,234 children. We excluded children who had a disease or handicap that interfered severely with daily functioning (N = 90) or attended specialized education (N = 79), in the Dutch education system special schools are available for children who need extra care due to learning problems, physical and/or mental disabilities or a behavioral disorder, resulting in data for 7228 complete and 1609 incomplete twin pairs. The main reason for incomplete data is that twins attend different