# How Fine Motor Skills Influence the Assessment of High Abilities and Underachievement in Math

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*Previously, fine motor skills have been of little or no interest to giftedness research. New lines of thought have been advanced that imply that fine motor skills can be of significance in the identification of gifted persons as well as gifted underachievers. This would also have consequences for the diagnostic process underlying identification. An empirical investigation with 788 fourth-grade pupils could show that fine motor skills have an incremental predictive value for mathematics achievement beyond cognitive abilities. Among pupils who had been identified as gifted by either an IQ test that places high demands on fine motor skills or an IQ test that places low demands on fine motor skills, only about every fourth child was identified by both intelligence tests. Furthermore, it could be shown that, when using the IQ test that places low demands on fine motor skills, more underachievers could be identified than with the test that places high demands on fine motor skills. The discussion offers several recommendations for the selection of IQ tests best suited for the identification of gifted students in general and gifted underachievers.*

In 2000 Ziegler and Raul published a comprehensive analysis of articles appearing in scientific journals on giftedness focusing on the methods being applied, at that time, to identify gifted persons. In almost two thirds of all identifications, intelligence tests were the solitary method or were used in combination with other methods. This analysis was repeated by Ziegler (2008) for the period of time that had elapsed since then. However, this time the analysis included, in addition to journal articles, works presented during the proceedings

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of conferences held by the World Council for Gifted and Talented Children (WCGTC), the European Council for High Ability (ECHA), and the Asia-Pacific Federation (APF). Significant differences between empirical articles published in scientific journals and empirical works presented during conferences were not evident. Of the manuscripts that specifically identified gifted persons in their studies, 21.2% relied exclusively on IQ and a further 31.0% utilized a combination of achievement and IQ. Although the application of intelligence tests had declined somewhat, they still played a predominant role in the identification of gifted individuals. This still predominant role of IQ tests in the identification of gifted persons is, however, not without contention.

Those who criticize the use of IQ tests to assess giftedness can be roughly divided into two camps. On the one hand are scientists who react with skepticism to IQ testing and/or disregard it completely for a variety of reasons. Often these researchers point to the social biases evident in IQ tests and express severe doubt with regard to their theoretical foundations (e.g., Berliner & Biddle, 1995; Borland, 2003; Margolin, 1994). Others in the field assume a more moderate position. They admit to some of the weaknesses inherent in IQ tests, and encourage taking them into account when interpreting the results they generate. For instance, all practitioners are aware that in the assessment of IQ test results one also needs to consider factors such as concentration level, motivation, and sleepiness experienced by the subject during testing. Similarly, it is well known that a speed test, for example, would be poorly suited to accurately assess skills in a child with high test anxiety or that one should be skeptical of the IQ measurements of members of foreign ethnic groups that are made with tests developed for and/or by the dominant culture. This paper falls into the second category, which advocates dealing with the results of IQ tests in a constructive manner. We will present theoretical arguments, as well as empirical evidence, to demonstrate that interindividual differences in fine motor skills can lead to, in part, dramatically different results on IQ tests.

If intelligence tests are executed as paper-and-pencil tests or in a computer-generated version, the subject must obviously be in possession of some degree of fine motor skills. One is required to either use a pencil or enter the answers into a computer by typing on a keyboard or moving and activating a mouse. It is known that mastering any of these three activities necessitates a long period of learning (Beilei, Lei, Qi, & von Hofsten, 2002; Graham & Weintraub, 1996). Although there are studies that show that fine motor skills correlate with results in intelligence tests, and although in the past few years there has been a movement to reduce motoric components of intelligence tests (Baedke, 1980; Solan, Mozlin, & Rumpf, 1985; Wasserberg et al., 2005), little is known about how interindividual differences in fine motor skills can influence the results obtained with different kinds of intelligence tests.

## Fine Motor Skills and Abilities

Although the results of intelligence tests are, naturally, based on cognitive abilities, there are reasons to expect fine motor skills could also exercise an influence. Fine motor skills are basic for individual development, and their absence would render the attainment of a number of milestones in early child socialization unthinkable. The fine coordination of small muscle groups, above all those in the hand, is essential for a variety of activities. Among these are dressing and undressing; tying shoes; the utilization of eating utensils; holding and guiding pencils, paintbrushes, and rulers; using scissors; turning the pages of a book; and piecing together Lego tiles or jigsaw puzzles (Cantell, Smyth, & Ahonen, 1994; Losse et al., 1991). In fact, fine motor skills correlate consistently with general as well as specific cognitive abilities. Relationships have been confirmed with optical differential abilities, reaction speed (e.g., Voelcker-Rehage, 2005) and intelligence (e.g., Baedke, 1980; Solan et al., 1985; Wasserberg et al., 2005). In accordance with expectations, positive relationships have also been shown for achievement. Vacc, Vacc, and Fogleman (1987) found, for example, that fine motor skills among pre-school aged children can best predict later performance on standardized achievement tests in the first grade. Further studies confirm correlations between fine motor skills and scholastic performance up through, at the very least, the end of primary school (e.g., Baedke, 1980; Beilei et al., 2002).

