Integration of Speed and Quality in Measuring Graphomotor Skills: The Zurich Graphomotor Test

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Importance: In educational settings, children are under pressure to finish their work successfully within required time frames. Existing tools for assessing graphomotor skills measure either quality or speed of performance, and the speed–accuracy trade-off (SAT) in such tools has never been investigated.

Objective: We aimed to evaluate a newly developed tool for measuring graphomotor skills, the Zurich Graphomotor Test (ZGT), that assesses both speed and quality of performance. We also explored whether graphomotor tests are affected by the SAT and, if so, the effects it has on graphomotor test results.

Design: Cross-sectional study.

Setting: Educational institutions in Switzerland.

Participants: Children, adolescents, and young adults ($N = 547$) ages 4–22 yr (50.3% female).

Outcomes and Measures: Graphomotor performance was measured with the ZGT and the Developmental Test of Visual Perception, Second Edition (DVTP–2). Standard deviation scores were used to quantify performance. We combined ZGT speed and quality measurements into a performance score adjusted for age and sex.

Results: ZGT results indicated a marked developmental trend in graphomotor performance; older children were faster than younger children. Girls showed higher overall performance than boys. The pattern of making more mistakes when being faster and making fewer mistakes when being slower was observed for both graphomotor tests, regardless of time pressure, indicating that the SAT affected the children's scores on both tests.

Conclusions and Relevance: SAT is influential in graphomotor assessment. The ZGT captures this trade-off by combining accuracy and speed measurements into one score that provides a realistic assessment of graphomotor skills.

What This Article Adds: The newly developed ZGT provides occupational therapy practitioners with more precise information on graphomotor skills in children, adolescents, and young adults than currently available tools.

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Despite the increased use of technical devices in recent years, handwriting proficiency remains a fundamental educational goal. Handwriting and drawing are graphomotor skills that involve the most demanding and complex of human fine motor actions (Bonoti et al., 2005). Graphomotor skills comprise a subset of fine motor skills executed manually using a pencil or pen, typically during writing or drawing (Suggate et al., 2016). When a child reproduces letters, figures, or pictures either from memory or by copying, somatosensory and visual perception, cognitive processes, and motor control (Bonoti et al., 2005; Ziviani & Wallen, 2006) interact with the child's maturational, developmental, and learning processes (Smits-Engelsman & Van Galen, 1997).

Children with fine motor deficits often show lower academic performance than their peers (Grissmer et al., 2010) and are more vulnerable to social and emotional difficulties, including lower self-esteem (Bart et al., 2007). These outcomes are not surprising, since fine motor tasks constitute up to 60% of daily school and kindergarten activities (Marr et al., 2003; McHale & Cermak, 1992). Affected children cannot keep up in class or finish their work successfully within predefined time frames because either they write too slowly (Prunty et al., 2013) or their handwriting is difficult to read (Bieber et al., 2016; Ziviani & Wallen, 2006). Fine motor deficits are one of the main reasons for referral to occupational therapy (Barnes et al., 2003; Diekema et al., 1998).

Fine motor skills during the preschool years have been shown to be important predictors of later academic success (Dinehart & Manfra, 2013; Escolano-Pérez et al., 2020; Grissmer et al., 2010; Pagani et al., 2010). Early graphomotor skills, such as scribbling and drawing, can be useful in evaluating a child's development (Jenni, 2013) and, for children who lack proficiency, can help clinicians identify minor neuromotor dysfunction (Blank et al., 2000; Smits-Engelsman & Van Galen, 1997). In addition, drawings can be used to predict future handwriting problems and as an early diagnostic tool (Bonoti et al., 2005). Thus, identifying graphomotor problems at the earliest possible stage can inform intervention to prevent later learning difficulties.

Assessing graphomotor skills is a challenging task because of the subjective nature of evaluating graphomotor quality and the many performance components inherent in this complex, sensorimotor task (Feder & Majnemer, 2003). Numerous graphomotor evaluation tools are available for children. However, a review by Feder and Majnemer (2003) found only a few reliable measures specifically designed for children ages 3–7 yr. Many graphomotor tools, including the Developmental Test of Visual Perception, Second Edition (DTVP–2; Hamill et al., 1993), and the Beery–Buktenica Developmental Test of Visual–Motor Integration (Beery et al., 2010), disregard speed and focus exclusively on quality; quality includes factors such as accuracy and legibility. Tools that assess speed, such as the Detailed Assessment of Speed of Handwriting (DASH; Barnett et al., 2009) and the Handwriting Speed Test (HST; Wallen & Mackay, 1999), focus on handwriting rather than general graphomotor skills and thus can be used only with children who can write (i.e., ages ≥8 yr for the DASH and ≥9 yr for the HST). In addition, the DASH and HST are based on the Latin alphabet and a certain level of written language acquisition. However, the paper-and-pencil (or pen) format of these tools makes them close to realistic school tasks. Additionally, they are inexpensive and easy to administer.

