

RESEARCH ARTICLE

Evaluating Fine Motor Coordination in Children Who Are Not Ready for Handwriting: Which Test Should We Take?

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Abstract

When children are not ready to write, assessment of fine motor coordination may be indicated. The purpose of this study was to evaluate which fine motor test, the Nine-Hole Peg Test (9-HPT) or the newly developed Timed Test of In-Hand Manipulation (Timed-TIHM), correlates best with handwriting readiness as measured by the Writing Readiness Inventory Tool In Context-Task Performance (WRITIC-TP). From the 119 participating children, 43 were poor performers. Convergent validity of the 9-HPT and Timed-TIHM with WRITIC-TP was determined, and test-retest reliability of the Timed-TIHM was examined in 59 children. The results showed that correlations of the 9-HPT and Timed-TIHM with the WRITIC-TP were similar ($r_s = -0.40$). The 9-HPT and the complex rotation subtask of the Timed-TIHM had a low correlation with the WRITIC-TP in poor performers ($r_s = -0.30$ and -0.32 respectively). Test-retest reliability of the Timed-TIHM was significant (Intraclass Correlation Coefficient = 0.71). Neither of these two fine motor tests is appeared superior. They both relate to different aspects of fine motor performance. One of the limitations of the methodology was unequal numbers of children in subgroups. It is recommended that further research is indicated to evaluate the relation between development of fine motor coordination and handwriting proficiency, on the Timed-TIHM in different age groups. Copyright © 2015 John Wiley & Sons, Ltd.

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Keywords

handwriting; fine motor coordination; Nine-Hole Peg Test, Timed Test of In-Hand Manipulation (Timed-TIHM); Writing Readiness Inventory Tool in Context-Task Performance (WRITIC-TP)

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Introduction

During the first years in school, children learn to write. Proficient handwriting is essential for a child's

participation in a regular classroom environment (Rosenblum, 2008). Handwriting difficulties have negative effects on a child's academic performance

and self-esteem (Bart et al., 2007). Early identification of children who are not ready to learn the mastery of handwriting can provide information for tailored advice and timely interventions in order to prevent the negative consequences of handwriting difficulties.

From the literature, we know that in the development of handwriting, several processes are involved. These processes are represented in a conceptual model, comprising factors related to handwriting readiness (Figure 1) (Berninger et al., 1992; Abbott and Berninger, 1993; Volman et al., 2006; van Hartingsveldt et al., 2014a). Handwriting readiness is the stage before handwriting (Marr et al., 2001; Schneck and Amundson, 2010) and is defined as a developmental stage at which a child has the capacity to profit satisfactorily from the instruction given in the teaching of handwriting (Marr et al., 2001). The conceptual model, based on the model of Berninger, is used to identify the perceptual–motor and cognitive factors relating to handwriting readiness. This model shows that learning “text writing” is based on different processes: the perceptual–motor process “handwriting” and the cognitive language processes of “spelling” and “composition” (Abbott and Berninger, 1993). In the phase in which children learn the

perceptual–motor skill of preliminary writing, “visual motor integration” and “fine motor coordination” are important performance components (Volman et al., 2006). Fine motor coordination (motor planning and execution) has proven to be a key component in the early learning stages of handwriting (Berninger, 2009).

To assess handwriting readiness in the pre-writing phase, a new occupation-based instrument has been developed: the Writing Readiness Inventory Tool in Context (WRITIC; van Hartingsveldt et al., 2014a, 2014c). The WRITIC has items in three domains and six subdomains: child (“interest” and “sustained attention”), environment (“physical” and “social”) and paper-and-pencil tasks (“task performance” and “intensity of performance”). In a series of studies, the reliability and validity of the WRITIC have been established (van Hartingsveldt et al., 2014a, 2014c).