Fine motor skills form the basis for several scholastic skills that retain importance over the course of scholastic education. Those worthy of emphasis include writing speed and the disposition to rework written assignments (Graham, 1990; Graham & Weintraub, 1996). Interestingly, significant relationships have been detected between fine motor skills and reading skills that are indispensable for all scholastic subjects (Graham, 1990; La Paro & Pianta, 2000; Reno, 1995; Savage, 2004; Share, Jorm, Maclean, & Matthews, 1984). Furthermore, deficits in fine motor skills can be expected to have indirect effects on cognitive achievement. For instance, Losse and colleagues (1991) found increased dispositions toward irritated reactions and designative, depressive moods among school children with deficits in fine motor skills.

The examples cited above lead one to expect that fine motor skills may influence achievement. However, the causal mechanism at work has not yet been clarified. In fact, the variety of influences evidenced lead one to suspect a series of several causal mechanisms. The most systematic research program on this topic was developed by Christensen (2004, 2005). She started from the assumption that many scholastic achievements are based on the interplay among three factors: domain-specific knowledge, orthographic knowledge, and fine motor skills. The orthographic-motor integration is particularly capacity intensive. She was able to establish this with substantial correlations between orthographic-motor integration (e.g., quickly writing out as much of the alphabet as possible within a predetermined period of time) and assessments of the texts produced with respect to creativity, number of presented ideas, use of proper syntax, and text coherence. On this basis, the author derives a straightforward explanation for positive correlations between fine motor skills and scholastic achievement. The automation of basic fine motor functions (e.g., writing) opens up capacity resources. These can then be utilized for higher order cognitive activities. Should this argumentation prove to be valid, this would also suggest a relationship between fine motor skills and the results obtained with intelligence tests. Should this, in turn, turn out to be correct, then the question is raised as to whether this also affects the identification of gifted persons through IQ tests.

Studies on the effects of fine motor skills among gifted individuals are generally lacking, aside from two exceptions (Stoeger, Ziegler, & Martzog, 2008; Ziegler, Stoeger, & Martzog, 2008). Both of these prior studies were conducted in pursuit of the causes of underachievement. Ziegler et al. (2008) made comparisons between gifted underachievers and achievers with regard to several variables including self-concept, motivation, concentration, and fine motor skills. Underachievers and achievers could be differentiated on concentration as well as the interaction between concentration and fine motor skills. They discussed these results against the background of the attention deficient hypothesis put forth by Christensen (2004, 2005). In a replication study, Stoeger et al. (2008) confirmed the results of this study with different measuring instruments and a larger sample. Interestingly, these results provided the first indications that deficits in fine motor skills can be predictors of underachievement and, consequently, could well be integrated into the identification process of gifted underachievers in the future.

## The Current Research

In our empirical study we utilized two different intelligence tests: the revised version of the Culture Fair Intelligence Test (CFT20; Weiss, 2006) and the Prüfsystem für Schul- und Bildungsberatung für vierte bis sechste Klassen (Testing System for Scholastic and Educational Counseling, Grades 4 to 6, PSB; Horn, Lukesch, Kormann, & Mayrhofer, 2002). We assumed that the CFT20 would impose low levels of demand on the fine motor skills of the pupils being tested and the PSB would place rather high demands on such skills.

**Hypothesis 1.** The two intelligence tests correlate with mathematics achievement levels. This hypothesis is founded in the well-documented correlation between mathematical skills and IQ. In fact, this hypothesis is rather obvious in that IQ tests are validated through performances and achievements in academic subjects. Should Hypothesis 1 be confirmed, some of the alternative explanations for the following hypotheses can be excluded.

**Hypothesis 2.** Motor skills have an incremental predictive value for mathematics achievement beyond cognitive abilities. This hypothesis was formulated in accord with a series of studies (e.g., Baedke, 1980; Beilei et al., 2002; Stoeger et al., 2008; Ziegler et al., 2008), which confirm a relationship between fine motor skills and achievement. The present study, however, would generate the first evidence that fine motor skills have an incremental predictive value beyond intelligence.

