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Individual differences in dynamic measures of verbal learning abilities in young twin pairs and their older siblings

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ABSTRACT

We explored the genetic background of individual differences in dynamic measures of verbal learning ability in children, using a Dutch version of the Auditory Verbal Learning Test (AVLT). Nine-year-old twin pairs ($N=112$ pairs) were recruited from the Netherlands Twin Register. When possible, an older sibling between 10 and 14 years old participated as well ($N=99$). To assess verbal learning, non-linear curves were fitted for each child individually. Two parameters were estimated: Learning Speed (LS) and Forgetting Speed (FS). Larger twin correlations in monozygotic (MZ) than in dizygotic (DZ) and sibling pairs for LS and FS indicated the importance of genetic factors in explaining variation in these traits. The heritability estimate (percentage of variance explained by genetic factors) for LS was 43% for both twins and siblings. For FS heritability was estimated at 20% in twins and was slightly higher (30%) in their older siblings.

1. Introduction

The ability to store a limited amount of verbal information in highly accessible form over a short period of time, like remembering a shopping list, is an important cognitive ability for both children and adults in everyday life. A specialized component closely linked to these verbal learning abilities, is the phonological loop (Baddeley, Gathercole & Papagno, 1998). The phonological loop can be assessed by the use of verbal repetition paradigms, often called verbal learning paradigms, which may consist of familiar or non-word series of words (Gathercole, Willis, Baddeley & Emslie, 1994). Immediate recall of words is mediated by the semantic similarity between words, word frequency, the order of presentation and is related to long term memory (Cowan, 1988; Burgess & Hitch, 2006; Repovs & Baddeley, 2006; Richardson, 2007).

There are few studies that focus on the etiology of individual differences in verbal learning ability. Learning rates and achievement measures of the 'same' process do not necessarily overlap (Byrne et al 2008). This paper focuses on a possible contribution of genetic factors to variation in the dynamics of verbal learning during childhood. The contribution of genetic factors to trait variation can be estimated by comparing the trait similarity between identical (monozygotic, MZ) and non-identical (dizygotic, DZ) twin and sibling pairs. The proportion of the variance in a trait that can be attributed to genetic factors is termed heritability. For general cognitive ability it is well-documented that heritability increases from around 25% in 5- to 6-year olds to 80% in adults (Bartels, Rietveld, van Baal & Boomsma, 2002; Finkel, Pedersen, Plomin & McClearn, 1998; McClearn et al., 1997). Heritability estimates for measures of memory performance also suggest that they differ as a function of age, but data are scarcer than for general cognitive abilities.

Verbal learning is often assessed with the California Verbal Learning Test (CVLT) or the Rey's Auditory Verbal Learning Test (AVLT). The CVLT and AVLT include a list of words that is presented auditorily and repeatedly. Participants have to recall the words immediately after each presentation of the list and after a delay period of 20–30 min. A study in elderly male twin pairs (mean age 71.8 years), showed a heritability of verbal memory of 56 % (Swan et al., 1999). Other word repetition studies with a list of non-words, showed high heritability in young children (Bishop, North & Donlan, 1996; Bishop, Adams & Norbury, 2006; Byrne et al., 2006).

There are a limited number of studies that included a measure of the dynamics during the initial trials of a verbal learning task (e.g. adding and retaining words of a given list into the phonological loop). The most widely used measures of verbal learning are the total number of correctly recalled words or the difference between the correctly recalled words on e.g. trial 5 and trial 1. This is often called the learning slope or learning rate (Woods, Delis, Scott, Kramer &

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Holdnack, 2006; Vakil, Blachstein, Rochberg & Vardi, 2004; Vakil & Blachstein, 1993; Paolo, Troster & Ryan et al., 1997). By taking the difference in recalled words between trials, the learning curve is assumed to be linear while a non-linear learning curve might be more appropriate (van der Elst, Van Boxtel, Van Breukelen & Jolles, 2005; Poreh, 2005; van den Burg & Kingma, 1999). We apply a method to measure the dynamics during the process of keeping words into phonological loop to data collected in a sample of young twins and their siblings. By using non-linear regression analysis and fitting a learning curve for each individual, two parameters are estimated. The first parameter, Learning Speed (LS), represents the proportion of verbal material not yet recalled in a previous trial that is recalled in a following trial. The second parameter, Forgetting Speed (FS), represents the proportion of material that was successfully remembered previously, that can no longer be recalled in a following trial. By estimating these two indices a more comprehensive picture of the dynamics of verbal learning is obtained.

2. Materials and methods

2.1. Participants

Subjects were recruited from the Netherlands Twin Register (Boomsma et al., 2006) and participated in a larger ongoing study, described by van Leeuwen, van den Berg & Boomsma (2008) and Peper et al. (2008) in more detail. A total of 112 healthy twin pairs (23 MZ male, 25 MZ female, 23 DZ male, 21 DZ female, and 20 DZ opposite sex pairs) and their older siblings ($N=99$; 56 female) completed the verbal learning task. Mean age of the twins was 9.1 years, ranging from 8.9 to 9.5 years. Mean age of the siblings was 11.9 years, ranging from 9.9 to 14.9 years. Exclusion criteria consisted of chronic use of medication, any known major medical or psychiatric history, participation in special education or an IQ<70. Socio-economic status (SES) was slightly above the average of the Netherlands (Statistics Netherlands (CBS), 2004), but still showed substantial variation (low SES, $N=17$; middle SES, $N=54$; high SES, $N=37$; unknown SES, $N=4$). Written informed consents were obtained from all subjects and their parents and the study was approved by the Dutch Central Committee on Research involving Human Subjects (CCMO).