In the WRITIC, handwriting readiness is measured as having a proper seating posture (Pollock et al., 2009; Schneck and Amundson, 2010), a mature pencil grasp (Schwellnus et al., 2012, 2013) and performance of age-appropriate tasks such as colouring, writing patterns, writing own name and copying letters and

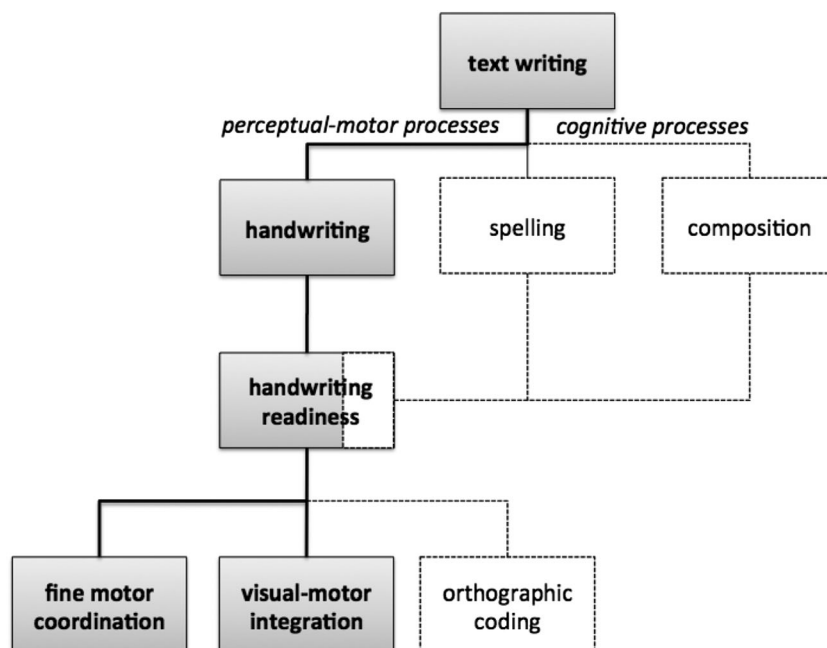


Figure 1. Conceptual model of handwriting readiness and its relation to handwriting, text writing and performance components, based on the model of Berninger (Abbott and Berninger, 1993; Berninger et al., 1992; van Hartingsveldt et al., 2014a, 2014b; Volman et al., 2006)

numbers. The WRITIC discriminates between children who are ready for instruction in handwriting and children who are not (van Hartingsveldt et al., 2014c).

Fine motor coordination

The International Classification of Function Disability and Health for Children and Youth (ICF-CY) defines fine hand use as “performing the coordinated actions of handling objects, picking up, manipulating and releasing them using one’s hand, fingers and thumb, such as required to lift coins off a table or turn a dial or knob” (WHO, 2007, p. 155). Exner (2010) defines fine motor coordination as skills of the hand that are needed to attain and manipulate objects. She describes different patterns of fine motor coordination. These include reaching, grasping, carrying and voluntarily releasing objects, as well as more complex skills such as in-hand manipulation (IHM) and bilateral hand use. IHM develops over a long period, from the age of approximately 18 months to 7 years. Progression can be observed in the transition from simple to more complex manipulation skills (Exner, 2010) and in improvements in the dimensions of speed, strategy and consistency (Pehoski et al., 1997b). Between the ages of 3 and 6 years, IHM develops most rapidly, and hand movements become more and more refined (Pehoski et al., 1997a). Fine motor skills are important in a child’s development and interaction with the environment (Exner, 2010). These skills contribute to the achievement of daily occupations such as handwriting. Two of the characteristics for skilled handwriting are stability in pencil grip and controlled dynamic finger movements (Ziviani and Wallen, 2006). Difficulties in fine motor coordination may result in an inability to direct pencil movements and correct errors of movement, particularly those of small amplitude observed in handwriting (Ziviani and Wallen, 2006).

In-hand manipulation is also studied in relation to handwriting. Cornhill and Case-Smith (1996) found a strong relationship between handwriting and IHM ($r=0.80$ for translation and $r=0.85$ for rotation). In their study ($n=48$, mean age 7.3 years), IHM differed significantly between good and poor performers in a task involving translation with stabilization and a task involving rotation, although translation was also an important predictor of most handwriting speed tasks. Translation was the main predictor and accounted for

63.7% of the variance in scores on a handwriting test (Cornhill and Case-Smith, 1996). Feder et al. (2005) determined that IHM significantly correlated with slow handwriting speed ($r=0.43$; $p<0.01$).

