Inspection Time and cognitive abilities in twins aged 7 to 17 years: age-related changes, heritability and genetic covariance

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Abstract

We studied the age-related differences in inspection time and multiple cognitive domains in a group of monozygotic (MZ) and dizygotic (DZ) twins aged 7 to 17 years. Data from 111 twin pairs and 19 singleton siblings were included. We found clear age-related trends towards more efficient visual information processing in older participants. There were substantial correlations between inspection time and cognitive abilities. The heritability of inspection time was 45%, and ranged from 73% to 85% for cognitive abilities. There were significant non-shared environmental effects on inspection time and Wechsler IQ scores, but no shared environmental effects. The genetic correlation between inspection time and Performance IQ was .55 and with Verbal IQ it was .28. There was a significant non-shared environmental correlation of .24 between inspection time and Verbal IQ.

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There has been a great deal of interest in inspection time as a psychological construct that correlates with general cognitive ability and might provide a partial foundation for individual differences in psychometric intelligence (Deary, 2000, chapter 7). This paper reports a cross-sectional study conducted on twins that assessed inspection time and psychometric tests of several cognitive abilities in children between the ages of 7 to 17 years. The twin design was used to examine the heritability of inspection time and cognitive abilities in childhood and adolescence. We examine the extent to which the association between inspection time and cognitive ability is associated with genetic or environmental factors by employing genetic covariance techniques.

Inspection Time as an Index of Processing Speed

The modelling and measurement of inspection time were developed in the 1970s (Vickers, 1970, 1979; Vickers, Nettelbeck & Wilson, 1972), from a theory of visual perception that assumes that information is acquired in small quanta from the environment. Each quantum is defined as an ‘inspection’, the characteristic stimulus duration needed by an individual in order to make a decision to a criterion level of accuracy (Vickers, 1970). An individual’s inspection time is the stimulus exposure time necessary for accurate perception, and is considered by many to be an index of the central nervous system’s speed of intake of information or speed of processing (Burns & Nettelbeck, 2003; Deary & Stough, 1996; Kranzler & Jensen, 1989; Nettelbeck, 1987; Nettelbeck & Wilson, 2004), although the precise nature of what inspection time measures is not fully understood (Deary, 2000, chapter 7).

Inspection times are significantly correlated with psychometric intelligence as measured by IQ-type tests; people with higher psychometric intelligence can make accurate perceptual judgements on the basis of shorter stimulus durations (Brand, 1981, 1984; Brand & Deary, 1982; Deary, 1993; Deary, Caryl, Egan & Wight, 1989; Grudnik & Kranzler, 2001; Kranzler & Jensen, 1989; Nettelbeck & Lally, 1976). Inspection times shorten over childhood, indicating more efficient information processing (Nettelbeck & Lally, 1979; Nettelbeck & Wilson, 1985, 2004). Furthermore, inspection times are substantially heritable (Luciano, Smith, Wright, Geffen, Geffen, & Martin, 2001; Posthuma, de Geus & Boomsma, 2001).

Visual inspection time measurement is usually undertaken as a two-alternative forced choice perceptual decision making task conducted under tachistoscopic presentation conditions with backward masking; Figure 1 shows an example of an inspection time stimulus. Typically, the task requires participants to make decisions on multiple trials about which one of two legs of an inverted u-shaped figure is longer. These stimuli are presented for a range of durations, from hundreds of milliseconds to very short durations in the range of several milliseconds. The inspection time describes the minimum stimulus exposure necessary for an accurate decision to be made about the stimulus's leg length. Each stimulus is followed by a backward pattern mask in order to control the effective processing duration of the stimuli. Participants need not make rapid responses to the stimulus since only the correctness of the response is noted; thus, inspection time tasks do not assess speed of reactions.

Insert Figure 1 about here

Inspection Time and Cognitive Abilities

The correlation in adults between inspection time and psychometric tests of cognitive abilities is well established. A meta-analysis that combined the results of 50 studies, comprising 2356 participants, found a corrected correlation coefficient between IQ and visual inspection time of -.49 (corrected correlation coefficients are adjusted for sampling error, measurement error and/or sample differences in variance; uncorrected *r* = -.32; Grudnik & Kranzler, 2001).

Inspection time has a stronger relationship with Performance IQ (PIQ) than Verbal IQ (VIQ) (Deary, 1993; Deary & Stough, 1996). Meta-analysis of multiple studies has reported inspection time-PIQ uncorrected correlation coefficients of approximately -.49 (corrected *r* = -.74) and inspection time-VIQ correlation coefficients of approximately -.3 in adults (Kranzler & Jensen, 1989). Two recent studies examining twins found correlations between inspection time and VIQ and inspection time and PIQ that were somewhat lower than those previously reported. Luciano, Smith, Wright, Geffen, Geffen & Martin (2001) reported uncorrected correlation coefficients between inspection time and PIQ of -.33 and inspection time and VIQ of -.26 in a study of 16 year old twins, while Posthuma, de Geus & Boomsma (2001) reported uncorrected coefficients of -.27 and -.19 for inspection time and PIQ, and inspection time and VIQ, respectively, in adults. Whereas the sample sizes in each of these twin studies exceeded Kranzler & Jensen's sample size, neither twin study encompassed the age range of the meta-analysis. Furthermore, there are likely to be other differences between the meta-analyses in the criteria used to select studies included in the analyses. In any case, the results of both twin studies replicate the finding that inspection time is more strongly correlated with PIQ than with VIQ. There is a common assumption that PIQ is more like fluid intelligence (Gf), while VIQ is more alike crystallised intelligence (Cattell-Horn model of intelligence, Horn & Cattell, 1966; Deary, 1993; Kline, 1991; Sattler, 1992), although see Burns & Nettelbeck (2003) for a different view). Thus, the stronger relationship between inspection time and PIQ than VIQ may reflect an association with fluid intelligence, rather than crystallised intelligence, although this has recently been questioned (e.g. Burns & Nettelbeck, 2003; Nettelbeck, 2001).

Many have argued that the relationship between inspection time and IQ is causal, with individual differences in inspection time causing individual differences in IQ (Anderson, 1992; Brand, 1981, 1984; Brand & Deary, 1982; Neubauer, 1997). Speed of processing has been argued to be the mechanism underlying this causal relationship (Anderson, 1992; Neubauer, 1997). However, others have suggested that a short inspection time is a consequence of being clever. The mechanisms proposed to underlie the suggested IQ→inspection time relationship include better macrolevel processing in more intelligent individuals (Ceci, 1990) and higher motivation (Mackintosh, 1986) or less anxiety (Irwin, 1984) in cleverer participants during inspection time task performance. A longitudinal study with a cross-lagged design, and subjected to structural equation modelling, used an auditory analogue of the inspection time procedure and IQ scores collected when children were aged 11- and then 13-years of age. It found that inspection time at age 11 predicted later IQ, but not the reverse, thus lending support to the argument that individual differences in inspection time cause individual differences in IQ (Deary, 1995).