More recently, digital writing boards such as tablets have enabled the analysis of dynamic and kinetic aspects of graphomotor skills. Despite their advantages for diagnostics, the tablet surface differs from that of paper, and children therefore must exert increased effort to control their handwriting movements, presenting additional challenges (Alamargot & Morin, 2015; Gerth et al., 2016).

In graphomotor tasks, each performed movement has two aspects: the quality of the movement and time it takes to complete. The inverse relationship between these two aspects of performance, first discussed by Fitts (1954) and now known as the speed–accuracy trade-off (SAT), is observed not only in purely motor tasks but also in perceptual and cognitive tasks (Heitz, 2014). The influence of the SAT has been discussed in the literature on motor control, learning, and planning (Al Borno et al., 2020; Zhang & Rowe, 2014), and the SAT is a foundational principle in human coordination and movement control.

Trading speed for accuracy and vice versa is ubiquitous across animal species and tasks (Heitz, 2014). Therefore, clinicians can expect the SAT to affect performance and test results when they assess graphomotor skills. To our knowledge, however, the SAT has never been addressed when discussing graphomotor skills or evaluating the psychometric properties of tests of those skills. In addition, as far as we know no existing graphomotor test for preschoolers and school-age children assesses both quality and speed using a paper-and-pencil format; this is surprising considering that speed and quality are the most important elements of handwriting performance (Bieber et al., 2016).

In response, we developed a new paper-and-pencil graphomotor test, the Zurich Graphomotor Test (ZGT), that integrates speed and quality of performance. The ZGT requires no writing skills and is independent of language knowledge, so it is suitable for use with children age 4 yr and older. In this article we describe a cross-sectional study to compare the ZGT results to results on the Eye–Hand Coordination subtest of the well-established DTVP–2 and the Zurich Neuromotor Assessment–2 (ZNA–2; Kakebeeke et al., 2019) to identify correlations between graphomotor performance and fine motor performance.

Method

Participants

Participants were 547 children, adolescents, and young adults (275 were female; 91% were right-handed) ages 4 yr, 0 mo to 22 yr, 5 mo (*Mdn* = 10 yr, 1 mo; interquartile range [IQR] = 8 yr, 0 mo). We recruited participants from day care centers, kindergartens, and primary, secondary, and vocational schools in the greater Zurich area between 2015 and 2017. Children whose caregivers reported medical, developmental, or behavioral disorders were excluded from the study. We conducted the sampling to include children from all social strata and all districts of the city of Zurich. We recorded parents' Highest International Socio-economic Index of Occupational Status (HISEI), which ranks the occupations from 16 to 90 on the basis of responses to a questionnaire item regarding parental

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occupation and takes the higher-value parent into account. We provided participants and parents with an information sheet that explained the study's methods and aims in detail, and we obtained written informed consent from the primary parent or guardian and all participants ages ≥14 yr. Participants ages <14 yr gave verbal consent. The study procedures were approved by the local ethics committee (KEK-ZH-No. StV-40/07) and performed consistent with principles of the Declaration of Helsinki (World Medical Association, 1964).

Measures

Zurich Graphomotor Test

The ZGT is a trail test with graphic representations of a gray street with parallel black boundary lines, an ambulance, and a hospital (see Figure S1 in the supplemental materials, available online with this article at https://research.aota.org/ajot). The trail is divided into three sections with identical straight, curved, and angled lines. The width of the gray street decreases from 10 mm in Section 1 to 6 mm in Section 2 and 2 mm in Section 3. Children younger than age 6 yr complete only Sections 1 and 2, whereas children age 6 and older complete all three sections. Lines representing boundaries of 2 mm on each side of the gray street appear in Section 2, and a second set of lines 2 mm from the first set appear in Section 3. Faint white lines divide the trail into 16 segments per section. The boundaries and segments are used to score graphomotor quality, and a stopwatch is used to score graphomotor speed. Children trace the trail with a pen that produces a 0.4-mm line width. Only the preferred (dominant) hand is tested.