Evaluation of fine motor coordination

When children are not ready to learn handwriting based on the WRITIC, it is recommended that performance components, such as fine motor coordination, be assessed. This is carried out to identify the underlying mechanism, which may help to provide appropriate support and interventions in order to make the child ready for handwriting and to prevent the potential negative influences caused by writing difficulties. In a systematic review of standardized tests of handwriting readiness (van Hartingsveldt et al., 2011), two tests were found that consist of only fine motor coordination tasks: the Nine-hole Peg Test (9-HPT) (Smith et al., 2000) and the Test of In-hand Manipulation Revised (TIHM-R) (Pont et al., 2008).

The aim of the current study is to examine which fine motor test, the 9-HPT or the newly developed Timed Test of In-Hand Manipulation (Timed-TIHM), correlates best with handwriting readiness as measured by the Writing Readiness Inventory Tool in Context – Task Performance (WRITIC-TP).

Based on research (Feder et al., 2005; Volman et al., 2006), we hypothesize that both fine motor coordination tests will have a moderate correlation with the WRITIC-TP. We hypothesize that the revised Timed-TIHM will have a higher correlation to the WRITIC-TP than the 9-HPT. Handwriting involves complex controlled dynamic finger movement, and we hypothesized that the movements as tested in the Timed-TIHM had a better ability than the less complex movements in the 9-HPT to indicate which children were, from a fine motor perspective, not yet ready to write and thus would show a higher correlation to the WRITIC-TP.

Methods

In this clinimetric study, we evaluated the convergent validity of the Timed-TIHM and 9-HPT with the WRITIC-TP. As the Timed-TIHM is a newly developed test, the test–re-test reliability of the Timed-TIHM was also studied.

Participants

For the study of convergent validity, we recruited 120 children aged 5 and 6 years by asking 20 directors of elementary schools in the middle and eastern parts of the Netherlands for their participation. In each school, we asked one kindergarten teacher to select six children per class: three with good performance on paper-and-pencil tasks (good writers) and three with poor performance on paper-and-pencil tasks (poor writers). When parents' consent was received, we asked children for their assent before testing. Children were excluded if they were not able to complete the items of the WRITIC because of a medical diagnosis or visual or auditory impairment.

To examine test–re-test reliability, 60 children aged 5 and 6 years from the western part of the Netherlands were recruited. Fourteen kindergarten teachers were asked to select four children: two with good performance on paper-and-pencil tasks and two with poor performance on paper-and-pencil tasks. The parents signed to give their informed consent. The local ethical committee provided formal ethical approval. The studies were in full compliance with the Committee on Research Involving Human Subjects (known by its Dutch initials, CMO) of the Arnhem–Nijmegen area.

Procedure

For the convergent validity study, children were assessed first on the WRITIC and then on the Timed-TIHM and the 9-HPT. The Timed-TIHM and the 9-HPT were administered in the same session outside the classroom in a one-to-one situation in random order. Hand use was determined by the WRITIC as this is an item within the WRITIC. The WRITIC was administered individually in the classroom during a time when all the children were doing different tasks in small groups. Test administrators included three paediatric physical therapists and one paediatric occupational therapist.

To determine test–re-test reliability, the Timed-TIHM was administered twice with an interval of 7–14 days (Streiner and Norman, 2008). Test administrators included three occupational therapy students.

To become competent in administering the tests, all administrators (1) attended training from the second author (M.v.H.); (2) practised the WRITIC with two typically developing children; and (3) checked their

inter-rater agreement through the use of a videotaped administration with the second author.

Instruments

Nine-hole Peg Test

The 9-HPT evaluates simple fine motor patterns, including reaching, grasping, carrying, entering and releasing with the time taken to perform these tasks as the outcome measure (Smith et al., 2000). The 9-HPT has been validated in a study population of 826 children between 5 and 10 years of age. High inter-rater and test–re-test reliability was established, and strong construct validity was obtained. Normative values are available for children in this age category (Smith et al., 2000).

The 9-HPT is a simple timed test of fine motor coordination in which nine pegs are inserted one by one and consecutively removed in a pegboard. The child completes the task twice with the dominant hand. The best time score is used, with a high score (more time needed to perform the task) corresponding to poor fine motor performance.