Recent research has suggested that inspection time correlates more specifically with general speed of processing (Gs), rather than fluid ability (Gf) or general visualisation ability (Gv) (e.g. Burns, Nettelbeck and Cooper, 1999; Burns & Nettelbeck, 2003). An analysis of processes involved in Gs has suggested four factors: test-taking speed or visualization speed, perceptual speed, decision time and movement time (O'Connor & Burns, 2003; Stankov & Roberts, 1997; Roberts & Stankov, 1999). So where does inspection time fit with this more detailed analysis of processing speed? Inspection time has consistently been found to be independent of movement time (MT) (Burns & Nettelbeck, 2003; Carroll, 1991; Kranzler & Jensen, 1991). The relationship between inspection time and decision time (DT) is less clear and influenced by the type of DT task (Burns & Nettelbeck, 2003; Frearson & Eysenck, 1986; Bates & Eysenck, 1993). The relationship of the Perceptual Speed (PSp) factor to inspection time is well known because, as O'Connor & Burns (2003) point out, many studies showing associations between inspection time and Gs used PSp tasks to asses Gs (Burns & Nettelbeck, 2003; Burns et al., 1999; Mackintosh & Bennett, 2002). In the present study, we examined the link between inspection time and general cognitive ability by correlating inspection time task performance with performance on IQ tests and tests of more specific cognitive abilities such as memory, attention, visuospatial processing, sensorimotor skills and language.

The Development of Inspection Time in Children

The research investigating inspection time across childhood, although scarce compared to that with adults, has shown that inspection time improves with increasing age (Nettelbeck & Lally, 1979; Nettelbeck & Wilson, 1985, 2004). For example, a recent cross-sectional study found an improvement in inspection time between the ages of 6 and 13 years (Nettelbeck & Wilson, 2004). While IQ scores are subject to the Flynn effect and, thus, increase across populations over time (Flynn, 1999), inspection time may not be subject to this effect (Nettelbeck & Wilson, 2004). Nettelbeck & Wilson tested two cohorts of children with inspection time and the Peabody Picture Vocabulary test (PPVT; Dunn, 1965); one cohort was tested in 1981 and the second in 2001. Both cohorts were selected from the same school that catered to a similar social background at the two timepoints. Children tested in 2001 obtained higher scores on the PPVT when the original norms were used compared to their scores when the restandardised norms of the PPVT-III were applied. However, the inspection times were no different in the two cohorts. This suggests that inspection time may be stable across generations and may not be subject to the same cohort effects as IQ. Thus, age related improvements in inspection time in a cross-sectional study design are unlikely to be contaminated by the Flynn effect.

While measured inspection time has been shown to improve over childhood, not everyone agrees that this results from developmental increases in speed of processing. Anderson (1986, 1992, 2001) has argued that speed of processing remains constant from childhood to adulthood. He initially suggested that younger children performed poorly relative to their older peers because they were more affected by task demands, and that reducing the load on attention and/or motivation may improve the performance of younger children (Anderson, 1986, 1992). However, counter to this argument, allowing extensive practice has been shown to reduce, but not remove, developmental trends in inspection time (Nettelbeck & Vita, 1992), suggesting a resilient age-related improvement in inspection time. On the other hand, a longitudinal study found that just one exposure to an inspection time task resulted in an improvement in inspection time scores one year later that was greater than the effect of one year's ageing (Anderson, Reid & Nelson, 2001), leading Anderson to conclude that strategic advances, rather than ageing, underlie the observed developmental trend. More recently, Anderson proposed that it is changes in "response selection processes that contribute to speeded performance on many reaction time tasks" (Anderson, 2001, p.293) that underlie developmental decreases in inspection time. These processes include executive functions, in which there are well documented developmental improvements (Korkman, Kirk & Kemp, 1998). Here, we examine age-related changes in inspection time from the age of 7 to 17 years.

Speed of Processing: Development and Heritability

There are biological reasons why speed of processing might be expected to improve with age. Certain developmental changes that occur in the brain across the period of childhood and adolescence might be expected to lead to an increase in speed of processing (e.g. Courchesne et al., 2000; Giedd et al., 1999; Miller, 1994). Myelination starts in the prenatal period and continues up until about the age of 20 (for a discussion see Pujol et al., 2004) and one effect of this is to increase the speed with which information can pass along myelinated processes (Miller, 1994). Kail (2000) argues that age-related changes in the proposed domain-general processing system underlying reaction time improvements with age are, in part, due to underlying biological factors, such as myelination and changes in the number of synaptic connections, both of which change over childhood and adolescence. These mechanisms may operate across the life span; for instance, cognitive ageing involves slowing of processing speed (Salthouse, 1996), which is associated with decreases in myelination at the upper end of the age continuum (Bartzokis, 2004).

The question of whether there is a biological contribution to inspection time can be further addressed by using a twin design and examining the genetic contribution to inspection time. To date, there have been only two studies examining inspection time and IQ using a twin design: one considering the performance of 16-year-old children (Luciano et al., 2001), and a second that assessed both younger (mean age 26 years) and older (mean age 50 years) adult cohorts (Posthuma et al., 2001). There have been no studies so far examining the genetic contribution to inspection time in children under the age of 16. Estimates of heritability of inspection time can be obtained from the data reported in these papers by doubling the difference between the MZ and DZ intraclass correlations and expressing this as a percentage (by multiplying the outcome by 100). Using this approach, estimates of heritability of inspection time are obtained of between 26% (Luciano et al., 2001) and 56% (Posthuma et al., 2001).

Genetic covariance can take the study of the biological contributions to the inspection time-cognitive ability association even further than examining heritability. It can address the extent to which the correlation between inspection time and cognitive abilities is caused by genetic and environmental (shared and non-shared) factors. The shared environmental factor describes non-genetic, environmental factors that are responsible for differences between rearing families, whereas the non-shared environmental factor describes environmental influences that are not shared by members of the same rearing family. Both Luciano et al. (2001) and Posthuma et al. (2001) found that the model that best suited the data included an additive genetic factor and a non-shared environmental factor and excluded a factor that explained variance due to shared environmental influences. A further common finding was that a greater proportion of the variance in inspection time was explained by the unique environment factor (54% Posthuma et al.; 64% Luciano et al.), than the genetic factor (46% Posthuma et al.; 36% Luciano et al.). When considering the genetic correlations between inspection time and IQ, both papers found stronger genetic correlations between inspection time and PIQ than between inspection time and VIQ. In the case of Posthuma et al., the genetic correlation between inspection time and PIQ was .47, while it was .31 between inspection time and VIQ. Thus, 22% of the genetic variance in PIQ was explained by factors shared with inspection time, while 10% of the genetic variance was shared between inspection time and VIQ. In the case of Luciano et al., the genetic correlations between inspection time and PIQ and inspection time and VIQ were -.65 and -.47 respectively (the sign of the correlation coefficients in these two studies differs because of the methods used to calculate inspection time; in the case of Luciano et al, faster inspection times resulted in lower scores, while faster inspection times were associated with higher scores in the case of Posthuma et al). These correspond to 42% of genetic variance shared between inspection time and PIQ, and 22% shared between inspection time and VIQ.

Present Study

In the present study, we tested twin pairs and singletons aged from 7 to 17 years and obtained measures of inspection time, cognitive abilities using standardised IQ-type tests, and measures of neuropsychological functioning. Data were available from 240 children in total. Thus, the present sample of children provided data to allow us to assess inspection time changes across childhood and to consider the question of whether the inspection time-IQ relationships observed in adulthood are present in childhood. The present study also provides the first twin study examining the heritability of inspection time in children and the first child study of the genetic and environmental correlations between inspection time and IQ.

Method

Participants

Same sex twin pairs were recruited from a database of children who have been followed by the Multiple Births Foundation (MBF). The MBF is a charity that supports families with multiple births and also provides information to professionals. The majority of children registered with the MBF were either born at Queen Charlotte's and Chelsea hospital or attended a clinic there. Families with children of the appropriate age were contacted and invited to take part. Singleton siblings of twins in the sample were also recruited in order to increase the sample size in the behavioural analyses. Two hundred and forty one children took part in the cognitive testing that included inspection time; not all children completed all other tests.