The examiner instructs the child to start at the ambulance and draw a single continuous line that follows the gray trail, emphasizing that the child should draw the line as quickly as possible while keeping between the boundary lines (see the Instructions section of Figure S1). The child is given a short separate trail to practice without time measurement before beginning the test.

Performance time measurement starts when the child places the pen on the paper at the ambulance and stops when the pen is lifted after finishing the trail at the hospital. The examiner measures quality by assigning penalty points when the drawn line crosses the boundaries outside the gray street for each segment. The number of possible penalty points differs depending on the section (see the Scoring Guidelines section of Figure S1).

Developmental Test of Visual Perception, Second Edition, Eye–Hand Coordination Subtest

The DTVP–2 is a measure of visual cognitive functions, including visual–perceptual and visual–motor integration skills, with eight subtests (Hamill et al., 1993). It can be administered to children between age 4 yr, 0 mo and 10 yr, 11 mo. For this study, only the Eye–Hand Coordination subtest was used. This subtest requires the child to draw a line as precisely as possible, with as few mistakes as possible, on five different trails, including one practice trail. Scoring is based solely on accuracy; no limit is placed on the time required to perform the task.

Zurich Neuromotor Assessment–2

The ZNA–2 (Kakebeeke et al., 2019) is a standardized test of motor proficiency in children ages 3 yr, 0 mo to 18 yr, 0 mo. It is a reliable and validated measure and has been described in more detail by Kakebeeke et al. (2018).

Procedure

Examiners were experienced ZNA–2 testers who had all been trained by Jon A. Caflisch and Tanja H. Kakebeeke. The examiners (Elisa Knaier, Jon A. Caflisch, Tanja H. Kakebeeke, Cristina Pizio) administered the fine motor component of the ZNA–2 and the ZGT to all children. Subsequently, children younger than age 11 yr ($N = 291$) were then administered the DTVP–2. The examiner verified handedness in children younger than age 6 yr using a hand preference test and in those age 6 yr and older by asking which hand they used when writing. The examiner then placed a graphomotor trail sheet on a table in front of the sitting child and provided the instructions. All testing sessions were recorded on digital video.

To assess test–retest reliability of the ZGT, a subset of 116 children repeated the graphomotor assessment 14 days after the first session (median age = 9 yr, 3 mo [IQR = 7 yr, 5 mo]; 59 were female; 93% were right-handed). Of these, 77 children (median age = 9 yr, 8 mo [IQR = 10 yr, 1 mo]; 37 were female; 93% were right-handed) performed the ZGT three trials in a row at both testing sessions; during the second trial, the children completed a horizontally mirrored version of the ZGT trail. A 1-min break between the three performances was provided.

The videos were used to collect a value for speed on the DTVP–2. Time measurement started when the child placed the pen on the paper and stopped when the pen was lifted after finishing the trail. We used time measurement on the last two trails in the analysis. To ensure a fair comparison with the ZGT, we did not include in the quality score any mistakes that were done by lifting the pen during measurement; this type of mistake consumes time, which would penalize the participant's performance twice (for time and for quality).

Statistical Analysis

Unlike the DTVP–2, which accounts only for number of mistakes when assessing drawing performance, the ZGT forces the child to find a balance between speed and quality of execution. Thus, measurement of the

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drawing performance of a child on the ZGT accounts for both the time required to complete the trail and the number of mistakes committed during that time. To build a performance score for the ZGT, we regressed the observed time performance against the number of mistakes, while adjusting for both age and sex. More specifically, we used the Box–Cox Cole and Green (BCCG) distribution (Cole & Green, 1992; also known as the lambda mu sigma [LMS] method) within the framework of generalized additive models for location, scale, and shape (Stasinopoulos & Rigby, 2007) to flexibly model the distribution of time performance as a function of age, sex, and number of mistakes. The BCCG distribution is a three-parameter distribution that allows modeling the median μ, the coefficient of variation σ, and the skewness ν of a strictly positive continuous outcome such as time. When $\nu = 0$, the BCCG distribution reduces to the well-known lognormal distribution.