**Hypothesis 3.** In the diagnosis of a talent, the test used to detect this talent plays a significant role. We decided to apply both the CFT and the PSB in this study because they place different degrees of demand on fine motor skills. Therefore, we assume that samples of gifted individuals identified with these two tests will turn out to overlap only slightly.

**Hypothesis 4.** Students identified as gifted by the PSB demonstrate better fine motor skills than CFT identified gifted students. We selected the PSB for our research because it places high demands on fine motor skills. Pupils who perform well on it must therefore have above-average fine motor skills at their disposal.

**Hypothesis 5.** More underachievers will be identified with the help of the CFT than the PSB. At first glance, this hypothesis seems to be counterintuitive in that some students, due to their deficits in fine motor skills, will be hindered and may not show a high performance on the PSB. However, this handicap only leads to—and this is decisive—underachievement on intelligence tests. One should not confuse *underachieving on an intelligence test* with the conventional use of the term underachievement in the field of gifted education. This is defined as an unexpectedly low level of *achievement* by a gifted person in comparison to their measured IQ. Under testing with the PSB, specific pupils will not even be identified as gifted due to their deficits in fine motor skills. According to the strict definition of the term, they cannot even be referred to as underachievers because their IQs, as measured with the PSB, are too low to be considered gifted. On the CFT, in contrast, pupils only have to mark the answer they think is correct. This means gifted pupils with deficits in fine motor skills are not impeded from obtaining high-IQ assessments by these limitations. However, fine motor deficiencies definitely have negative effects for these children with regard to scholastic performance. In other words: The number of underachievers with fine motor deficits should be greater for the CFT than the PSB, because deficits in fine motor skills do not affect performance on the CFT, but do have a detrimental effect on scholastic achievement.

**Hypothesis 6.** Although CFT underachievers should demonstrate less pronounced fine motor skills than CFT achievers, fine motor skills among PSB underachievers should be as good as, or even better than, those demonstrated by PSB achievers. This hypothesis, in light of the results obtained by Stoeger et al. (2008) and Ziegler et al. (2008), also appears at first to be counterintuitive. In both studies underachievers showed poorer fine motor skills than achievers. In fact, one of the most significant aims of these studies was to confirm fine motor skill deficits as a meaningful cause for underachievement. However, both studies used the CFT, which only places minimal demands on fine motor skills. The first part of this hypothesis is therefore solely concerned with replicating the findings obtained with these two studies.

In order to better understand the second part of this hypothesis, we must once again refer to the technical definition of underachievement: the discrepancy between IQ test performance and scholastic achievement. One commonly applied criterion is a difference of one standard deviation. In the first place, one must accept that fine motor skills play a much larger role in producing a good performance on the PSB than on the CFT. The demands placed by this test on fine motor skills are presumably even higher than those dictated by normal classroom activities. Should this assumption prove to be true, then a pupil assessed to be gifted by the PSB would have a specific, minimal standard of fine motor skills at his or her disposal. The more pronounced the fine motor skills, the easier it is to reach a critical discrepancy regarding unexpectedly poor scholastic performance.

# Method

## Participants

A total of 788 pupils (373 boys and 415 girls) in the fourth grade from 32 classes attending 15 different German primary schools took part in the investigation. They were from predominantly upper middle class areas. The mean age of the participants was 10.52 years ($SD = 0.41$). There was no significant age difference between girls and boys.

## Measuring Instruments

**Cognitive abilities.** The cognitive abilities of the pupils were assessed with the assistance of two different tests. We chose to apply one test that places a low degree of demand on fine motor skills and one that requires more highly developed fine motor skills.

***Culture Fair Intelligence Test.*** As a test with low demands on fine motor skills, the pupils worked through the German version (Weiss, 2006) of the Culture Fair Intelligence Test (CFT20; Cattell, 1960). It primarily assesses fluid intelligence; in other words, the capacity to process complex information. The test consists of two parts. The similar construction of both parts permits the sole use of the first part (Form A) as an abridged test format, as was done in the current study. The test consists of four subtests: Series (a series of three patterns is to be extended to include a fourth selected from five alternatives; 12 items), Classifications (a series of five figures are presented, the one figure that does not belong to the group is to be determined; 14 items), Matrices (a matrix is to be expanded to include one of five alternatives; 12 items), and Topological Reasoning (a figure is presented for which a matching complement is to be selected from five alternatives; 8 items). Each subtest is timed and the items increase in difficulty. The test, which is presented in a paper-and-pencil format, takes about 30 minutes to complete and demands only minor verbal competence. Because the answers are to be marked on a specifically prepared answer sheet, the test calls for a relatively low degree of fine motor skills. The test was renormed in the year 2004 with a sample of 4,300 students, among them 454 boys and girls from fourth grade. The test manual demonstrates ample evidence of reliability, as well as validity. The predictive validity of the test was very high as demonstrated in longitudinal studies of 6 and 10 years (refer also to Kuhn, Holling, & Freund, 2008).