There were 111 twin pairs and 19 singleton siblings (9 male; 10 female). Of the twins, 67 pairs were monozygotic (40 male; 27 female) and 44 pairs were dizygotic (27 male; 17 female). Zygosity was initially determined by ABO and Rh blood groups and, in twins with identical blood groups, by twelve independent polymorphic DNA markers. One child was excluded from the analyses because she was diagnosed with Attention Deficit Hyperactivity Disorder, thus compromising testing (MZ twin aged 8 years 7 months); removing this child reduced the sample to 240 children. In analyses that involved cross-twin comparisons, both members of this twin pair were excluded. Otherwise, data from the non-affected twin were included.

Twins were aged between 7 years 11 months and 17 years 3 months at the time of assessment (mean age at test 11 years 5 months; SD: 26 months). Singleton siblings were aged between 7 years 7 months and 16 years 7 months (mean: 12 years 6 months; SD: 33 months). Written informed consent was obtained from parents or guardians and assent from children, prior to testing. The study was approved by the local ethics committee.

A group of 10 twin pairs (8 MZ; 2 DZ) and 4 siblings were assessed during a week of intensive testing (intensive week protocol). Due to time constraints, these children were not administered the NEPSY standardised neuropsychological battery.

In addition, occasional subtests were omitted from the testing protocol for individual participants, for example, as a result of time limitations; the group size is stated in the appropriate tables.

Materials

The following series of psychometric assessments was administered.

Inspection time.

Inspection time was presented on a Compaq 300 Pentium III computer with an Iiyama VisionMaster Pro 410 screen running at a vertical refresh rate of 160 Hz. The task is the same as that described in Deary et al., (2004), but with a longer practice session. The cue, stimuli and mask are presented in Figure 1. The "+" shaped cue measured 4 mm by 4 mm. The stimulus was an inverted u-shape that was 25 mm across the top, 50 mm on the long leg and 25 mm on the short leg. The mask was a similar shape, but larger than the stimulus, and included an irregular array of vertical lines in order to cover the long and short stimulus lines completely. The mask was 25 mm across the top, both legs were 55 mm long and each leg was 14 mm wide at the widest point.

Each test trial began with the cue, presented for 500 ms. After an interval of 800 ms the inspection time figure appeared; 15 durations were used: 6, 12, 19, 25, 31, 37, 44, 50, 62, 75, 87, 100, 125, 150 and 200 ms. There were 10 trials at each duration and these were randomised over all trial presentations. Immediately after the stimulus offset, the mask was presented for 500 ms. After the mask, a "respond" command appeared at the bottom of the screen and participants pressed one of two keys to indicate the location of the longer leg; the right and left response keys indicated that the longer line was on the right and the left, respectively. Accuracy of responding, rather than speed, was emphasised. The "respond" command remained on screen until the child responded, or for 10 s, and no child failed to respond within this period. The screen presentations were tested and verified with a light detector applied to the screen and attached to an oscilloscope to check the timings.

There were three practice blocks to ensure familiarity with the requirements of the task. In practice block 1, the cue, stimuli and mask were introduced. The sequence of images of cue → stimulus → mask was demonstrated slowly, three times. Children were asked to say aloud which of the stimulus figure legs was longer and feedback was given. Practice block 2 comprised 15 trials with feedback; in trials 1-5 the stimulus was presented for 400 ms, for 150 ms in trials 6-10, and for 75 ms in trials 11-15. The longer leg alternated regularly between right and left. Practice block 3 comprised 10 trials with feedback. Five stimulus durations were used; 25, 50, 75, 100 and 125 ms. Each duration was presented with either a longer left or right leg and trials were randomised. All three practice blocks could be repeated if participants made substantial errors. The actual test trials were presented in five blocks, each comprising 30 randomised trials, with a brief break between blocks. No feedback was given in the test trials.

The inspection time score reported here is the sum of correct judgements over 150 trials; thus higher inspection time scores reflect better performance, and a score of 75 would be expected by chance.

Wechsler Intelligence Scales for Children Third edition (WISC-III).

A short form of the WISC-III (Wechsler 1992) was administered. VIQ was calculated using the Information, Similarities, Vocabulary and Digit Span subtests, while Picture Completion, Coding, Picture Arrangement and Block Design subtests were used to calculate PIQ (Sattler, 1992). Full Scale IQ (FSIQ) scores were based on all of the above subtests. In addition, Symbol Search was administered and, along with Coding, scores from these two subtests were used to calculate the Processing Speed index score. However, scores on Symbol

Search were not used to calculate IQ scores (Sattler, 1992). IQ and Index scores have a mean of 100 and a standard deviation of 15. Subtest scores have a mean of 10 and SD of 3.

NEPSY.

The NEPSY (Korkman et al., 1998) is a standardised neuropsychological assessment that measures ability in five distinct domains: Attention/Executive, Language, Sensorimotor, Visuospatial and Memory. While the initials NEPSY do not stand for individual words, the letters NE refer to neuro and PSY to psychology. All core subtests were administered and used to calculate the five domain scores, which have a mean of 100 and a standard deviation of 15. The population mean subtest score is 10 and the SD is 3. Since NEPSY norms cover the age range 3 years to 12 years, 11 months, no NEPSY data from children over the age of 13 years were included.

The results presented below, therefore, are based on a maximum of 240 children, except in the case of the NEPSY scores when a maximum of 155 children were included. Table 1 presents descriptive statistics for children given different protocols.

Insert Table 1 about here

Procedure

All children were tested individually at the MRC Childhood Nutrition Research Centre in London. The cognitive testing began in the late morning and continued to the late afternoon. There was a break for lunch and short breaks during the afternoon.

Statistical analyses

Children were grouped according to age quintiles and inspection time score was analysed across these groups in order to examine whether inspection time improves with age in a steady progression. In addition, the whole sample, with age as a continuous variable, was used in order to examine the age-related changes in inspection time. The second set of analyses examined the relationship between inspection time and IQ and NEPSY domain scores. We considered whether inspection time improves with age when mental age is controlled. In the first two sets of analyses the twin structure of the data was ignored. This has no effect on the estimates of the phenotypic correlation coefficients, but the estimated standard errors of the correlations are slightly too low. The third set considered genetic models of the data; we examined variance components and intra-class correlations from univariate and bivariate models. Components of variance between and within pairs of MZ and DZ twins were modelled in terms of a random effects model reflecting the contributions of additive genetic effects (A), shared environmental effects (C) and unique environmental effects, which also includes error (E). This is the so-called ACE model and follows the formulation of Jinks and Fulker (1970). The logic behind this model is that the resemblance of twins is caused by shared environmental effects and by additive genetic effects and that these effects can be separated when using MZ pairs and DZ pairs reared together (e.g., Plomin, De Fries, McClearn & McGuffin, 2001). MZ twins share all of their genes whereas DZ pairs have on average only 50% of their genes identical by descent. Therefore, if we assume that resemblance due to shared environmental effects is the same for MZ and DZ pairs, then a larger resemblance of MZ pairs when compared to DZ pairs is due to genetic factors. An alpha level of .05 was used for all statistical tests. Standard errors of the intra-class correlation are a function of their true values and the sample size. If the true MZ and DZ intra-class correlations are 0.6 and 0.3, then SE for 67 MZ and 44 DZ pairs are approximately 0.08 and 0.14, respectively (Visscher, 2004). Variance components were estimated by maximum likelihood, and the effects of sex and age (age at test in months) were fitted in the models as a factor and linear covariate, respectively. The ACE model assumes no dominance or non-additive genetic effects, no assortative mating and no GXE interaction.