Timed Test of In-hand Manipulation

The Timed-TIHM assesses three skills of IHM: (1) translation from finger to palm; (2) translation from palm to finger; and (3) complex rotation of 360° (Pont et al., 2009). The test is designed for children from 5 to 6 years of age and takes 5–7 minutes to administer. For the Timed-TIHM, the nine-hole pegboard was used (same as the pegboard from the 9-HPT). The child was asked to successively pick up two, three, four and five pegs with his or her dominant hand, manipulate the pegs with his or her fingertips to the palm and keep them in the palm of the hand (translation from finger to palm with stabilization [Task 1]) and then to replace the pegs one by one into the pegboard (translation from palm to finger with stabilization [Task 2]). The tasks with two, three and four pegs were included as practice items, whereas the task with five pegs was scored. The third task was a complex rotation task in which the child was asked to rotate one peg 360° for a total of five times using the fingertips of the dominant hand.

In both the rotation and translation tasks, two trials were given. The best time score was used as the outcome measure, with a high score corresponding to poor fine motor performance. The number of drops

and the times an external surface was used to compensate were recorded as supplemental qualitative information.

The Timed-TIHM was modified from the TIHM-R with approval of the test developers (Pont et al., 2008) to allow for separate scores for the three elements of IHM (finger-to-palm translation, palm-to-finger translation and rotation), to consider components in the literature on hand skills (Exner, 2010) and to use the timed scores of these three elements as an outcome measure: the Timed-TIHM.

Writing readiness inventory tool in context

The WRITIC is an occupation-based measurement to evaluate handwriting readiness in 5- and 6-year-old children. The WRITIC contains items in three domains: child, environment and paper-and-pencil tasks (Figure 2). The WRITIC is administered in the classroom, where the influence of the context can be taken into account. First, the child's interests in paper-and-pencil tasks are evaluated. After that, the child completes a drawing booklet with five paper-and-pencil tasks (including tracing, colouring, making pre-writing patterns, name writing and copying letters and numbers) while an assessor observes and scores performance.

The subdomain "task performance", used in this study, consists of seven items scored on a 3-point scale and six items scored on a 7-point scale (range 0–50). The other subdomains are criterion referenced and provide valuable information for advice and intervention. The WRITIC-TP has high internal consistency after factor analysis, discriminates between children with good and poor performance of paper-and-pencil tasks and has excellent test–re-test and inter-rater reliability (van Hartingsveldt et al., 2014a, 2014c). The WRITIC-TP, administered in kindergarten, is found to be the main predictor for handwriting quality (van Hartingsveldt et al., 2014b) evaluated in Grade 1 by the Systematic Screening for Handwriting Difficulties (Smits-Engelsman et al., 2005).

Data analysis

Raw scores were used for the Timed-TIHM, 9-HPT and WRITIC-TP. Because the WRITIC scores at an ordinal level, convergent validity was calculated using Spearman's rho correlation for the total group and

for the subgroups with poor and good performance on paper-and-pencil tasks.

Correlation is interpreted according to Andresen (2000): strong correlation $r_s > 0.60$, moderate correlation $r_s = 0.30–0.60$ and weak correlation $r_s < 0.30$. A high correlation was expected between the Timed-TIHM and the 9-HPT, because both are timed tests evaluating fine motor coordination. A moderate correlation was expected between the Timed-TIHM and 9-HPT with the WRITIC-TP. Test–re-test reliability was calculated using the intraclass correlation coefficient (ICC). Agreement of the ICC was interpreted using the classification of Portney and Watkins (2008): 0.01–0.50 = poor, 0.50–0.75 = moderate and 0.75–1.0 = good. To process the data, SPSS 19.0 (SPSS Inc., Chicago, IL, USA) was used.

Results

Convergent validity study

In total, 119 children were included, of which 60 (50.4%) were boys. One child was excluded because the parents did not give their written consent. In the group of poor writers ($n = 43$), there were 36 boys (83.7%), and in the group of good writers ($n = 76$), there were 24 boys (31.6%). Because teachers selected more children who in their opinion had good performance on paper-and-pencil tasks than children who in their opinion had poor performance on paper-and-pencil tasks, as they did not meet the selection criteria, the groups of good writers and poor writers were not equally divided.