***Prüfsystem für Schul- und Bildungsberatung.*** The second test the pupils took was the PSB (Horn et al., 2002). The test assesses intelligence in accordance with Thurstone's Primary Factors. It consists of seven different subtests: (1) Numeric Series (15 series of nine numbers are to be completed within 5 minutes. The number that contradicts the principle upon which the series is based is to be crossed out); (2) Alphabetic Series; (3) Figural Series (the principle used in the numeric series problems is applied to series of letters/figures. Fifteen series of nine letters/figures are to be completed within four/three minutes); (4) Verbal Fluidity (the test subjects have 45 seconds to write down as many words as possible that all start with the same letter); (5) Spatial Perception (40 different "forms drawn in perspective" are depicted, under each form is a series of five consecutive numbers. The test subjects are to indicate the number of surfaces for each of the forms among the series below them within 3 minutes); (6) General Knowledge (20 terms stemming from five fields of knowledge are printed in capital letters; each term contains one wrong letter; the test subjects are to indicate these letters in their test booklets); (7) Detecting Similarities (25 tasks are to be completed within 4 minutes. Each task consists of five words, one of which does not thematically belong to the other four); Arithmetic Addition (35 exercises are to be completed within 3 minutes, each exercise consists of seven, three-digit terms to be added together; test subjects are to write out the last digit of the sum obtained); and Numeric Comparisons (45 pairs of seven-digit numbers are split into two adjoining columns, the number in the right-hand column has one digit that is different from its partner in the left hand column—subjects are to mark this digit; time allowed, 90 seconds). Each subtest is timed and the items increase in difficulty. The test, which is presented in a paper-and-pencil format, takes about 60 minutes to complete.

Because the children are required to write out words or numbers under the pressure of time, the PSB calls for significantly more advanced fine motor skills than the CFT. The test manual demonstrates ample evidence of validity, as well as reliability (refer also to Fay, 2006).

**Fine motor skills.** To allow assessment of their fine motor skills, the pupils were asked to reproduce letters from the Greek alphabet as accurately as possible (refer also to Mäki, Voeten, Vauras, & Poskiparta, 2001). This measure is commonly applied in research in the assessment of visual-motor integration. Each of the children received one sheet of paper with lines of Greek lettering and one blank sheet of paper. To ensure that the children did not see the letters prior to the start of the test, the pages were placed face down on their desks. The session leader issued the following instructions:

> On this sheet of paper you will find a series of unusual symbols. They are all members of the Greek alphabet. In the next 3 minutes you should try to copy as many of them as possible. It is important to work as *quickly as possible*, however, at the same time the symbols you draw should be as *neat and accurate* as you can make them. Start with line one on the upper left-hand side, indicated by the arrow, and then continue from line to line. When time is up I will say stop, at which point you are to lay down your pencils. You may now turn your sheets over and start working.

The experimenter used a stopwatch to time the test. The test was evaluated in accordance with the following criteria: The actual number of Greek letters copied was recorded and the quality of the handwriting for each of the reproduced letters was graded along a scale of one (*very high quality penmanship*) to three (*very low*). Grading criteria were (a) sustained diameters, (b) a difference of less than 90 degrees between directions of lines in the model and in the drawing, (c) inclusion of all angles, and (d) the interpretability of the figures in question.

The quality of the handwriting used to reproduce the Greek letters can be assessed as a qualitative aspect of fine motor skills, and the number of letters actually produced as a quantitative aspect. Each of the assessments was evaluated by one of the authors and one of the school psychologists who conducted the testing. Although standardized execution and evaluation in empirical investigations forms one of the cornerstones in the education of school psychologists in Germany, the investigators in this study received a supplementary 3-hour introduction to the evaluation of fine motor skill tests. The interrater reliability calculated for writing quality resulted in a Kappa of .73, which is satisfactory.

**Scholastic grades.** The classroom teachers supplied us with recent grades obtained by their pupils for the subject of mathematics. Here, one should note that the grade scale in Germany ranges from one to six, whereby one represents the best grade possible and six the poorest.

### Data Collection

The fine motor skill test and the two cognitive ability tests were administered to the pupils in the second semester of the school year, during regular classroom instruction. The survey, including a short break, took about 2 hours to complete. The investigation was conducted by school psychologists who were specially trained in the standardized execution and evaluation of research investigations.