Results

In order to describe the relationship between inspection time and age at test, children were grouped into quintiles based on age at assessment. Quintiles were used because these resulted in more even group *n* than stratifying by age. The first quintile described the youngest 20% of the sample, the second quintile the next 20% and so on. The mean age at test of children in quintile 1 was 8 years 10 months (range 7,7 to 9,6); quintile 2 mean was 10 years 3 months (range 9,7 to 10,8); quintile 3 mean was 11 years 2 months (10,9 to 11,7); quintile 4 was mean 12 years 8 months (11,8 to 13,10); quintile 5 was mean 15 years 2 months (range 13,11 to 17,3). Data on mean birthweight and gestational age were considered for both twins and singletons in each quintile and for the whole sample (data available from the authors). These birth data were examined because they are associated with cognitive test scores later in childhood and it is important to establish that any age differences in cognitive abilities and inspection time are not confounded with birth characteristics (Shenkin, Starr, & Deary, 2004). Over the whole sample, age at assessment was not associated with perinatal variables such as gestation length and birthweight; a regression of age at test on gestation and birthweight was not significant, $F(1,215) = .63$, $p = .53$. When considering the quintile groups, the birthweights and gestational ages of the twins were, as expected, lower than the values for singletons, but similar across quintiles.

Inspection Time and Age at Test

The overall mean inspection time score, defined as the number of correct judgements out of 150, was 121.1 (SD = 14.1). Mean inspection time scores are shown by age quintiles in

Table 2; the data show that mean inspection time score increases in each age quintile. A oneway ANOVA showed a significant effect of age quintile on inspection time score, $F,(1,235) = 23.39$, $p < .01$. Post hoc Sheffe tests revealed that the inspection time of the youngest age quintile was significantly lower than that of all other age quintiles; quintile 2 differed significantly from quintiles 1, 4 and 5 and quintile 3 differed from quintiles 1 and 5. Figure 2 shows psychometric curves showing stimulus duration by number correct, separately for each age quintile. Each quintile shows a similar s-shaped curve with those for older quintiles shifted to the left, indicating better performance. Similar s-shaped curves were observed in children of each gender (Figure available from the authors).

Insert Table 2 about here

Insert Figure 2 about here

In the whole sample, there was a positive relationship between inspection time score and age at test, $r = .51$, $p < .01$, as demonstrated in the scatterplot of inspection time scores presented in Figure 3. Using regression, there was a linear relationship between inspection time score and age at test; for every additional year in age, inspection time score increased by an average of 3.2 points (inspection time score = .27 age + 84.40; $F(1,238) = 85.1$, $p < .01$).

Insert Figure 3 about here

It is important to rule out the possibility that apparent age differences in inspection time might be confounded with differences in the children's family backgrounds. Therefore, we examined whether children in the different age-based quintiles came from similar families in terms of demographic variables such as parental qualifications and social code (based on standard occupational classification; Office of Population Census and Surveys, 1995). In each quintile, over 60% of fathers and 47% of mothers were educated to degree level or equivalent (fathers range from 61.2 to 75.6%; mothers range from 47.1 to 70.7%). Over 78% of households in each quintile were categorised as professional or managerial (range from 78.5 to 90.3%).

Age at test did not correlate significantly with parental qualifications (r = .08 for mother's, and .00 for father's) or social code (r = .09); therefore, there was no confounding of age and social position or parental education. Inspection time scores correlated significantly with mother's (r = .13, p < .05) and father's (r = .19, p < .01) qualifications. In the case of both fathers and mothers, the higher the level of qualifications obtained, the lower the social code; since low values for social code represent more professional job status, this relationship is in the expected direction. Social code itself did not correlate significantly with child's inspection time score (r = .03).

Inspection time, IQ, Processing Speed and NEPSY

Mean IQ scores, Processing Speed Index score, NEPSY domain scores and all subtest mean scores are shown in Table 3. All mean IQ, Index and Domain scores were above the population mean of 100 and within 1 SD of this mean; all standard deviations were similar to those expected in the population. In the case of subtest scores, almost all were within one SD of the expected mean of 10.

Insert Table 3 about here

Table 4 presents correlations between inspection time score, FSIQ, VIQ and PIQ scores, and the five NEPSY domain scores. These were calculated using both raw scores (not age-scaled; raw scores are shown above diagonal) and age-scaled (below diagonal) scores for the mental ability tests. The coefficients from the raw score analyses were larger than those obtained in the analyses using age-scaled scores; this occurred because both inspection time score and raw WISC-III scores improved with age. The correlations between inspection time and all three WISC-III derived IQ scores were highly significant, ranging from .50 to .58 in the case of raw scores, and between .19 to .27 in the case of age scaled scores. Almost all NEPSY domain scores correlated with inspection time scores significantly and in the expected direction. For raw Sensorimotor domain scores the correlation coefficients were negative. This occurred because a bigger value in the raw score indicates poorer performance; this sign is reversed when scores are age scaled. Coefficients between inspection time scores and age-scaled Visuospatial domain scores did not reach significance.

Insert Table 4 about here

Inspection Time and IQ, Mental Age and Chronological Age

Does inspection time score increase with age when IQ is held constant?

Older children had a higher inspection time score and inspection time score also correlated positively with FSIQ score (age scaled $r = .26$, $p < .01$; raw score $r = .58$, $p < .01$). The relationship between inspection time score and age remained significant when partial correlations were conducted that took FSIQ into account (age scaled $r = .53$, $p < .01$; raw score $r = .14$, $p = .03$). Therefore, there is an improvement in inspection time with age, over and above the general level of measured intelligence. There was a significant relationship between inspection time and WISC-III FSIQ raw score when age at assessment was held constant (raw score $r = .35$, $p < .01$). This association suggests that inspection time score is related to differences in measured general intelligence (mental age) over and above the effect of chronological age.

Insert Table 5 about here

Table 5 shows the correlation coefficients obtained when all raw NEPSY and WISC-III subtest scores were correlated with inspection time score, and age at test; we also show the correlation with age at assessment when inspection time score was covaried. The final column shows the percentage of variance in the relationship between subtest scores and age at test that is accounted for by inspection time score. Inspection time score makes a substantial contribution to the variance between age at assessment and many WISC-III subtests (overall range 27.0% to 45.9%). The contribution to the relationships between NEPSY subtests and age at test were more variable (overall range 10.3% to 100%).

Genetic Models

Variance components and intra-class correlations

Variance components and intra-class correlations for birthweight, IT and IQ measures were estimated for MZ and DZ twins separately, using maximum likelihood and a linear model in which age and sex were fitted. The estimates are similar to ANOVA-based estimates of the intra-class correlations. These data are shown in Table 6. For all measures, the between pairs variance was greater than the within pairs variance in the case of MZ twins, while the reverse was true for DZ twins. This is reflected in higher intra-class correlations for MZ twins compared to DZ twins.

On the inspection time measure, the zero estimate of between pair variance in the case of DZ twins was a result of a partial confounding between the effect of age and the effect of a twin pair. When age was removed, this between pair variance rose above zero, and the estimates are shown in the footnote of Table 6. This occurred because of the nature of the cross-sectional design. The displayed results from all twin analyses (Tables 8-10) are from fitting age and sex in the model of analysis

Insert Table 6 about here

Univariate ACE models.