2.2. Experimental procedure

The Dutch version of the Rey's Auditory Verbal Learning Test (AVLT) was used (van den Burg & Kingma, 1999). It contains 15 unrelated, concrete nouns and was presented to the children by a neutral computerized voice over 5 identical trials. After each presentation the child was asked to recall as many words as possible.

2.3. Learning and forgetting speed

For each child a non-linear learning curve was fitted using the number of correctly recalled words over the first 5 trials. This learning curve was identified by two parameters, namely Learning Speed (LS) and Forgetting Speed (FS). LS represent the proportion of verbal material not yet recalled in a previous trial that is recalled in a following trial. When LS increase in value, a steeper increase in correctly recalled words is seen over the first 5 trials. FS represents the proportion of material that was successfully remembered previously, that can no longer be recalled in a following trial.

An individual learning curve of the performance from trial 1 to trial 5 was described as: $Y(t)=A*(1-[1-b]^t)$, where Y is the total amount of words recalled, A and b are learning parameters and t is the trial number (Mulder et al., 1996). The formula is derived from the difference equation: $\Delta Y=a-b*Y$, which describes a dynamic growth process. Because the specific task at hand has a fixed amount to be learned, this equation can be reparametrized as: $\Delta Y=a*(15-Y)-b*Y$, where a and b can be interpreted as LS and FS, respectively (in solving this equation it is assumed, that on trial 0 nothing has been learned, that is $Y_{(t=0)}=0$). Both LS and FS were estimated by the Newton–Raphson method for non-linear regression (Dorn & McCracken, 1972).

2.4. Genetic modeling

Structural equation modeling (SEM) was used to decompose variance in LS and FS into genetic and environmental variances (e.g. Boomsma and Molenaar, 1986; Neale, Boker, Xie & Maes, 2006). These estimations are based on the assumption that monozygotic (MZ) twin pairs are genetically identical and share (nearly) 100% of their genetic material, while dizygotic (DZ) twin pairs and full siblings share on average 50% of their segregating genes (Boomsma, Busjahn & Peltonen, 2002). By adding an additional sibling in the analyses statistical power will increase (Posthuma & Boomsma, 2000). Additive genetic effects (A) represent the effects on the phenotype of multiple alleles at different loci on the genome that act additively. It is possible that effects of alleles do not simple add up and depend on the presence of other alleles, resulting in non-additive or dominance genetic effects (D). This results in a relatively large difference between MZ and the DZ correlations. Common environmental influences (C)

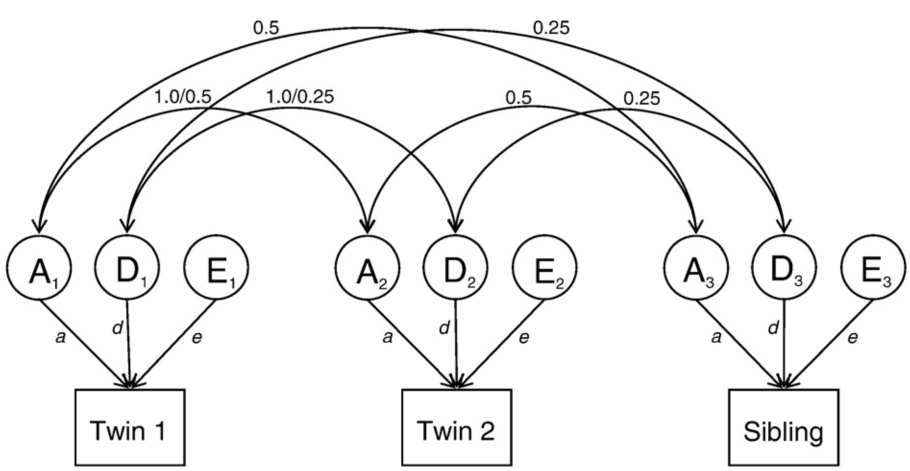

Fig. 1. Genetic ADE model for the LS and FS including the 9-years old twin pairs and their older siblings. Total variance in twins and siblings is explained by A (additive genetic), D (dominance genetic), or E (unique environment) effects. The covariance of the A component between twins (i.e. A_1 and A_2) or twin–sibling pairs is fixed at 1.0 and 0.5 for MZ and DZ, respectively. For twin–sibling pairs (i.e. A_1 and A_3 or A_2 and A_3) the covariance of the A component is fixed at 0.5. Covariance of the D component is fixed at 1.0 and 0.25 for MZ, DZ and twin–sibling pairs respectively. The influence of E is non-shared by family members.