## Results

Means ($M$) and standard deviations ($SD$) for all measures are presented in Table 1. The results of the empirical investigation are recounted in the following in accordance with the hypotheses developed. As anticipated in Hypothesis 1, significant correlations were found between achievement in mathematics and both of the intelligence tests administered (CFT: $r = .54$, $p < .001$; PSB: $r = .55$, $p < .001$). The better the results obtained on the two intelligence tests, the better the grades recorded on the students' most

Table 1

*Means and Standard Deviations of All Measures*

| Variables | | Mean | Standard Deviation | *n* |
|---|---|---|---|---|
| CFT 20 (IQ) | | 96.92 | 12.23 | 95 |
| PSB (IQ) | | 98.41 | 14.01 | 83 |
| Fine motor skills | Number of Greek letters copied | 26.46 | 10.30 | 140 |
| | Quality of handwriting* | 1.81 | 0.54 | 140 |
| Math grade** | | 2.53 | 0.87 | 140 |

* 1= very high quality, 3 = very low quality.
** The grade scale in Germany ranges from 1–6, with 1 = best grade possible and 6 = poorest grade possible.

recent report cards for mathematics class. The correlations were almost identical.

According to Hypothesis 2, fine motor skills should demonstrate an incremental predictive value for mathematics achievement beyond cognitive abilities. In order to examine this hypothesis, a stepwise regression analysis with 773 degrees of freedom was calculated. The predictors applied in the analysis were the percentiles recorded for the two cognitive ability tests and the results obtained on the fine motor tests (number and quality of the Greek letters reproduced). The $R^2$ for the entire model came to .40. The best predictor of mathematics achievement turned out to be the results obtained with the PSB ($t$ = -10.49, $p$ < .001, $\beta$ = -.37, $R^2$ = .30) followed by results on the CFT ($t$ = -9.53, $p$ < .001, $\beta$ = -.33, $R^2$ = .08). In accord with our hypothesis, the number of Greek letters reproduced ($t$ = 2.91, $p$ < .01, $\beta$ = .08, $R^2$ = .01), as well as the quality of the letters copied ($t$ = 2.73, $p$ < .01, $\beta$ = .08, $R^2$ = .01), displayed an incremental predictive value.

Hypothesis 3 predicted that the two IQ tests applied would have a strong influence on the composition of the samples of gifted pupils identified with them. In accordance with Gagné (2004), a percentile of 90 or above was used as an indicator of giftedness. As illustrated by Table 2, Hypothesis 3 could also be confirmed. Out of the 140 children who were among the top 10% for at least

Table 2

*Numbers of Gifted Pupils Identified With the CFT and the PSB*

| | Percentile on the PSB | | |
|---|---|---|---|
| Percentile on the CFT | < 90 | $\geq$ 90 | Total |
| < 90 | 648 | 45 | 693 |
| $\geq$ 90 | 57 | 38 | 95 |
| Total | 705 | 83 | 788 |

one intelligence test, only a minority of 38 children, or about 27%, were identified as gifted by both tests. The PSB did not identify 57 (approximately 41%) of the 140 children as gifted; the CFT missed 45 (approximately 32%) of them.

According to Hypothesis 4, students identified as gifted with the PSB should demonstrate better fine motor skills than students identified to be gifted with the CFT. In order to validate this hypothesis, an analysis was conducted among those pupils who had attained a percentile of 90 or above on only one of these two tests. For the actual number of Greek letters copied, which represents the quantitative aspect of fine motor skills, Hypothesis 4 was confirmed. Pupils who scored among the top 10% on the PSB were actually able to reproduce more Greek letters than those who were tested among the top 10% on the CFT (number of Greek letters reproduced: top 10% on the PSB: $M = 32.44$, $SD = 10.33$; top 10% on the CFT: $M = 25.49$, $SD = 8.97$; $t(100) = 3.64$, $p < .001$). As for penmanship or the qualitative aspect of fine motor skills, contrary to expectations, no differences could be found between the two groups (handwriting quality of the Greek letters reproduced: top 10% on the PSB: $M = 1.64$, $SD = 0.57$; top 10% on the CFT: $M = 1.70$, $SD = 0.53$; $t(100) = 0.52$, $p > .10$).