Using Mx (Neale et al., 2002), univariate ACE models were fitted to WISC-III raw scores and inspection time scores (Table 7). Age at test (linear covariate) and sex were fitted in all analyses and the estimates of their effects are shown as the female minus male mean for sex and the increase per month of test for age. In all cases the contribution from the shared environment did not differ significantly from zero. The genetic contribution to WISC-III scores was approximately 80% of the variance, with the remainder accounted for by the unique environment/error term. The genetic contribution to inspection time scores was 45% of the variance, with 55% accounted for by the unique environment/error term. Because the shared environment did not contribute significantly to the WISC-III and inspection time scores, the models were re-run with only the A and E terms. The main difference as a result of this was a reduction in the 95% confidence intervals for the estimates of the heritability (h^2), but not for the proportion of total variance due to unique environmental effects (e^2). Since the MZ intraclass correlations were more than twice the DZ correlations for all traits except birthweight (Table 6), a model with dominance effects might be more appropriate. We fitted an ADE model to the data (results not shown in tables); this models additive genetic effects (A), dominant genetic effects (D) and unique environmental effects (E). However, A and D are highly confounded and there are not enough data to separate the two effects, as was evident from the very large 95% confidence intervals for estimates of the narrow sense heritability that varied from 0-0.6 to 0-0.9. Dominance variation was not significant for any of the traits, even for IT where the estimate of the additive heritability was 0. Dropping A from the model caused a non-significant reduction in the fit (as evident from the large confidence intervals for the heritability estimates), but a DE model is biologically not plausible. Therefore, the most parsimonious model for these traits is the simple AE model. However, our sample size is not large enough to conclude that non-additive genetic effects are not important for IT, hence we lack the power to reject dominance in an ADE model

Insert Table 7 about here

Bivariate models.

Bivariate models were performed using Mx. Only the A (additive genetic) and E (unique environment and error) terms were included, and sex and age at test were included as covariates. The hypothesis that the genetic correlation coefficient (r_g) or the unique environmental correlation coefficient (r_e) were significantly different from zero was tested using a likelihood-ratio-test. Results are shown in Table 8. The genetic correlation between inspection time and WISC-III Performance IQ was .55 ($p < .01$), and that between inspection time and Verbal IQ was .28 ($p = .03$). Only Verbal IQ showed a significant environmental correlation with inspection time, at .24 ($p = .04$). Therefore, shared genetic influences are a moderate to strong contributor to the phenotypic correlation between inspection time and WISC-III IQ scores, especially Full Scale and Performance IQ.

Insert Table 8 about here

Discussion

Summary of Findings

The study reported in this paper is the first twin study of inspection time in pre- and post-adolescent children, providing important data about the way in which inspection time changes with age, how it relates to different cognitive abilities, its environmental and genetic foundations, and its genetic and environmental correlations with cognitive abilities. Our data showed an improvement in inspection time with increasing age. When children were grouped into quintiles by age, the pattern was for inspection time to increase over each quintile. Age-related trends were not due to confounding with background variables such as birth characteristics or social position. Significant correlations were found between inspection time and general intelligence measured by IQ scores. The inspection time-IQ relationship persisted when age was taken into account. Thus, the results indicate that a similar relationship between inspection time and IQ is found in children to that observed in adults (Grudnik & Kranzler, 2001). We found significant correlations between inspection time and all WISC-III subtests. We also report moderately high heritability estimates for inspection time and higher estimates for IQ; the heritability of inspection time has not previously been reported in this age group. The models of genetic covariance of inspection time and IQ showed genetic and unique environment contributions to the shared variance.

Age-related changes in Inspection Time

Our findings are congruent with other studies that have reported that inspection time improves across childhood (Anderson, 1986, 1992, 2001; Nettelbeck & Lally, 1979; Nettelbeck & Wilson, 1985; 2004). It is unlikely that this age-related trend was due to differences in social background because, in our sample, social background was well controlled over the different age groups tested. In particular, our data correspond with those reported by Deary (1995), who showed an improvement in auditory inspection time across a similar age range. While the cross-sectional design does not allow inspection time development to be tracked in individual children, visual inspection of the data grouped by quintiles shown in Table 2 and Figure 2 indicates an improvement in each increasing age band. One advantage of the cross-sectional design is that it excludes practice effects.

Inspection Time and General Cognitive Ability

The correlation coefficients between age scaled IQ scores and inspection time were somewhat lower than those commonly reported in the literature (Kranzler & Jensen, 1989). However, they were very similar to those reported in two recent twin studies (Luciano et al., 2001; Posthuma et al., 2001). The correlations we report and those reported by Luciano et al. (2001) and Posthuma et al. (2001) may be lower than those reported in studies of singletons because twin samples may be somehow different to samples of singletons, perhaps in terms of factors such as early prenatal environment and upbringing. A large scale comparison of twins and singletons would be necessary to address the question of potential differences in such individuals. However, it is worth noting that approximately 40% of Posthuma et al.'s sample were singleton siblings of twins (calculated from data presented in Table II, p.595) and they reported that there were no differences between singletons and twins when examining mean scores.

Alternatively, the difference in correlation coefficients between studies of twins and studies of singletons could be a result of different sample sizes. Our sample size was larger than that in many studies of singletons and the other two twin studies in the literature had bigger samples still. However, these sample sizes are small compared to that available for Kranzler & Jensen's (1989) meta-analysis. One difference between Kranzler & Jensen's meta-analysis, our study and those of Luciano et al. (2001) and Posthuma et al. (2001), is that they all encompass different age ranges. It is possible that differences in the developing brain result in a different relationship between inspection time and IQ in children, than that observed in adults.

Considering the relationship between chronological age, mental age (raw IQ scores) and inspection time, we found that inspection time was related to differences in mental age over and above the effect of chronological ageing. This suggests that mental age does contribute to inspection time, in the direction of cleverer individuals having faster inspection time. However, taking into account general cognitive ability, we still found a chronological age-based improvement in inspection time. This is in contrast to the view proposed by Anderson et al. (2001) who argued that rather than chronological ageing underlying developmental improvements in inspection time, age related changes in strategic thought were responsible for advances in inspection time that occur as children age.

Inspection Time and Specific Cognitive Abilities

Few studies have examined correlations between inspection time and specific cognitive abilities in children. Using the NEPSY allowed us to assess the relationship between inspection time and five domains of cognition: Attention/Executive, Language, Sensorimotor, Visuospatial and Memory. Inspection time correlated significantly with all raw and age-scaled NEPSY domain scores, with the exception of the age-scaled Visuospatial domain score. Apart from Memory for Faces, all NEPSY subtests correlated significantly with inspection time.

Heritability and Genetic Covariance of Inspection Time and General Cognitive Ability

The genetic analyses of inspection time and IQ make a new contribution to the literature. To date, there have been only two twin studies examining heritability of inspection time and the genetic covariance of inspection time and IQ, neither of which investigated the age range of late childhood to early adolescence. Previous estimates of the heritability of inspection time were 26% (Luciano et al., 2001) and 56% (Posthuma et al., 2001) in cohorts of 16 year old children and adults, respectively. Our inspection time estimate fell between these two, at 45%. Our data provide the first estimate of the heritability of inspection time in late childhood/early adolescence and suggest that a high proportion of the variation in inspection time is genetic at this stage of development.

When modelling the sources of covariance of inspection time and IQ, a model containing genetic and unique environment factors was the best fit for the data. This model is congruent with those reported by Luciano et al. (2001) and Posthuma et al. (2001). We observed genetic correlations that were higher between inspection time and PIQ (.55) than between inspection time and VIQ (.24), a set of findings that is also consistent with Luciano et al. (2001) and Posthuma et al. (2001). Our data suggest that the foundation of the well established correlation between inspection time and PIQ is genetic. We found a within-individual environmental contribution to the relationship between inspection time and VIQ (.24), but not to the relationship between inspection time and PIQ (.06).

