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Differential environmental influences on the development of cognitive abilities during childhood

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ABSTRACT

Twin studies have shown strong evidence that cognitive abilities are heritable. This longitudinal study examines genetic and environmental influences on distinct developmental patterns of verbal and non-verbal cognitive abilities from age 7 to 12 in 4718 British twins. Six subgroups with distinct patterns were identified with comparable heritabilities of group membership (ranging 0.37–0.62). Non-shared environmental influences that differentiate family members on group membership appear to be particularly strong in the three subgroups that demonstrated substantial developmental mean changes of cognitive abilities (ranging 0.51–0.54), compared to the other three subgroups with relatively stable mean levels (ranging 0.29–0.34). Shared environmental influences making family members similar for group membership were significant in only two subgroups – among the children with continuously low scores (0.20) and developmental early starters (0.28). These results suggest the existence of distinct developmental patterns of cognitive abilities. The impact of shared and non-shared environment on the membership of different developmental patterns may be greater for some children than others.

1. Introduction

Cognitive abilities are among the most potent predictors of developmental outcomes, such as longevity and health (Deary, Whiteman, Starr, Whalley, & Fox, 2004; Gottfredson & Deary, 2004), occupational attainment and job performance (Schmidt & Hunter, 2004), and educational and social achievement (Campbell, Pungello, Miller-Johnson, Burchinal, & Ramey, 2001; Neisser et al., 1996). Children experience substantial developmental changes in their cognitive abilities during childhood and adolescence (Feinstein & Bynner, 2004; Luna, Garver, Urban, Lazar, & Sweeney, 2004). Additionally, children also follow different patterns or trajectories of cognitive development, such as in their communication skills (Määttä, Laakso, Tolvanen, Ahonen, & Aro, 2012), number sense (Jordan, Kaplan, Oláh, & Locuniak, 2006), and reading skills (Boscardin, Muthén, Francis, & Baker, 2008). In a study of early communication development among 508 children from 12 to 21 months old, children showed different developmental patterns in their levels of social, speech, and symbolic skills. Some were continuously above, around, or below average on all domains, whereas others primarily showed difficulties in one particular domain (Määttä et al., 2012). Another study using a sample of 411 children found three distinct developmental trajectories in number sense through kindergarten: *stable low*, *average level and increasing*, and *high level and increasing* (Jordan et al., 2006). Boscardin et al. (2008) found that children's phonological awareness and word recognition abilities showed substantial heterogeneity in their general level (e.g., low, average, high) and their developmental slope (e.g., flat/stable, moderate increasing) from kindergarten to grade 2. Previous studies have shown that different cognitive developmental patterns are linked with different developmental outcomes in childhood, adolescence, and adulthood. For instance, children identified as having reading difficulties early in kindergarten showed slower development in their word recognition skills in subsequent years (Boscardin et al., 2008), while children continuously showing low cognitive abilities from age 5 to 10 showed the worst adult outcomes at age 30 regarding educational and social achievement (Feinstein & Bynner, 2004). Therefore, it is important to investigate the developmental patterns and trajectories of cognitive abilities through childhood and to examine the associations of different patterns with later developmental outcomes.

Numerous twin studies have studied the etiology of cognitive abilities in children and adolescents. These studies have generally shown that genetic factors make a substantial contribution to individual differences in cognitive abilities and that genetic influence increases from childhood through adolescence to adulthood. The remaining variation

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in cognitive abilities is primarily explained by environmental factors not shared between family members that differentiate them (non-shared environment). Environmental factors that make family members similar to each other (shared environment) have only a modest influence that gradually attenuates over time (Bouchard & McGue, 1981; Deary, Spinath, & Bates, 2006; Haworth et al., 2009; Plomin & Deary, 2015; Plomin & Spinath, 2004). Longitudinal twin studies have also shown that the temporal stability of cognitive abilities is largely explained by a single set of genetic factors expressed throughout development, and by shared environment to a lesser degree, whereas the non-shared environment predominately contributes to change in cognitive abilities (Bartels, Rietveld, van Baal, & Boomsma, 2002; Franić et al., 2014; Hoekstra, Bartels, & Boomsma, 2007; Petrill et al., 2004; Rietveld, Dolan, van Baal, & Boomsma, 2003).

Prior twin studies, however, have largely investigated the age-dependent or age-to-age pattern of genetic and environmental influences. Such studies do not capture between-individual differences in within-individual patterns of change (e.g., increasing vs. decreasing) in cognitive development. Consequently, they did not probe the extent to which extent genes and environment influence children's different developmental patterns of cognitive abilities. These questions require a person-oriented approach that captures between-group differences in their respective developmental patterns (Lanza & Cooper, 2016; Magnusson, 1999). A few recent twin studies have adopted this approach and have found evidence of differential genetic and/or environmental influences across different subgroups. In a sample of 787 twin pairs (mean age 7 years old), a cross-sectional study found that the heritability was lower, but shared environmental influences were larger in the membership of two subgroups of child temperament, *regulated, typical reactive*, and *dysregulated, negative reactive*, than the other two subgroups, *well-regulated, positive reactive*, and *regulated*, *surgent* (Scott et al., 2016). One longitudinal twin study with a small sample found that genetic influences were stronger for the membership in the group chronically showing moderate level of antisocial behavior, than the group showing a decreasing pattern, from adolescence to young adulthood (Zheng & Cleveland, 2015). Another longitudinal twin study with a large sample of 9462 twins showed that shared environment made a strong contribution to girls showing a stably high pattern of callous-unemotional traits, but its influence was not significant among those showing a decreasing pattern from age 7 to 12 years old (Fontaine, Rijsdijk, McCrory, & Viding, 2010).