In Hypothesis 5 it was postulated that with the help of the CFT more underachievers can be identified than with the help of the PSB. In accordance with a number of investigative studies (Phillipson, 2008; Ziegler & Stoeger, 2003), we use the term underachiever to refer to those pupils whose $z$-standardized average scholastic performances in mathematics were at least one standard deviation below their $z$-standardized result on the

Table 3

*Numbers of Underachievers Identified With the CFT and the PSB*

| | Identified with the PSB | | |
|---|---|---|---|
| Identified with the CFT | Underachievers | Achievers | Total |
| Underachievers | 34 | 128 | 162 |
| Achievers | 85 | 541 | 626 |
| Total | 119 | 669 | 788 |

intelligence test. As represented in Table 3, Hypothesis 5 can also be confirmed. Although the application of the CFT resulted in the identification of a total of 162 pupils as underachievers, by using the same terminological criteria and under the exact same conditions, the application of the PSB was only able to identify 119 pupils as underachievers (Fisher's Exact Test: $p < .05$).

Hypothesis 6 proposed that underachievers identified through the CFT would demonstrate poorer fine motor skills than achievers identified through the CFT. Underachievers identified through the PSB, in contrast, should not have significantly poorer, and may demonstrate even better, fine motor skills than their corresponding achievers. As illustrated in Table 4, the first half of Hypothesis 6 can only be confirmed in part. Underachievers who had been identified through the CFT did show—as anticipated—poorer qualitative achievement (aesthetic quality of the Greek letters reproduced), but could not be significantly distinguished from achievers with respect to quantitative achievement in the fine motor skills test (total number of Greek letters reproduced). The second assumption of Hypothesis 6 could, in contrast, be fully confirmed. The underachievers identified through the PSB demonstrated equivalent qualitative achievement levels (aesthetic quality of the Greek letters reproduced) and even better quantitative achievement levels (total number of Greek letters reproduced) on fine motor skills than correspondent achievers (see Table 4).

Table 4

*Means (Standard Deviations) for Total Number and Quality of Greek Letters Reproduced by Gifted Underachievers and Achievers According to IQ Test Applied*

| | CFT | | | PSB | | |
|---|---|---|---|---|---|---|
| | *n* | Letters reproduced | Letter quality | *n* | Letters reproduced | Letter quality |
| Underachievers | 51 | 27.27 (8.47) | 1.83 (0.52) | 25 | 35.12 (10.93) | 1.64 (0.49) |
| Achievers | 44 | 26.89 (10.12) | 1.62 (0.49) | 58 | 29.34 (9.02) | 1.72 (0.56) |
| | | $t(93) = 0.19$, $p > .10$ | $t(93) = 2.09$, $p < .05$ | | $t(81) = 2.51$, $p < .05$ | $t(81) = -0.66$, $p > .10$ |

## Discussion

The issue of fine motors skills is one that has not previously found much focus among giftedness researchers. The goal of this paper was to demonstrate that the role fine motor skills play in the identification of gifted individuals as well as the identification of gifted underachievers should not be disregarded.

The introduction developed arguments as to why fine motor skills could exercise an influence on learning outcome. In particular, evidence was presented showing that deficits in fine motor skills could contribute to underachievement among gifted pupils. This was, in fact, confirmed in two scientific investigations (Stoeger et al., 2008; Ziegler et al., 2008). These studies suggest that giftedness research should be taking a closer look at fine motor skills. In our investigation, we administered two different intelligence tests: the CFT and the PSB. The CFT places minimal demands on subjects' fine motor skills (Cattell, 1960; Weiss, 2006). Therefore, pupils with fine motor skill deficits should be able to perform well on this test. The PSB (Horn et al., 2002), in contrast, places higher demands on fine motor skills, which is why one may assume that some pupils will not attain the IQ threshold defining giftedness due to their fine motor deficits.

In Hypothesis 1 it was postulated that both intelligence tests would correlate with mathematics achievement. This turned out to be the case. The correlations between the two different test and math achievement scores were almost identical. In Hypothesis 2 we postulated that fine motor skills would have an incremental predictive value for mathematics achievement beyond cognitive abilities. This hypothesis could also be confirmed. The results suggest that in order to have a complete understanding of mathematics achievement in primary school, one must also include fine motor skills in future considerations. Presently, we are not aware of how the causal mechanisms involved are organized. Information gathered through other studies (Christensen, 2004, 2005; Stoeger et al., 2008; Ziegler et al., 2008) lead to the cautious assumption that fine motor deficits consume attention that could otherwise be directed toward the understanding of mathematical principles and operations.