In our data, the heritability of PIQ was 73%, VIQ was 85% and FSIQ was 83%. Previously, IQ heritability has been estimated at approximately 50% on the basis of model-fitting analyses that combine data from many studies (Chipuer, Rovine & Plomin, 1990; Loehlin, 1989). IQ heritability increases across the lifespan, rising from 40% in childhood, to 60% in adulthood and 80% later in life (McGue, Bouchard, Iacono & Lykken, 1993; Pedersen, Plomin, Nesselroade & McClearn, 1992; Plomin, 1986; Plomin & Petrill, 1997). Thus, our data suggest a genetic contribution to IQ higher than that reported in the literature. Heritability is related to social class; it is lower in more deprived groups of children (Turkheimer at al., 2003). Thus, our high heritability may be associated with the advantaged status of our sample (the majority of families were professional or managerial).

Potential Limitations

For the most part, the sample studied here comprised twins. It is possible that twins may not be representative of the population and our results may not generalise to singletons. Measures of cognitive ability acquired from twins have been shown to be different from similar data acquired from singletons (Record, McKeown, & Edwards, 1970). However, it has been demonstrated conversely that IQ scores obtained from twins do not differ from those of singletons if the singletons to whom twins are compared are their own siblings (Posthuma, De Geus, Bleichordt & Boomsma, 2000). Assessment of a larger singleton sample would be necessary to examine whether our twin data extends to singletons.

Our study showed a clear age-related trend in inspection time over the whole age range tested. A larger sample size within each of the five age quintiles would be necessary to investigate whether inspection time increases at each of the five time points in a similar manner. The trend may be linear across childhood, or alternatively, it may be characterised by periods of change interspersed with periods of little or no change.

Future Work

Having established an age-related improvement in inspection time and the inspection time-IQ relationship in children, future work should investigate the mechanistic basis of these relationships. This could be approached in three ways. Firstly, the neural correlates of inspection time should be investigated. Two recent studies have shown developmental changes in brain structure over an age range similar to that tested in the present study (Courchesne et al., 2000; Giedd et al., 1999), and these changes may be associated with the age-related improvements in inspection time. Both studies reported that white matter volume increased in childhood prior to adolescence, with Courchesne et al. reporting a substantial increase of 74% from early childhood to adolescence (ages 12 to 15 years). Gray matter also increased in total over childhood, but showed different developmental changes in different lobes (Giedd et al., 1999).

More specifically, a recent fMRI study identified brain areas associated with performance of a visual inspection time task. Deary et al. (2004) found bilateral activation in the inferior fronto-opercular cortex,superior/medial frontal gyrus, and anterior cingulate gyrus, while bilateral deactivation was observed in the posterior cingulate gyrus and precuneus. MRI structural brain scans were acquired for a large proportion of our participants and we intend to use Statistical Parametric Mapping software (Ashburner & Friston, 2000) to conduct Voxel Based Morphometry (Wright, McGuire, Poline, Travere, Murray, Frith, Frackowiak, & Friston, 1995) analyses in gray and white matter to try to identify a structural correlate of the age-related changes in inspection time, using the areas found by Deary et al to make predictions about localisation. Because it has been hypothesised that the development in speed of processing may be associated with age-related increases in myelination, we would expect white matter particularly to be implicated. In future work we intend to look at the relationship between white matter tracts and inspection time by analysing Diffusion Tensor Image (DTI) scans that give detailed information about white matter tracts and their connections.

Secondly, future work should include the search for specific genes that contribute to the shared variance between inspection time and cognitive ability. Candidate genes will have to be identified; recent research has investigated the influence of *APOE* polymorphisms on cognitive function. ε4 status does not affect the level of mental ability in childhood or change across the lifespan (Deary, Whalley, St Clair, Breen, Leaper, Lemmon, Hayward & Starr, 2002), but poorer memory performance in middle-age has been found in individuals with at least one ε4 allele (Flory, Manuk, Ferrell, Ryan & Muldoon, 2000). *APOE* status may make a good candidate for exploring the genetic basis of inspection time because it has been linked to tasks involving processing speed (Anstey & Christensen, 2000). Blood samples were obtained for the majority of children in our sample study and we intend to ascertain *APOE* status in order to see if there is a relationship between ε4 status and inspection time.

Thirdly, environmental factors that improve the relationship between VIQ and inspection time should be identified. In our sample, fathers' and mothers' qualifications were significantly related to inspection time in children, but social code was not.

Conclusions

In conclusion, the results indicate that inspection time improves across the age range of 7 to 17 years, that inspection time is related to cognitive abilities in childhood as well as in adulthood, that inspection time is moderately heritable, and that genetic and non-shared environmental factors underlie the relationship between inspection time and IQ.

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Figure Captions

Figure 1. Inspection time figure.

Figure 2. Mean correct IT trials by stimulus duration and age quintiles.

Figure 3. Scatterplot of IT total correct by age at test.

Figure 1.

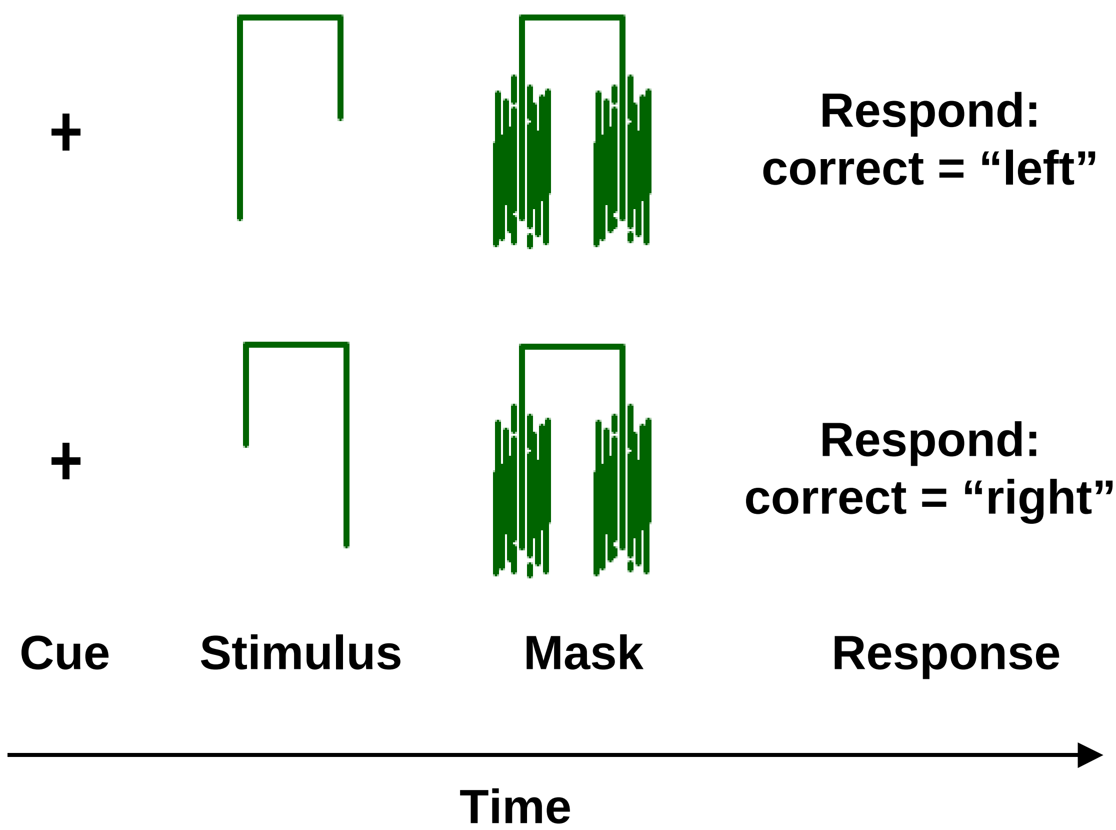
+
Respond:
correct = “left”
+
Respond:
correct = “right”
Cue
Stimulus
Mask
Response
Time

