Relation Between Cognitive and Motor Performance in 5- to 6-Year-Old Children: Results From a Large-Scale Cross-Sectional Study

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The relation between cognitive and motor performance was studied in a sample of 378 children aged 5–6. Half of these children had no behavior problems; the others were selected for externalizing (38%) or internalizing problems (12%). Quantitative and qualitative aspects of motor performance were related to several aspects of cognition, after controlling for the influence of attention. No relation between global aspects of cognitive and motor performance was found. Specific positive relations were found between both aspects of motor performance, visual motor integration and working memory, and between quantitative aspects of motor performance and fluency. These findings reveal interesting parallels between normal cognitive and motor development in 5- to 6-year-old children that cannot be ascribed to attention processes.

Over the years, there has been a stable interest in the relation between cognitive and motor performance in children. Most research that has focused on this topic assumed a relation between the global aspects of cognitive behavior and those of motor behavior. However, little experimental evidence exists that supports this assumption. In this study, we investigated both the global relations and the more specific links between cognitive and motor behavior.

A global-to-global relation between cognitive and motor behavior was assumed by Bushnell and Boudreau (1993), who stated that motor development might determine the sequence in which certain perceptual and cognitive abilities unfold. This notion is experimentally supported by the finding that the development of spatial search skills in children is facilitated by locomotion experience; however, this facilitation does not appear to provide any long-lasting benefits to children who achieve locomotor milestones early (Kermoian & Campos, 1988; Lehnhung et al., 2003; Yan, Thomas, & Downing, 1998).

The effect of delayed or deviant motor development early in life has been investigated by a number of researchers. For example, idiopathic toe walking, a motor abnormality without a known cause, is considered to be a precursor of developmental language and learning problems (Sala, Shulman, Kennedy, Grant, & Chu, 1999; Shulman, Sala, Chu, McCaul, & Sandler, 1997). Also, impaired motor function early in life is a precursor of problems with language acquisition and attention skills later on (Amiel-Tison et al., 1996; Cantell, Smyth, & Ahonen, 1994; Hadders-Algra & Groothuis, 1999; Hamilton, 2002). For instance, in a 10-year follow-up study, the academic, social, and emotional problems associated with “clumsiness” (Losse et al., 1991), later referred to as developmental coordination disorder (DCD, American Psychiatric Association [APA], 1994), at age 6 were still present at the age of 16 (Losse et al., 1991).
In other studies, motor performance at pre-kindergarten age has been found to be related to reading and language achievement in the first grade (Solan & Mozlin, 1986; Wolff, Gunnoe, & Cohen, 1985).

The discussion on the relation between global aspects of cognitive and motor performance was started many centuries ago by Descartes (1596–1650), who stated that cognitive processes are entirely different from motor processes (Hattiefield, 2003). More recently, Piaget argued that cognitive and motor processes cannot be seen as separate entities because cognitive development relies totally on motor functioning (Piaget & Inhelder, 1966). One of the major criticisms on Piaget’s theory of cognitive development is that he gave too little consideration to the motor possibilities and impossibilities of the young child (Berger, 1988). Moreover, little experimental evidence exists that supports his assumption of a global-to-global relation. Churchland (1986, 2002) formulated the relation between cognitive and motor performance more subtly, stating that if we want to understand cognition, we may need to understand its emergence in evolution, and, as a result, we may need to understand its origins in sensorimotor control. In other words, Churchland hypothesized the existence of a continuum of motor and cognitive functions, with lower (sensorimotor) functions (e.g. grasping and visual perception) at the one end, and higher cognitive functions (e.g. planning and regulating of behavior) at the other end (Churchland, 1986).

Neurobiological evidence for specific relations between cognitive and motor development is derived from recent work in which it was shown that both complex cognitive and motor development continues into early adulthood (Diamond, 2000). Evidence exists that aspects of cognitive performance related to abstraction, behavioral planning, and executive functioning develop between 5 and 10 years (Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Anderson, 2002), an age when motor processes, such as movement control and visuomotor coordination, develop rapidly (Ferrel-Chapuis, Hay, Olivier, Bard, & Fleury, 2002). Historically, the pre-frontal cortex has been thought to be critical for the most complex cognitive abilities, whereas the cerebellum would fulfill this role for motor skills. Conversely, recent research using functional brain imaging techniques showed the cerebellum to be active during new, complex cognitive operations as well (Berman et al., 1995; Diamond, 2000; Raichle, 1994; Schlosser et al., 1998). Other structures, such as the basal ganglia and the frontal cortex, and certain neurotransmitters, such as dopamine, are also believed to be involved in particular higher order aspects of both cognitive and motor performance (Diamond, 2000; Geurts, 1997; Kandel, Schwartz, & Jessell, 2000).