Hypothesis 3 alluded to an issue important for the identification of gifted individuals. It was shown that a significant role is played by the choice of intelligence test used to diagnose gifted children. Among those children who had been identified as gifted by at least one of the two intelligence tests, only about every fourth child was identified by both intelligence tests. For the rest of these pupils, it would have been a matter of luck as to what sort of test they would be requested to submit to, should they be interested, for example, in applying to a gifted program. Of course, one must take precautions and avoid reducing all differences here to divergences in the demands placed on fine motor skills. Further characteristics of intelligence tests (or tests in general) certainly play a role here. Our results, however, provide ample grounds to advocate launching controlled studies to systematically investigate the differential influence fine motor skills have on the identification of gifted children. This is by no means a trivial question in that acknowledgment, or in some cases the lack of acknowledgment, of giftedness can be decisive in questions pertaining to future opportunities and obtaining support. For this reason, we will later address the question as to whether one of the two tests should be preferred over the other.

In Hypothesis 4 the assumption was made that students identified as gifted with the PSB would demonstrate better fine motor skills than those identified with the CFT. The underlying logic here is that the PSB places higher demands on the fine motor skills of the participants. Pupils who perform well on it must, therefore, have more acutely developed fine motor skills at their disposal. This hypothesis was, in fact, also confirmed.

Hypothesis 5 addressed the number of underachievers who could be identified with each of the two intelligence tests. As expected, with the help of the CFT more underachievers could be identified than with the help of the PSB. One must, however, keep in mind that whether or not a pupil is an underachiever is, of course, not an objective characteristic of said pupil but must always be understood in the context of a definition of measurement (Phillipson, 2008). For instance, should a large discrepancy such as two standard deviations between scholastic achievement and IQ be considered the barrier to significance, then one would isolate fewer underachievers than one would was this barrier defined by a smaller discrepancy, such as one standard deviation. Our study was able to show that the measuring instruments applied can also play a role. An intelligence test that places higher demands on fine motor skills is not well suited to identify underachievers who primarily underachieve due to deficits in their fine motor skills. This result can definitely be transferred to other causes of underachievement: In the identification of underachievers it is in no way helpful to increase demands on specific, extra-intelligent areas that could be the cause for underachievement. Precisely those pupils who demonstrate deficits in these areas will not be recognized as underachievers.

In examining Hypothesis 6 it could be shown that the CFT underachievers demonstrate, in part, poorer fine motor skills than the CFT achievers. In contrast, PSB underachievers proved to have better fine motor skills than PSB achievers. Paradoxically, the last finding could lead one to the conclusion that better fine motor skills are detrimental for scholastic performance. This is, of course, wrong. As addressed in the discussion of the hypothesis, this result is a consequence of how underachievement is defined and measured. The finding, however, also comprises a meaningful insight: Before differences between underachievers and achievers can be accepted as the causes for underachievement, it must be demonstrated that these causes are not more important for a good performance on the intelligence test applied than for a good performance with regard to scholastic achievement. Because correspondent systematic evidence for a series of variables is missing (e.g., concentration, persistence), analogous findings are only preliminary. They are plausible, however, one should not rely solely on concepts considered plausible.

## Limitations

We must, at this point, turn to some of the weaknesses in our investigation. In the study, underachievement was not measured in relation to scholastic achievement, but only with respect to the subject of mathematics. The consequence of this limitation is that the results obtained here can only be transferred to other groups of underachievers under restrictions. Also, the utilization of grades assigned by teachers to measure achievement forms a weakness of the present study, in that these are often criticized as being subjective and insufficient measurements of quality. Unfortunately, due to technical limitations on the investigation, we were not in the position to conduct an assessment with standardized, norm-referenced achievement tests. Similar difficulties were confronted concerning the measuring instrument used to assess fine motor skills. Regrettably, a norm-referenced group test does not yet exist in Germany, and it was not possible in the investigation to conduct individual testing sessions.

In addressing these points of criticism, future replications of this research investigation should be conducted with standardized, norm-referenced achievement tests. These should reference a wide variety of scholastic domains, not just mathematics. With respect to assessments of fine motor skills, individual tests are the optimal choice for evaluations of the various aspects of fine motor skills such as digital and manual dexterity, movement accuracy, and rapidity of movement. The measurement applied in the present research is relatively undifferentiated, and primarily assesses visual-motor skills. In future studies it would be preferable to subject purer forms of fine motor skills to differentiated evaluation.

## Conclusion

In conclusion, we would like to address what consequences the results of our study have for the administration of intelligence tests. To start off, we differentiate among three approaches that take one of the following three points under consideration:

1. Whether a combination of IQ tests can rectify the difficulties named in the identification of gifted individuals and gifted underachievers.
2. What must be taken into consideration when only one single IQ test will be administered?
3. What should be taken into consideration when the identification is to be carried out on the basis of an IQ test and achievement?