Figure 2

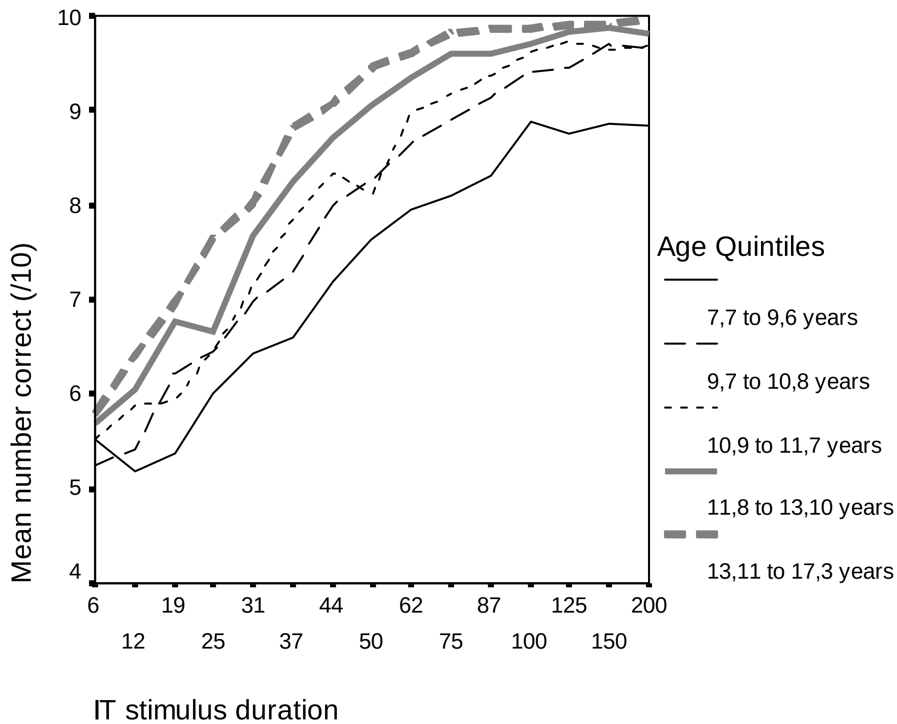
10
9
8
7
6
5
4
Mean number correct (/10)
6
19
31
44
62
87
125
200
12
25
37
50
75
100
150
IT stimulus duration
Age Quintiles
7,7 to 9,6 years
9,7 to 10,8 years
10,9 to 11,7 years
11,8 to 13,10 years
13,11 to 17,3 years

Figure 3.

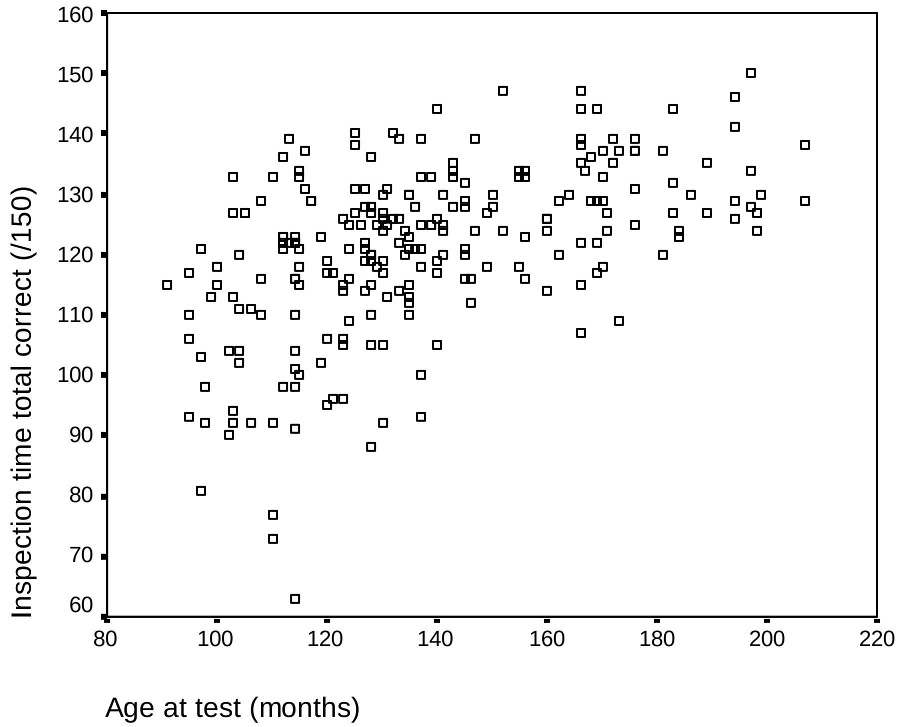
160
150
140
130
120
110
100
90
80
70
60
Inspection time total correct (/150)
80
100
120
140
160
180
200
220
Age at test (months)

Table 1. Zygosity, gender and age at test by protocol

Age group	Protocol	Zygosity[a] MZ; DZ; Sib *n*	Gender[a] M; F *n*	Age in months *M*	range
under 13 years	Younger Protocol (includes NEPSY)	86; 61; 8	88; 67	124	91-155
13 years & older	Older Protocol (excludes NEPSY)	32; 18; 3	34; 19	175	155-207
All ages	Intensive Week Protocol (excludes NEPSY)	16; 8;8	21; 11	142	98-199
Total	All Protocols	134; 87; 19	141; 97	138	91-207

Note. [a] the *n* refer to individual children.

Table 2: Mean Inspection Time score by age quintiles

Quintile	*n*	Inspection time (total correct)	
		M	*SD*
7,7 to 9,6 years	55	109.6	16.4
9,7 to 10,8 years	49	118.8	12.2
10,9 to 11,7 years	41	121.4	10.8
11,8 to 13,10 years	51	126.6	19.6
13,11 to 17,3 years	44	131.1	8.2
Total	240	121.1	14.1

Table 3: Mean scores on WISC-III IQ, Index and subtest scores and NEPSY domain and subtest scores for the total sample

Scores	*M*[a]	*SD*[b]	*n*[c]
IQ and Index scores			
FSIQ	108.2	15.7	240
VIQ	109.6	14.9	240
PIQ	104.5	16.7	240
Processing Speed	108.2	17.3	240
PIQ subtest scores			
Picture Completion	10.7	2.8	240
Coding	10.8	3.3	240
Picture Arrangement	10.7	3.9	240
Block Design	10.4	3.0	240
Symbol Search	12.3	3.7	240
VIQ subtest Scores			
Information	12.3	3.4	240
Similarities	12.2	3.1	240
Vocabulary	11.6	2.9	240
Digit Span	10.4	3.2	240
NEPSY Domain Scores			
Attention/Executive	104.6	13.4	153
Language	104.0	14.8	152
Sensorimotor	100.8	14.8	150

Visuo-Spatial	111.2	14.0	153
Memory	107.8	16.3	153

Scores	*M*[a]	*SD*[b]	*n*[c]
Attention/Executive subtest scores			
Tower	10.2	2.5	152
Auditory Attention and Response Set	10.3	1.9	155
Visual Attention	11.2	3.2	155
Language subtest scores			
Phonological Processing	10.6	2.4	153
Speeded Naming	10.9	2.5	152
Comprehension of Instructions	10.4	3.4	153
Sensorimotor subset scores			
Fingertip Tapping	9.8	2.5	152
Imitating Hand Positions	10.3	3.0	151
Visuomotor Precision	10.3	3.0	154
Visuospatial subtest scores			
Design Copying	13.3	2.3	155
Arrows	10.3	3.5	153
Memory subtest scores			
Memory for Faces	11.6	2.9	153
Memory for Names	10.3	3.1	153
Narrative Memory	11.4	3.4	153

Note. [a],[b] WISC-III IQ scores, Index scores and NEPSY domain scores have a population mean of 100 and a population standard deviation of 15. Subtest scores from WISC-III and NEPSY have a population mean of 10 and standard deviation of 3.