Interestingly, research focussing on developmental disorders, such as attention deficit hyperactivity disorder (ADHD), DCD, and developmental apraxia of speech (DAS), has suggested that cognitive and motor performance are associated. These developmental disorders co-occur with both cognitive and motor function deficits (DCD: Dewey, Kaplan, Crawford, & Wilson, 2002; Hamilton, 2002; Mandich, Buckolz, & Polotajko, 2003; Pitcher, Piek, & Hay, 2003; Visser, 2003; DAS: Nijland, 2003; ADHD: Klimkeit, Sheppard, Lee, & Bradshaw, 2004). Children who are at risk of dyslexia because of a family history often show delayed motor development in the first year of life (Viholainen, Ahonen, Cantell, Lyttinen & Lyttinen, 2002).

Overall, little experimental evidence exists to support a global-to-global relation between cognitive and motor behavior. Past research suggests a more specific association between aspects of cognitive and motor performance. However, it is hard to establish whether this relation is direct, or whether the link is mediated by some other factor. A factor that is known to mediate both cognitive and motor performance is attention (Baron, 2004; Lezak, Howieson, & Loring, 2004). The study of Lehnung et al. (2003), mentioned above, controlled for this by including only children who performed within normal limits on attention tasks. In most studies examining the link between cognitive and motor performance, attention was not controlled for (Sala et al., 1999; Yan et al., 1998). Furthermore, most studies in which the relationship between cognitive and motor performance in children was investigated were performed with children already at risk of cognitive problems because of their motor problems or vice versa, and attention is often impaired in such groups (Tannock, 2003). Therefore, the aim of this study was to investigate the attention-controlled relation between cognitive and motor performance in a sample including both normally and sub-normally performing children. The Child Behavior Checklist, a questionnaire that measures general pathology and is completed by parents (CBCL, Achenbach, 1991; translated into Dutch by Verbulst, van der Ende, & Koot, 1996) was used as a selection criterion.

A large sample of children aged 5 and 6 years was included to control for the influence of specific tasks and sex. Five- to 6-year-olds were chosen because little is known about the development of so-called “higher” cognitive processes in this age group. Previous
research has focused for the most part either on very young children (Diamond, 1985, 2002) or on children aged 7 years and older (Anderson, 2002; Anderson et al., 2001; Schonfeld, Shaffer, & Barmack, 1989). Additionally, it has been suggested that adequate motor performance at the age of 5–6 years is a prerequisite for learning. Inadequate motor performance is thought to be a marker of possible academic problems (Losse et al., 1991). However, the direct link between early motor difficulties and later academic performance has not been explicitly established.

With regard to the influence of sex on motor performance, it is well known that motor problems generally occur more in boys than in girls (APA, 1994; Dewey et al., 2002). Therefore, it could be expected that the relation between cognitive and motor performance would be more pronounced in boys than in girls. For this reason, analyses were performed both for the total group, and for boys and girls separately.

In our study, several aspects of both cognitive and motor performance were measured. With regard to cognition, we measured aspects of verbal and perceptual abilities, working memory, and executive functioning (as advised by Lezak et al., 2004). Results were analyzed both separately and in combination, as an estimate of general cognitive performance. With regard to motor performance, both quantitative and qualitative aspects were measured (Kroes, 2002; Kroes, Kessels, et al., 2002, 2004; Largo et al., 2001; Largo, Fischer, & Rousson, 2003; Prechtl et al., 1997). The quantitative aspects of movement reflect the acquisition of motor milestones, whereas qualitative aspects capture the acquisition of fundamental movement patterns (Boyce et al., 1995). Children with developmental disorders often display impaired qualitative motor performance, such as deviant gracefulness and lack of precision (Farber & Nijoki, 1993), while motor milestones are achieved at the appropriate age. Qualitative aspects of movement, in particular, are considered to reflect the maturity and integrity of the brain (Hadders-Algra & Groothuis, 1999; Prechtl et al., 1997). Qualitative aspects may, therefore, be more relevant than quantitative aspects in predicting overall developmental cognitive problems. In an earlier study, qualitative but not quantitative aspects of motor performance were found to be related to ADHD (Kroes, Kessels, et al., 2002). Thus, it was expected that qualitative aspects would be better related to cognitive performance than quantitative aspects. We investigated both aspects of motor performance and how these aspects were associated with cognitive performance.