(1) In response to the finding that the overlap of children identified as gifted with the PSB and the CFT proved to be rather small, one may be inclined to utilize both tests in a testing procedure. We would like to warn against making a knee-jerk decision here. In particular, it is rather unclear as to if and how one can combine the results. For instance, one could calculate the average of the two test results, which is in fact frequently the case in practice (Grassinger, 2006). This brings to mind that in order to improve the reliability of an assessment, a perfectly logical step would be to increase the number of items (Krauth, 1995). Such comparisons are, however, not correct. In order to improve quality of measurement, one should utilize two comparable intelligence tests. If two intelligence tests with different profile demands are utilized, one is adding apples to oranges. The second approach would be to consider all pupils to be gifted who reach a particular threshold level on at least one of the two tests. This would make sense if the administration of both intelligence tests would enable a more comprehensive operationalization of one's own conception of giftedness. For example, proponents of multiple intelligences (Gardner, 2006; Tirri & Nokelainen, 2008) would be served well. However, it does not make good sense if factors are responsible for different results, which are not an integral part of

the operationalization of the concept of giftedness. These factors would exercise a systematic bias on the identification process.

(2) Should one decide to administer only one IQ test to identify a gifted person, then preference should be given to the test that—holding all other factors constant—proves to have the highest degree of construct validity. However, no single test can supply a pure assessment of intelligence. Factors such as motivation, concentration, and the like are always involved in the final outcome. The hope will always be that the influence exercised by such factors can be minimized through clever test designs. This prospect may, however, be compromised when assessing underachievement. Should one be harboring the suspicion that a specific factor is causing underachievement (e.g., deficits in fine motor skills), then the influence this factor can have on the result of the intelligence test administered should be reduced as much as possible. In other words, should one suspect that underachievement may be caused by fine motor skill deficits, then IQ tests should be administered that place low demands on fine motor skills.

In the identification of gifted individuals one should be pursuing the ultimate goal of being able to predict proficient future achievements, in particular, achievement excellence (Ziegler, 2010). Here is an example: Let us presume that in the process of predicting achievement excellence of pilots, an IQ test is to be administered. Unquestionably, learning to pilot a plane also calls for the development of a number of fine motor skills (Ackerman, 1987). Therefore, one would suspect that a test like the PSB, which necessitates fine motor skills, would provide, under certain circumstances, a better prediction of achievement excellence for this talent. However, at the same time, the use of this test would oversee pilots who were slight underachievers. In generalizing this finding, one could maintain that intelligence tests that additionally measure specific skills or talents that are significant for success in a domain are most probably better predictors of achievement excellence than "purer" intelligence tests. All the same, they also make it much more difficult to recognize persons who are underachieving. It all boils down to a trade-off upon which the researcher needs to deliberate.

(3) We introduced this manuscript with statistics pertaining to how frequently various diagnostic approaches are used in the identification of gifted individuals (Ziegler, 2008; Ziegler & Raul, 2000). In the previous paragraph it was demonstrated that the application of intelligence tests alone is insufficient to avoid the trade-off encountered between effectively predicting achievement excellence and detecting underachievement. Also, achievement alone is insufficient as a criterion of identification, because underachievers will be overlooked. A rather obvious alternative would be a simultaneous assessment of performance and intelligence. But how would one go about selecting an appropriate intelligence test in this case?

In the normal case (the exception to the rule will be addressed in the next paragraph), intelligence tests should only minimally measure specific skills that are considered significant for attaining success in the domain. These specific skills are already indirectly incorporated into individual performances. The combination of a "purified" intelligence test and an achievement test could thereby be used to discover underachievement.[1] Therefore, we actively endorse using a combination of this type, unless it is known that the domain for which gifted individuals are to be identified is one for which the exceptions described in the next paragraph hold true.

The recommendation made above assumes that the factors intending to influence performance development will remain constant over time. However, it may well be the case that the results of a current performance may not have been influenced by factors that will gain in significance for later achievement development. This is, in fact, most likely the usual case. For instance, Ackerman (1987) was able to show that among pilots, IQ is the best predictor of achievement in early learning phases. In later learning phases, however, motor skills are the best predictors of achievement, although they did not prove capable of predicting achievement in earlier training phases. For pilots, the combination of initial

[1] However, should a discrepancy exist—one that corresponds to the definition of underachievement used above—performance and IQ are not considered equivalently in the prognosis. This should not occur until after a remedial phase, in which an attempt is made to rectify the performance deficit.

performance rates and a test like the PSB, which taps motor skills, would enable better predictions of the achievement levels to be expected at the end of the training. Because motor skills do not play a role for achievement in the initial phases of training, one would be able to uncover underachievers in this specific case.

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