[c] Every child completed all subtests from the WISC-III. The NEPSY was administered to age-appropriate children; occasional subtests were omitted.

Table 4. Pearson correlations between IT score, WISC-III IQ scores and NEPSY domain scores in the whole sample. Age scaled scores are below the diagonal; raw scores above the diagonal

Measure	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. IT Score	–	.58**	.50**	.58**	.35**	.58**	-.22**	.33**	.38**
2. FSIQ	.26**	–	.90**	.97**	.54**	.76**	-.25**	.49**	.63**
3. VIQ	.19**	.89**	–	.77**	.44	.73**	-.20*	.38**	.62**
4. PIQ	.27**	.8**	.57**	–	.55**	.69**	-.25 **	.51**	.57**
5. Attention Executive	.28**	.58**	.50**	.54**	–	.53**	-.30**	.39**	.43**
6. Language	.30**	.73**	.72**	.61**	.59**	–	-.29**	.49**	.65**
7. Sensorimotor	.22**	.27**	.15	.35**	.42**	.33**	–	-.23**	-.19*
8. Visuospatial	.11	.48**	.40**	.48**	.29**	.47**	.36**	–	.30**
9. Memory	.27**	.58**	.55**	.48**	.54**	.56**	.26	.18*	–

* *p* < .05   ** *p* < .01

Table 5. Pearson correlations in the whole sample between WISC-III and NEPSY subtests (raw scores) and inspection time score, age at test and partial correlations with age at test covarying inspection time score; reduction in variance accounted for in the age correlation when inspection time score was partialled out.

Measure	Corr. with IT[a]	Corr. with age[b]	Corr. Age Cov. inspection time[c]	% reduction in covariance with age when inspection time-adjusted[d]
WISC-III				
Performance subtests				
Picture Completion	.42**	.54**	.42**	39.5
Coding	.57**	.73**	.61**	30.2
Picture Arrangement	.24**	.40**	.33**	32.0
Block Design	.58**	.61**	.45*	45.6
Symbol Search	.49**	.64**	.52**	34.0
Verbal subtests				

Measure	Corr. with IT[a]	Corr. with age[b]	Corr. Age Cov. inspection time[c]	% reduction in covariance with age when inspection time-adjusted[d]
Information	.44**	.67**	.58**	25.1
Similarities	.42**	.56**	.44**	38.3
Vocabulary	.48**	.67**	.56**	30.1
Digit Span	.41**	.49**	.35**	49.0
NEPSY				
Attention/Executive				
Tower	.27**	.17*	.06	87.5
Auditory Attention and Response Set	.26**	.11	.00	100
Visual Attention	.35**	.32**	.24**	43.8
Language				

Measure	Corr. with IT[a]	Corr. with age[b]	Corr. Age Cov. inspection time[c]	% reduction in covariance with age when inspection time-adjusted[d]
Phonological Processing	.28**	.27**	.17*	60.4
Speeded Naming	.62**	.40	.22**	69.8
Comp. of Instructions	.37**	.206*	.05	99.9
Sensorimotor				
Fingertip Tapping	-.32**	-.31**	-.23**	45.0
Imitating Hand Positions	.18*	.17*	.12	50.2
Visuomotor Precision	.26**	.23**	.12	72.8
Visuospatial				
Design Copying	.29**	.17*	.07	83.0
Arrows	.21**	.10	.03	91.0
Memory				

Measure	Corr. with IT[a]	Corr. with age[b]	Corr. Age Cov. inspection time[c]	% reduction in covariance with age when inspection time-adjusted[d]
Memory for Faces	.08	.17*	.16	11.4
Memory for Names	.41**	.40**	.29**	47.4
Narrative Memory	.29**	.18*	.07	84.9

Note. [a] the correlation between inspection time total correct and subtest score. [b]. the correlation between age at test and subtest score. [c]. the partial correlation between age at test and subtest score, covarying inspection time total correct. [d]. the % reduction in covariance between age at test and subtest score ([b]) when the additional variance explained by inspection time score was taken into account. This was calculated as the difference in variance between [b] and [c], expressed as a % of the variance in [b].

* $p < .05$ ** $p < .01$

Table 6. Maximum likelihood estimates of variance components and intra-class correlation coefficients for Birthweight, IT and IQ measures by zygosity

Trait	MZ				DZ			
	Between	Within	Intra-class correlation	*SE*	Between	Within	Intra-class correlation	*SE*
Birthweight	138739	130680	.515	.084	133653	87485	.604	.095
FSIQ	1041.7	190.7	.845	.033	326.5	662.8	.330	.133
VIQ	226.8	33.0	.873	.027	44.0	117.4	.273	.138
PIQ	387.3	145.8	.727	.054	174.7	358.7	.328	.133
IT	78.0	77.0	.503	.086	0[a]	140.5	.000[b]	.149

Note. [a and b] The zero estimate of between-pair variance of IT for DZ twins was from a model with sex and age fitted. When age was dropped from the model, the estimates of the between and within variance components and the intra-class correlation were 49.5, 145.2 and .254 respectively. When age was dropped from the model for the MZ, the parameter estimates were 129.4, 76.9 and .627 respectively.

Table 7. Genetic and environmental contributions (and 95% confidence intervals) to individual differences in WISC raw scores and inspection time scores.

Trait	A	C	E	h^2		c^2		e^2		sex		age	
				%	Confidence Intervals	%	Confidence Intervals	%	Confidence Intervals	estimate	Confidence Intervals	estimate	Confidence Intervals
FSIQ	955	0	190	0.83	0.47, 0.88	0	0, 0.36	0.17	0.12, 0.24	8.5	-2.8, 19.8	1.4	1.2, 1.6
VIQ	184	0	33	0.85	0.49, 0.90	0	0, 0.36	0.15	0.10, 0.22	-1.73	-6.7, 3.2	0.47	0.38, 0.56
PIQ	402	0	147	0.73	0.32, 0.81	0	0, 0.38	0.27	0.19, 0.38	10.2	2.6, 17.8	0.93	0.79, 1.07
IT	69	0	83	0.45	0.12, 0.62	0	0, 0.26	0.55	0.38, 0.75	3.3	-0.63, 7.2	0.28	0.20, 0.35

Table 8. Estimates of genetic (r_g), environmental (r_e) and phenotypic (r_p) correlations (95% confidence intervals) and *p* values.

Traits	r_g			r_e			r_p	
	Correlation	Confidence Interval	*p*	Correlation	Confidence Interval	*p*	Correlation	Confidence Interval
PIQ and VIQ	.67	0.54-0.79	$p < .01$	.08	-0.14-0.30	$p = .46$	.55	0.44-0.64
IT and FSIQ	.48	0.25-0.69	$p < .01$	.15	-0.08-0.37	$p = .20$	.34	0.20-0.46
IT and VIQ	.28	0.03-0.51	$p = .03$	.24	0.01-0.45	$p = .04$	.24	0.10-0.38
IT and PIQ	.55	0.30-0.51	$p < .01$	.06	-0.17-0.29	$p = .62$	.34	0.21-0.46