In sum, this study focused on the attention-controlled relation between cognitive and motor performance in 5- to 6-year-old children, while the effect of sex was studied as well. Moreover, cognition was measured with several tests that were analyzed separately and in combination, and the difference between quantitative and qualitative aspects of motor performance was addressed as well.

Method

Participants and Procedure

This study is part of “the Study of Attention disorders Maastricht (SAM),” which is a multidisciplinary research program carried out by the Brain and Behaviour Institute, University of Maastricht (Departments of Neuropsychology & Biological Psychology), the University Hospital of Maastricht (Departments of Neurology, Pediatrics, and Psychiatry & Neuropsychology), the Youth Health Care (YHC) Division of the Regional Public Health Institute of Maastricht, and the Child Rehabilitation Centre Franciscausoord. A prospective four-stage longitudinal research design was used, of which only the first two stages are relevant for this study (for a full description of the SAM study, see Kalff et al., 2002; Kroes et al., 2001).

First stage. In the Netherlands, all children are periodically invited for a health examination by the YHC. About 98% of parents respond to this invitation. In the school year 1996–1997, all children (as a rule aged 5–6 years) attending the second grade of normal kindergarten in Maastricht, the Netherlands and immediate surroundings (n = 2,290) were invited to participate in the study during the periodic health examination performed by the YHC organization. The parents of 1,317 children (699 boys and 618 girls, mean age 5.87 years, SD = .40) decided to participate in the SAM study and filled out the CBCL (Achenbach, 1991; translated into Dutch by Verhulst et al., 1996). Not all parent pairs were Dutch natives; about 10% were born in a country outside the Netherlands (n = 141). However, it was ensured that all participants (parents and their child) had an adequate command of the Dutch language so they would be able to complete the questionnaires and examinations. Socioeconomic status was as follows: 35.8% low, 29.4% middle, 33.9% high, and .9% missing. Parental level of education was distributed as follows: 36.1% high (higher vocational education to university), 40.4% middle (lower general secondary education to pre-university education), 14.0% low (primary education to lower vocational
education), and 9.4% missing. Most children lived with both parents (88%), whereas 10.7% lived with one parent.

Responders and non-responders were compared by randomly sampling 200 children from both groups. Information concerning non-responders was obtained anonymously from YHC records, which is permitted by law. No significant differences were found with regard to age, sex, and demographic factors and, therefore, the responders can be considered a fair sample of the original population (Kroes et al., 2001).

To select not only normally developing children, but also children at risk of behavior problems, the CBCL score was used. Two groups were created: an Externalizing group (E), which included children with CBCL externalizing-scale scores above the 90th percentile and/or CBCL attention problem scores above the 95th percentile (n = 173), and an Internalizing group (I), which included children with CBCL internalizing-scale scores above the 90th percentile and who did not fulfill the criteria for group E (n = 59). A control group was formed, consisting of children who were matched to the children from groups E and I on the basis of age (± 3 months), sex, and school area, and whose CBCL total problem scale scores fell within the normal range (n = 220).

Four to 9 months later, the 452 selected children were invited to participate in the second stage, which consisted of a neuropsychological evaluation (n = 400; see for a previous report on this population Kalff et al., 2002) and a semi-quantified evaluation of motor behavior (n = 438; Kroes, 2002; Kroes et al., 2004; Vles, Kroes, & Feron, 2004). A total of 378 children (213 boys, 165 girls, mean age 6.18 years (SD = 4.5)) completed both the motor and the cognitive evaluation. Of these children, 187 fell in the control group (49.5%), 145 fell in the externalizing group (38.3%), and 46 fell in the internalizing group (12.2%).