The mean age of the total group was 70.4 months (70.1 months for the poor writers and 70.6 months for the good writers). The majority of the children were right-handed (84% of the total group, 79.1% of the poor writers and 86.8% of the good writers). Fifteen percent of the children in total were left-handed (20.9% of the poor writers and 11.8% of the good writers), and only one had a variable hand use (in the group of good performers). Neither age nor handedness was significantly different between the two subgroups, although gender distribution was significantly different between the two groups ($p < 0.000$).

The good writers differed significantly ($p < 0.001$) from the poor writers on the WRITIC-TP, on the Timed-TIHM and on the 9-HPT (Table 1) with the poor writers performing more poorly on each of the measures.

WRITIC Domains	WRITIC Subdomains	
Child	Interest Questionnaire 6 items 3-point scale Range 0-12	Sustained attention <i>Scored by tester</i> 1 item 3-point scale Range 0-2
Environment	Physical <i>Scored by tester</i> 2 items 3-point scale Range 0-4	Social <i>Scored by tester</i> 1 item 3-point scale Range 0-2
Paper-and-pencil tasks	Task performance[†] <i>Scored by tester</i> 7 items 3-point scale 6 items 7-point scale Range 0-50	Intensity of performance <i>Scored by tester</i> 4 items 7-point scale Range 0-24

† Norm-referenced part of the WRITIC
WRITIC – Writing Readiness Inventory Tool In Context

Figure 2. Overview of the domains and subdomains of the Writing Readiness Inventory Tool in Context with the number of items, sort of scale and range in each

For the total group, the correlations of the WRITIC-TP with the Timed-TIHM and the 9-HPT were all statistically significant except the finger-to-palm translation task ($p=0.065$). The correlations of the total scores of the Timed-TIHM and 9-HPT with the scores of the WRITIC-TP were similar ($r_s=-0.40$ and $r_s=-0.40$ respectively).

The correlation of the total scores of the Timed-TIHM with the scores of the 9-HPT was $r_s=0.40$ ($p<0.001$).

For the poor writers, the WRITIC-TP had a significant moderate correlation with the complex rotation task of the Timed-TIHM and the 9-HPT, $r_s=-0.32$ ($p=0.042$) and $r_s=-0.30$ ($p=0.05$), respectively

(Table 2), but did not show a significant correlation with either of the translation tasks of the Timed-TIHM.

Test-re-test study

The study population consisted of 59 children with 57.6% boys ($n=34$); one child was excluded because of an incomplete dataset. The mean age was 66 months (range 59–81, standard deviation [SD] 4.6), the majority was right-handed (88.1%), 8.5% was left-handed and two children had variable hand use (3.4%).

The ICC of the total scores of the Timed-TIHM was moderate, $r=0.71$, $p=0.001$. The ICCs for the different

Table 1. Descriptive data of the outcome scores (mean, ranges) for the total group and for the subgroups of poor and good performers

Test	Total group (<i>n</i> = 119)	Good ^a (<i>n</i> = 76)	Poor ^a (<i>n</i> = 43)	<i>p</i> -value Mann–Whitney U
	Mean (SD)	Mean (SD)	Mean (SD)	
Timed-TIHM (seconds) ^b				
Total score	31.2 (8.55)	28.8 (9.12)	35.4 (7.24)	<0.001
Finger-to-palm translation task	4.4 (1.38)	4.1 (1.47)	4.9 (1.23)	0.002
Palm-to-finger translation task	11.3 (4.05)	10.6 (4.02)	12.4 (3.96)	0.010
Complex rotation task	15.6 (5.75)	14.1 (6.89)	18.1 (4.43)	<0.001
9-HPT (seconds) ^c	26.3 (3.64)	25.2 (4.12)	28.4 (2.82)	<0.001
WRITIC-TP (points) ^d	41.5 (5.19)	43.3 (5.07)	38.3 (4.31)	<0.001

SD = standard deviation; Timed-TIHM = Timed Test for In-hand Manipulation; 9-HPT = Nine-hole Peg Test; WRITIC-TP = Writing Readiness Inventory Tool in Context – Task Performance.

^aPoor and good performers as rated by the teacher.

^bA high score corresponds to poor in-hand manipulation.

^cA high score corresponds to poor fine motor coordination.