The current longitudinal study aimed to examine genetic and environmental influences on children's membership of subgroups based on distinct developmental patterns of cognitive abilities during childhood. Consistent with previous studies, we examined the development of verbal and non-verbal cognitive abilities, rather than general intelligence (e.g., Franić et al., 2014; Hoekstra et al., 2007; Rietveld et al., 2003). Using longitudinal prospective data from the Twins Early Development Study (TEDS; Haworth, Davis, & Plomin, 2013), we used latent profile analysis to find out whether there is evidence of meaningful developmental subgroups of verbal and non-verbal cognitive abilities assessed at ages 7 and 12 years old in a large group of twins. Then we investigated the etiology of children's membership of different subgroups of distinct developmental patterns. Based on prior studies (e.g., Boscardin et al., 2008; Jordan et al., 2006; Määttä et al., 2012), we expected that children would demonstrate different developmental patterns of cognitive abilities during childhood regarding their general level (e.g., above or below average) and their developmental change/slope (e.g., increasing, decreasing, flat/stable), and that genetic and/or environmental influences could differ across different developmental patterns.

2. Methods

2.1. Participants and procedures

Participants from the study came from the Twins Early Development Study (TEDS). TEDS is a longitudinal study of twins born in English and Wales in 1994–1996. Despite some attrition, at age 12 the TEDS sample remains fairly representative of the general population of England and Wales (Haworth et al., 2013). Zygosity was assessed with a parent-reported questionnaire that has been shown to be > 95% accurate compared with a direct genetic test; DNA testing was conducted where zygosity was unclear (Price et al., 2000). At ages 7 and 12, children from TEDS were administered two verbal and two non-verbal tests of cognitive ability. To minimize confounding from factors that may contribute to the focal outcomes, our selection criteria for inclusion comprised children with parent-reported White ethnicity; English as a first language; no medical problems at birth, and no perinatal outliers such as low birth weight. For analyses we needed both children within a twin pair to have provided at least one test score. The final sample included in the analyses comprised 4718 twins: 366 monozygotic (MZ) male pairs, 552 MZ female pairs, 324 dizygotic (DZ) male pairs, 420 DZ female pairs, and 697 DZ opposite-sex pairs (total 2359 pairs, 918 MZ pairs and 1441 DZ pairs). Mean age was 7.12 years ($SD = 0.24$) at age 7 and 11.84 years ($SD = 0.36$) at age 12.

2.2. Measures

At age 7 cognitive ability data were collected by telephone interview. Prior to the telephone call, parents were sent a booklet of test items together with instructions. The verbal measure scores were the summed score from the Similarities and Vocabulary subtests of the Wechsler Intelligence Scale for Children (WISC-III-UK; Wechsler, 1992). The non-verbal measures were the summed scores from the Conceptual Grouping and Picture Completion subtests of the WISC-III-UK.

At age 12 measures were collected over the web (Haworth et al., 2007). The two verbal measures were the summed scores from WISC-III-UK Multiple Choice Information (General Knowledge) and Vocabulary Multiple Choice subtests (Wechsler, 1992). The two non-verbal measures were the summed scores from the WISC-III-UK Picture Completion (Wechsler, 1992) and Raven's Standard and Advanced Progressive Matrices (Raven, Court, & Raven, 1996, 1998). At both ages all measures were corrected for main effects of age and sex, the standardized residuals of which were used in all following twin analyses (McGue & Bouchard, 1984).

2.3. Analyses

Descriptive statistics of raw verbal and non-verbal test scores at each time point were first examined. Next, Latent Profile Analysis (LPA) was conducted in Mplus 7.2 (Muthén & Muthén, 1998–2012) to identify subgroups of children with different developmental patterns in verbal and non-verbal cognitive abilities from age 7 to 12. LPA takes a person-oriented approach to identify distinct subgroups of people measured on continuous indicators (here, verbal and non-verbal cognitive ability scores) that demonstrate similar patterns within each subgroup, yet distinct patterns between subgroups. A maximum likelihood estimator with robust standard errors (MLR) that are robust to non-normality and non-independency of the data was used in all analyses, and missing data were handled with full-information maximum likelihood (FIML). The statement of CLUSTER = family was used to account for the fact that twins in the same pair were nested in the same family. Beginning with a 2-class and ending with a 7-class solution, multiple models (500) with randomly generated starting values were run for each solution to avoid local optima. The Lo-Mendell-Rubin adjusted likelihood ratio test (LMR-LRT; Lo, Mendell, & Rubin, 2001) and the Vuong-Lo-Mendell-Rubin likelihood ratio test (VLMR-LRT) was used to choose the best