Instruments

Cognitive instruments. The neuropsychological test protocol investigated language, visuo-perception, construction, attention, and executive functioning, as suggested by Lezak, et al. (2004). The protocol included for all cognitive aspects 1 or more tests suitable for the assessment of children in elementary school, with satisfactory reliability and validity. All outcome variables were transformed to standard scores according to age norms.

The Beery Developmental Test of Visual Motor Integration (VMI Beery; Armstrong & Knopf, 1982; Beery, 1997) was used to measure the integration of visual perceptual and fine motor abilities. In this test, the child is asked to copy 24 increasingly difficult geometric forms and is not allowed to use an eraser. The outcome is the number of correctly copied forms according to both quantitative and qualitative standards. Standard scores range from 1 to 19 (mean = 10, SD = 3).

The Picture Vocabulary test of the Revised Amsterdam Child Intelligence Test (RAKIT; Bleichrodt, Drenth, Zaal, & Resing, 1987; Evers, van Vliet-Mulder, & Groot, 2000) measures passive vocabulary ability. It closely resembles the Peabody Picture Vocabulary test (Dunn, Robertson, & Eisenberg, 1979), a commonly used instrument to estimate verbal intelligence (Marakovitz & Campbell, 1998). Also, the Picture Vocabulary test is related to the verbal tasks of the WISC-R: the correlation between the Picture Vocabulary and the WISC-R Vocabulary tests has been established as r = .30. In a study investigating the relation, the RAKIT and the WISC-R, Picture Vocabulary loaded together with the verbal WISC-R tasks Information, Similarities, Mathematics, Vocabulary, and Comprehension on one factor when using a factor analysis (Bleichrodt, Resing, Drenth, & Zaal, 1987). During the Vocabulary subtest, the child must choose one of four pictures shown that matches the word the psychologist reads aloud. These words increase in complexity. Outcome is the number of correctly chosen pictures. Standard scores range from 1 to 29 (mean = 15, SD = 5).

The Verbal Fluency test of the RAKIT (Bleichrodt et al., 1987; Evers et al., 2000) was used to measure the ability to retrieve information from semantic memory as well as verbal organization, as a measure of attention capacity and executive functioning. The child is asked five questions (including concrete and more abstract questions, e.g. “What can you drink?” , “What can you do on the street?”) and must generate as many answers as possible within 1 min (per question). The outcome is the number of correct answers for all five questions combined. Standard scores range from 1 to 29 (mean = 15, SD = 5).

The Embedded Figures test of the RAKIT (Bleichrodt et al., 1987; Evers et al., 2000) is a test of perceptual functioning that measures visual analysis, pattern recognition, and matching. Also, selective attention is important for resisting the distracting stimuli. The child is shown a complex picture with intersecting lines and six simple drawings beneath it. The task is to recognize from the simple drawings the one that is completely presented in the complex picture. The drawings increase in complexity. The outcome is the total number of correctly recognized drawings. Standard scores range from 1 to 29 (mean = 15, SD = 5).
The Gestalt Closure test of the Kaufman Assessment Battery for Children (K-ABC; Kaufman & Kaufman, 1983) was used to measure perceptual closure. The child is asked to name a series of drawings, which are only partially completed. These drawings increase in complexity. The outcome is the total number of correctly identified drawings. Standard scores range from 1 to 19 (mean = 10, SD = 3).

The Number Recall test and the Word Order test of the K-ABC (Kaufman & Kaufman, 1983) were used to measure attention span and auditory working memory. The Number Recall test consists of a series of strings of digits that are presented verbally to the child. The child is subsequently asked to repeat these digits in the same order. The digit strings are progressively longer. The outcome is the number of correctly repeated strings.

In the more complex Word Order test, which also measures inhibition, the child must point to a sequence of pictures in the same order as the test assistant reads aloud the names of the objects. For children older than 5 years, there is a second, interfering part, in which the child has to name colored dots before pointing out the sequence of pictures. The outcome is the number of correctly pointed sequences over both parts. Standard scores for both tests range from 1 to 19 (mean = 10, SD = 3).