^dA high score corresponds to good writing readiness.

Table 2. Correlations of the Timed-TIHM and 9-HPT with the WRITIC-TP for the total group and for the subgroups of poor and good performers

	WRITIC-TP total group (<i>n</i> = 119), Spearman <i>r</i> (<i>p</i> -value)	WRITIC-TP good performers ^a (<i>n</i> = 76), Spearman <i>r</i> (<i>p</i> -value)	WRITIC-TP poor performers ^a (<i>n</i> = 43), Spearman <i>r</i> (<i>p</i> -value)
Timed-TIHM			
Total score	−0.402 (<i>p</i> ≤ 0.000)	−0.243 (<i>p</i> = 0.040)	−0.251 (<i>p</i> = 0.114)
Finger-to-palm task	−0.384 (<i>p</i> ≤ 0.000)	−0.450 (<i>p</i> ≤ 0.000)	0.043 (<i>p</i> = 0.786)
Palm-to-finger task	−0.170 (<i>p</i> = 0.065)	−0.068 (<i>p</i> = 0.564)	0.027 (<i>p</i> = 0.862)
Complex rotation task	−0.427 (<i>p</i> ≤ 0.000)	−0.248 (<i>p</i> = 0.036)	−0.319 (<i>p</i> = 0.042)
9-HPT	−0.404 (<i>p</i> ≤ 0.000)	−0.178 (<i>p</i> = 0.126)	−0.301 (<i>p</i> = 0.053)

Timed-TIHM = Timed Test for In-hand Manipulation; 9-HPT = Nine-Hole Peg Test; WRITIC-TP = Writing Readiness Inventory Tool in Context – Task Performance.

^aPoor and good performers as rated by the teacher.

tasks were $r = 0.53$ ($p < 0.001$) for the finger-to-palm translation task; $r = 0.63$ ($p < 0.001$) for the palm-to-finger translation task; and $r = 0.60$ ($p < 0.001$) for the complex rotation task.

Discussion

Our hypothesis that both fine motor coordination tests would have a moderate correlation with the performance of paper-and-pencil tasks was supported.

However, the Timed-TIHM did not show better correlation with the WRITIC-TP in the total group or the group of poor writers than the 9-HPT, in contrast to what we expected. Thus, our hypothesis that the Timed-TIHM is more closely related to writing readiness in children who are not ready for handwriting is not supported. The complex rotation task of the Timed-TIHM and the 9-HPT showed similar correlations with the WRITIC-TP in the total group and in the poor-performance group.

In contrast with our hypothesis, the correlation between the Timed-TIHM and the 9-HPT was moderate. This could be explained by the assumption that these tests measure different aspects of fine motor coordination. The Timed-TIHM evaluates complex patterns, including IHM skills, and the 9-HPT evaluates simple patterns of fine motor coordination (picking up, placing and releasing pegs). This needs further investigation.

Overall, the correlations of the Timed-TIHM and the 9-HPT with the WRITIC-TP were moderate. This is comparable with studies that show the correlation of fine motor coordination with the quality of handwriting (Feder et al., 2005; Volman et al., 2006). This can be explained by the fact that fine motor coordination is one of several factors that are involved in handwriting (Figure 1).

For the poor writers, the highest correlations were found between the 9-HPT and the WRITIC-TP and between the complex rotation subtask of the Timed-TIHM and the WRITIC-TP. This could mean that the 9-HPT and this complex rotation subtask of the Timed-TIHM are most appropriate for evaluating fine motor coordination in this group and for discriminating between good and poor fine motor skills in this age group. The 9-HPT has the advantages that (1) normative values are available for children between 5 and 10 years of age (Smith et al., 2000); (2) it is an internationally well-known test; and (3) it is quicker and easier to apply.