The Progressive Figures Test (Reitan & Wolfson, 1985) is part of the original Halstead–Reitan neuropsychological battery and was used in this study to measure working memory, mental control, and attention switching. The child is presented a sheet of small figures within larger figures and is asked to connect each small figure with the identical larger figure using a pencil. Each pair of figures is unique. The small figures within the larger figures point out the sequence of connecting. To do this, the child constantly has to switch between small and larger figures. Outcome is the amount of time the child needs to complete the task successfully.

The Sustained Attention and Focussed Attention tasks of the computerized test battery, Amsterdam Neuropsychological Tasks (ANT; De Sonneville, 1999), were used to measure attention. During both tasks, the child is required to respond as rapidly and accurately as possible to visual stimuli presented on a laptop screen. Trials with response times falling outside a pre-defined valid response window (200–8000 ms post-stimulus onset) were automatically replaced by similar trials. The Sustained Attention task is a variant of a continuous performance task. During this task, a house is continuously depicted on the screen. In each of the trials, an animal is randomly placed in one of the three windows. The child is instructed to press the “yes” key with the preferred hand when the animal is a bee (target signal) and the “no” key with the non-preferred hand when the animal is a cat or mouse (non-target signals). In total, there are 20 series with 12 trials, each containing six targets and six non-targets. Visual feedback on error responses is given by a red square that appears in the center of the house. In the Focussed Attention task, a fruit basket is continuously depicted on the screen. Each of the 56 trials consists of the simultaneous presentation of four pieces of fruit in the basket. These pieces are aligned on a vertical (top and bottom) and on a horizontal axis (left and right). The child is instructed to attend to the vertical axis and to ignore the horizontal axis. Whenever there are cherries on the vertical axis (target signal), the child has to press the “yes” key. In all other conditions (cherries on the horizontal axis (irrelevant target signal) or no cherries (non-target signals)), the child has to press the “no” key. These three types of signals are randomly presented (28 target signals, 14 irrelevant target signals, and 14 non-target signals). For both ANTs, two outcome variables were used, namely mean median of speed (in ms) as an index for speed of information processing and the mean within-subject standard deviation of reaction times as a measure of speed variability.

Motor performance instrument. The Maastricht Motor Test (MMT: Kroes, 2002; Kroes et al., 2004; Vles et al., 2004) was developed to score the quality and quantity of movement in an objective way in children in the second year of kindergarten (age 5–6 years). The MMT measures motor function in 4 areas: static balance (14 items), dynamic balance (20 items), ball skills (8 items), and diadochokinesis and manual dexterity (28 items). In the diadochokinesis tasks, the children were shown sequences of movements, such as tapping the hand on the table, and were told to repeat these sequences as fast as they could. Of the total of 70 items, 36 deal with qualitative and 34 with quantitative aspects of motor function. For example, one of the ball skills items requests the child to bounce the ball five times while standing still. The qualitative aspect of this item involves whether the child can maintain balance and catch the ball with both hands in front of the body. The quantitative aspect involves how many times the child is able to bounce the ball. The scores of the four areas are combined in a total score, a quality score and a quantity score. The inter- and intra-observer reliability of the MMT total, quality, and quantity scores ranges from .92 to .96 (Kroes et al., 2004). The test–re-test reliability of the MMT ranges from .61 to .74 (Kroes et al., 2004), but because motor control and
Visuomotor coordination develop rapidly in children of this age (Ferrel-Chapus et al., 2002), scores are not expected to be constant (Kroes et al., 2004). Validity was calculated by using a Receiver Operating Characteristic Curve with the school doctor’s judgement being used as final outcome. Areas under the curve were relatively high: .81 for the quantitative score, .86 for the qualitative score, and .87 for the total score of the MMT (Kroes et al., 2004).

Statistical Analyses

A compound score was calculated as an overall measure of cognitive performance, using the mean of the z-scores of all tests administered, except the Focused and Sustained attention tasks (cf. De Groot et al., 2000, 2001; Van Boxtel et al., 1998). The relation between this overall measure of cognitive performance and motor performance was investigated by linear regression analyses with the three motor performance measures (total, quality, and quantity of motor performance) as independent variables and the overall measure of cognitive performance as dependent variable. Linear regression analysis was also used to investigate the relation between cognitive performance (dependent variable) and motor performance (independent variable) for each cognitive variable.

Logistic regression analysis was used to investigate the nature of the specific relations between cognitive and motor performance. Compared with the test means, cognitive scores were divided more or less normally, and were trichotomized: “Cognition below average” (a score of 1 or more standard deviation(s) below the test mean), “Cognition average” (a score between 1 standard deviation below and 1 above the test mean), and “Cognition above average” (a score of 1 or more standard deviation(s) above the test mean). This classification left about 23% of all participants in each of the “Cognition below average” groups, about 59% in each of the “Cognition average” groups, and about 18% in each of the “Cognition above average” groups.

On the other hand, MMT scores were skewed to the left in our sample compared with the test mean, i.e., there were more children who obtained high scores than children with low scores. Therefore, motor scores were dichotomized as follows: “Motor below average” (a score of 1 or more standard deviation(s) below the test mean) and “Motor average” (score higher than 1 standard deviation below the test mean). This classification left about 5% of all participants in the motor below average groups, and 95% in the motor average group.

Then separate logistic regression analyses were performed for the “Cognition below average” versus the “Cognition average” condition (dependent variable) and the dichotomized motor scores, and for the “Cognition above average” versus the “Cognition average” condition (dependent variable) and the dichotomized motor scores.

All analyses described above were executed without statistically controlling for attention. Next, a compound score of the four attention variables was calculated, and this compound score was included in all analyses to control for the influence of attention.

Sex was included in all analyses to control for a possible confounding effect. The significance level was set at .05. Because the study population was selected on the basis of the CBCL score, the group was not a random sample of the total population. To control for possible sample bias, all analyses were weighted for selection characteristics (sex, age, and rural or city environment), using the “sampling weight option” of STATA 8 (Statacorp, 2003). The weights were calculated as the inverse of the probability of selection (Kroes, Kalff, Steyaert, et al., 2002).

Results

Linear Regression Analyses

Pearson’s bivariate correlation between the quantity total score and the quality total score of the MMT was calculated to ensure that analysis of the two aspects of motor performance separately was justified. A correlation coefficient of .545 was found ($p < .001$).

The estimate of general cognitive performance was found to be significantly related to all three motor performance measures, i.e., total, quality, and quantity of motor performance. After we statistically controlled for attention, however, the relation with quantity of motor performance disappeared (see Table 1). To filter out the influence of those cognitive tasks with a substantial motor component (VMI and Progressive Figures), the estimate of cognitive performance was recalculated without these two measures. The relation of this new compound score with motor performance did not reach significance, when attention was controlled. This argues against a global relation between cognitive and motor performance.

Initial analyses using separate linear regression analyses indicated that four aspects of cognitive performance (VMI, Word Order, Embedded Figures, and Verbal Fluency) were related to several aspects of motor performance. After statistically controlling for attention, however, only the relations between all
aspects of motor performance and VMI and Word Order remained significant, as well as the relation between quantity of motor performance and Verbal Fluency (see Table 1).

### Logistic Regression Analyses

Logistic regression analyses, corrected for attention (see Tables 2A and 2B), showed that motor performance had a significant effect on three cognitive variables in the cognition below average/cognition average condition: VMI (quality of motor performance), Verbal Fluency (quantity of motor performance), and Word Order (all three motor performance measures). The odds ratios (ORs) were higher than 1, which implies that the children with a score below average on the motor measures also performed below average on the cognitive measures. In the cognition average/cognition above average condition, no cognitive variable was significantly associated with motor performance measures, although the relation between Embedded Figures and quality of motor performance approached significance.

### Sex

The influence of sex was addressed by repeating the analyses separately for boys and girls. The relation between general cognitive performance and quantitative and total motor performance remained significant in both boys and girls. However, the relation between general cognitive performance and qualitative motor performance was significant only in boys. After controlling for attention, only the relations in girls remained significant.

When attention-controlled logistic regression analyses between specific cognitive measures and motor measures were performed separately for boys and girls, it was found that the relation between VMI and motor performance was of equal strength in boys and girls. The relation between Verbal Fluency and quantity of motor performance occurred solely in boys, while the relation between Word Order and motor performance was significant only in girls.

When attention-controlled logistic regression analyses were performed separately for boys and girls, it was found that the relation between VMI and motor performance was significant in both sexes. However, different relations were significant in boys and girls: in boys only, lower performance on the Verbal Fluency test was related to a lower quantity of movement, and in girls only, lower performance on the Word Order test was related to lower quantity, quality, and total motor performance.