The Timed-TIHM consists of three different tasks that show different correlations with the WRITIC-TP. These three different tasks of the Timed-TIHM require different finger–thumb movements and are of different complexity. The complex rotation task shows the best correlation with the WRITIC-TP, and the palm-to-finger translation task shows the poorest correlation and is more variable than the other tasks in the poor performers and also in the total group. The reason for this could be that this task requires movements that are too complex and not (yet) well developed in this age group. This is especially the case in the poor writers, and therefore, children are using different and varying strategies (Pehoski et al., 1997a, 1997b). On the other hand, the palm-to-finger translation task only correlates significantly with the WRITIC-TP in the good-performance group; the variance in scores is smaller, which could mean that this group is more mature and uses a more consistent and efficient strategy

than the poor performers. This is in line with the development of IHM as described by Exner (2010). Manipulation tasks with stabilization (the translation from finger to palm and from palm to finger in the Timed-TIHM) are more difficult than those without stabilization (the complex rotation in the Timed-TIHM). Therefore, translation from finger to palm is easier than translation from palm to finger, which is in agreement with the correlations. Until the age of 7 years, IHM skills develop progressively into more complex skills (Exner, 2010), and there is still a large variety in the skills that children master. The three different tasks of the Timed-TIHM show a large variety in scores. This might represent a wide range of scores in the performance of these IHM skills in these children. Large variation in performance is an indication that these skills are not yet fully automatized, children are still searching for the most efficient strategy and these IHM skills are still in the developmental phase (Pehoski et al., 1997a, 1997b). Using the Timed-TIHM could thus possibly show how far children are in their development of IHM, marking their progress from mastering complex rotation (without stabilization) to mastering translation from finger to palm and, finally, translation from palm to finger (with stabilization). This is an advantage of the Timed-TIHM over the 9-HPT.

For the current study, we adapted the TIHM-R and developed the Timed-TIHM. Changes were made in order to improve sensitivity of scores and test–re-test reliability. The Timed-TIHM is now easier and quicker to assess, because only time scores are used as compared with the TIHM-R in which time scores and quality scores are combined. The stability of the test scores of the Timed-TIHM is acceptable, which is shown in moderate test–re-test reliability for the total score as well as for the three subtasks. This was not expected because children are likely to use different performance strategies during the test and the re-test.

In this study the “finger succession task” or “sequential finger movements” task was not included. Berninger et al. (1992, cited in Berninger, 2009) determined that sequential finger movements have a closer relationship to handwriting than other fine motor tasks do ($r=0.32$). In this task, the child has to touch the thumb with each finger in sequential order, starting at the little finger and moving to the index finger, as quickly as possible. In Berninger’s interdisciplinary, programmatic line of research on writing over the past

25 years, the sequential finger movements task was a frequently used fine motor test (Berninger, 2009). Because the finger succession task falls outside the scope of the definitions of fine motor coordination by Exner (2010) and the ICF-CY (WHO, 2007), we did not include this in our research on fine motor tests. Possibly, this test has a significant correlation with the 9-HPT and/or the Timed-TIHM. To investigate this, further research is needed.

The correlations that were found are specific for children aged from 5 to 6 years. Findings and conclusions might be different in other age groups, such as in children aged over 8 years who have already mastered the skill of handwriting and are more stable in their fine motor performance. Future studies are recommended on the Timed-TIHM in different age groups to evaluate the relation between development of fine motor coordination and handwriting proficiency.

A possible limitation of this study is that the group of 43 children who were poor writers was smaller than the expected 60 children because teachers selected more children with good performance on paper-and-pencil tasks. For evaluating the psychomotor properties of measurements, the group must contain at least 50 participants (Terwee et al., 2007), which was not the case in our study. There were more boys in the group with poor performance on paper-and-pencil tasks. This depicts the actual situation, as is also shown in several studies: namely that the handwriting skill of girls exceeds that of boys (Berninger et al., 2008). However, the total group had an equal balance between boys and girls.

Conclusion

The correlations of the 9-HPT and Timed-TIHM with the WRITIC-TP for the total group were similar. The Timed-TIHM and the 9-HPT seem to measure different constructs of fine motor coordination. The Timed-TIHM evaluates complex fine motor patterns, including IHM skills, and the 9-HPT evaluates simple patterns of fine motor coordination. Both have their advantages in the evaluation of fine motor coordination in children who are not ready for handwriting. The 9-HPT is easier, quicker and more internationally known, and it has normative values for children aged from 5 to 10 years, whereas the Timed-TIHM provides information about the development of the IHM of the child. However, both tests provide information about

different skills that seem related to handwriting, so we suggest the use of both tests.

Conflict of interest

The authors declare no conflict of interest.

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