### Psychopathology

It is likely that some of the children studied here might have displayed signs of psychopathology, which could have influenced the results. To evaluate

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**Table 1**

**Linear Regression Analyses, Statistically Controlled for Attention**

<table>
<thead>
<tr>
<th></th>
<th>Total motor score</th>
<th>Quality motor score</th>
<th>Quantity motor score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coef. 95% CI</td>
<td>Coef. 95% CI</td>
<td>Coef. 95% CI</td>
</tr>
<tr>
<td>General estimate</td>
<td>0.01 (−0.001−0.01)</td>
<td>0.01 (−0.001−0.01)</td>
<td>0.01 (−0.01−0.03)</td>
</tr>
<tr>
<td>Visual motor integration</td>
<td>0.05 (0.03−0.07)**</td>
<td>0.07 (0.04–0.10)**</td>
<td>0.09 (0.02–0.15)**</td>
</tr>
<tr>
<td>Picture vocabulary</td>
<td>0.02 (0.03−0.06)</td>
<td>0.02 (0.04–0.08)</td>
<td>0.04 (0.11–0.18)</td>
</tr>
<tr>
<td>Verbal fluency</td>
<td>0.03 (0.02–0.07)</td>
<td>0.01 (0.05–0.08)</td>
<td>0.16 (0.03–0.28)*</td>
</tr>
<tr>
<td>Embedded figures</td>
<td>0.03 (0.02–0.08)</td>
<td>0.06 (0.01–0.12)</td>
<td>0.002 (0.15–0.15)</td>
</tr>
<tr>
<td>Gestalt closure</td>
<td>0.01 (0.02–0.04)</td>
<td>0.01 (0.03–0.05)</td>
<td>0.03 (0.05–0.11)</td>
</tr>
<tr>
<td>Word order</td>
<td>0.04 (0.01–0.07)**</td>
<td>0.04 (0.01–0.08)*</td>
<td>0.10 (0.01–0.19)*</td>
</tr>
<tr>
<td>Number recall</td>
<td>0.02 (0.02–0.03)</td>
<td>0.003 (0.03–0.04)</td>
<td>0.001 (0.08–0.08)</td>
</tr>
<tr>
<td>Progressive figures</td>
<td>0.04 (0.07–0.14)</td>
<td>0.07 (0.07–0.21)</td>
<td>−0.02 (0.28–0.23)</td>
</tr>
</tbody>
</table>

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**Notes.** Coef., coefficient; CI, confidence interval. **p < .05, **p < .01, ***p < .001.

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*The general estimate of cognitive performance was calculated by averaging the z-scores of all eight cognitive tests administered. In case of missing variables, the total number was divided by the number of tests administered. Displayed here is the general estimate of cognitive performance without tasks with a motor component.

*Beery (1997).

*Bleichrodt et al. (1987).


whether the group of children with increased CBCL scores (including children at risk of psychopathology) influenced the relation between cognitive and motor performance, the same analyses were repeated in the control group of 187 children only. Results were highly comparable. Thus, the relation we found between aspects of cognitive and motor behavior was not caused by psychopathology in some children and can therefore be seen as a global relation in healthy children aged 5–6 years.

**Discussion**

The aim of this study was to investigate the relation between cognitive and motor performance, statistically corrected for attention, in a large cross-sectional sample drawn from a population of 5- to 6-year-old children attending normal kindergarden. The relationship between both quantitative and qualitative motor performance on the one hand, and an estimate of general cognitive performance as well as specific cognitive functions on the other hand were studied. Although findings became less strong after controlling for attention, positive linear relations remained between an estimate of general cognitive performance and total and qualitative aspects of motor performance. However, the relations found were rather small and when only cognitive tasks without a motor component were included in the estimate of cognitive performance, no significant association with motor performance was found. This finding argues against a global relation between cognitive and motor performance. Thus, we could not support the theoretical assumption, raised by influential researchers such as Piaget, of a direct linkage between global aspects of cognitive and motor behavior.

In addition to a global-to-global relation between cognitive and motor behavior, more specific relations were investigated between aspects of both. It was shown that performance on several specific cognitive tests, i.e. of working memory, verbal fluency, and VMI, was related to motor performance, independently of attention. All relations were positive, i.e. a lower performance on the above-mentioned cognitive tests indicated a lower performance on the motor test. These relations were not more pronounced in children who performed below average than in children with average performance. Thus, several
aspects of cognitive and motor performance in 5- to 6-year-old children seem to be on a continuum, ranging from children who perform well on both cognitive and motor tasks, those who perform at an average level, and those who perform poorly on both types of tasks. Our findings and those of previous studies are determined to a large extent by the tasks used to assess both cognitive and motor performance. We have taken care to minimize the effects of this limitation, underlying all studies using tests, by including only tasks known to be sensitive to the function they are intended to measure in children aged 5- to 6-years old.

This is the first study to show that specific aspects of cognitive and motor performance are related, independently of attention, in a large sample of healthy children aged 5–6 years. Interestingly, earlier studies showed these two processes to be related in children with clinical problems such as ADHD, DAS, DCD, and dyslexia (Hamilton, 2002; Viholainen et al., 2002; Nijland, 2003; Pitcher et al., 2003).

The relation found between VMI and qualitative and quantitative aspects of motor performance is not surprising, considering the role of fine motor performance in the VMI test. Both quantitative and qualitative aspects of motor performance as well as visual perception are important in this task (Beery, 1997). Although it is difficult to exclude the visual perception aspects from the motor aspects of this test, evidence against a relation between visual perception and motor performance stems from the negative finding of a relation between motor performance and the other test of visual perception, the embedded figures test. Thus, visual perception, as assessed by the tasks used in this study, seems not to be related to motor performance.

Performance on a working memory test and a verbal fluency test, two measures of executive functioning (Baron, 2004), was related to motor performance. It has been suggested that certain brain structures, such as the basal ganglia or frontal cortex, and dopamine transmission are common to both cognitive and motor performance (Diamond, 2000; Geurts, 1997; Kandel et al., 2000; Nieoullon, 2002). However, performance on the Progressive Figures test, a third measure of executive functioning, was not related to motor performance. Thus, there seems to be a relation especially between certain aspects of executive functioning and motor performance. Future research should specify this relation further by relating performance on different measures of aspects of executive functioning to motor performance.

Our expectation that the relation between cognitive and motor performance would be more pronounced in boys than in girls (APA, 1994; Dewey et al., 2002) was not confirmed. After controlling for attention, it was found that the relation between general cognitive performance and motor performance was still present in girls, but not in boys. In addition, the relation between verbal fluency and quantity of motor performance occurred solely in boys, while the relation between Word Order and motor performance occurred solely in girls. Thus, the relation between cognitive and motor performance in 5- to 6-year-old children is of similar strength in boys and girls, but there is a difference regarding the specific cognitive functions that are associated with motor performance.

We did not confirm our expectation, based on the literature (Kroes, Kessels, et al., 2002; Prechtl et al., 1997), that qualitative aspects of motor performance would be more relevant than quantitative aspects in predicting general cognitive performance. Although general cognitive performance was related only to qualitative aspects of motor performance, no consistent pattern was seen in the relations between four specific cognitive functions and motor performance. This contrasts with the findings of Kroes, Kessels, et al. (2002), who reported that qualitative aspects of motor performance could predict disorders in the attention spectrum whereas quantitative aspects could not. Apparently, there is a more general relation between cognitive performance and motor performance in healthy children aged 5–6 years, in which both quantitative and qualitative aspects are important. However, we did not include specific measures of impulsiveness, a function hypothesized to be especially impaired in children with ADHD (Barkle, 1997). It is possible that performance on such a measure would be related only to qualitative aspects of motor performance. Future research should focus on this question.

In summary, in this cohort of 5- to 6-year-old children, no consistent relations were found between an estimate of general cognitive performance and motor performance. Conversely, it was found that motor performance was related to performance on several specific cognitive measures, which involved attention and other aspects of executive functioning. This could indicate that attention, executive functioning, and motor performance are related in 5- to 6-year-old children. These findings show the parallel development of specific cognitive and motor functions in children, during both normal and delayed development. Future research should extend these findings to other developmental periods, in order to more comprehensively investigate the parallels between cognitive and motor development of children.
References