We used standard deviation scores (SDSs) to quantify drawing performance on the ZGT. SDSs are routinely used in motor development studies to quantify age- and gender-adjusted motor performance (Kakebeeke et al., 2018; Largo et al., 2007). They should be approximately normally distributed with a mean of 0 and a variance of 1 in the population of typically developing children, with positive SDSs indicating above-average performance and negative SDSs indicating below-average performance. With T_i and M_i denoting the time performance and number of mistakes of child *i*, the corresponding SDS, z_i, is calculated as

$$z_i = \begin{cases} \dfrac{1 - \left(\frac{T_i}{\mu_i}\right)^{\nu}}{\nu\sigma_i} & \text{when } \nu \neq 0 \\ \dfrac{\log(\mu_i) - \log(T_i)}{\sigma_i} & \text{when } \nu = 0 \end{cases}$$

with

$$\log(\mu_i) = \beta_0 + \beta_1 f_1(age_i) + \beta_2 f_2(age_i) + \beta_3 g_1(M_i) + \beta_4 g_2(M_i) + \beta_5 female_i + \beta_6 I(age_i < 72)$$

$$\log(\sigma_i) = \gamma_0 + \gamma_1 I(age_i < 72).$$

In this model, μ_i and σ_i refer to the expected time performance and coefficient of variation, respectively, for peers (i.e., same age and sex) who committed the same number of mistakes, M_i, as child *i*. In addition, age_i is the age (in months) of child *i*, $female_i$ is a binary indicator for gender (0 = male; 1 = female), $I(age_i < 72)$ is a binary indicator taking the value 1 if child *i* is younger than 6 yr (72 mo) and 0 otherwise, and $\{f_1, f_2\}$ and $\{g_1, g_2\}$ are smooth functions defining second-degree fractional polynomials (Royston & Altman, 1994) that capture potential nonlinear effects of age and number of mistakes, respectively (for more details, see Figure S2 in the Supplemental Material, available online with this article at https://research.aota.org/ajot). The indicator $I(age_i < 72)$ was included in the model to accommodate the change in length of the task at age 6 yr, with younger children receiving a shorter version of the ZGT (i.e., only Sections 1 and 2) than older children (i.e., all three sections). The coefficients $\beta_0 \ldots \beta_6$, γ_0, and γ_1, as well as the skewness parameter ν, were estimated from the data.

We assessed the presence of interactions between age and sex and between age and number of mistakes using graphic representations. Goodness of fit was assessed using residual diagnostic plots. The test–retest reliability was quantified on SDSs using the intraclass correlation coefficient (ICC; Shrout & Fleiss, 1979).

Results

The mean HISEI was 59 ($SD = 20.2$), slightly higher than the general population in Zurich ($M = 55$; Konsortium PISA, 2014). Ninety-one percent of the children in the sample were right-handed, comparable to the general population (Papadatou-Pastou et al., 2020). Because the subsample of left-handed participants was small ($n = 49$), we did not develop separate norms for these children. However, we compared the SDS distribution (i.e., calculated using norms developed on all data) between right- and left-handed participants. The mean SDSs were 0.01 for right-handers and 0.14 for left-handers; this difference in the mean was not significant ($p = .384$) in a two-sample *t* test.

Figure 1 illustrates the association between time needed to complete the task and number of mistakes made on the DTVP–2 (Panel A) and the ZGT (Panel B), separately for children ages 4 yr, 0 mo to 5 yr, 11 mo and 6 yr, 0 mo to 10 yr, 11 mo. Although the DTVP–2 does not put children under time pressure, results for both tests show the same pattern, with children committing more mistakes being generally faster than those who made fewer mistakes. On the ZGT, children age 6 yr or older required more time to complete the trail than younger children because of the increased trail length (see Panel B).

We modeled time performance on the ZGT as a function of age, sex, and number of mistakes over the whole age range (i.e., from 4 yr, 0 mo to 22 yr, 5 mo) using a BCCG distribution with a skewness parameter $\nu = -0.666$ ($p < .001$). Such a distribution fit the data significantly better than a lognormal distribution (i.e., $\nu = 0$). All variables entered the model in an additive fashion. Plotting the standardized residuals of the model either as a function of age (within different quartiles of number of mistakes) or as a function of number of mistakes (within different quartiles of age) did not suggest the presence of any visible interaction between these predictors. Other residual diagnostic plots also suggested that the model was describing the data adequately. Parameter estimates of the model with standard errors are reported in Figure S3 of the Supplemental Material.

Figure 2 illustrates that the predicted median time required to complete the ZGT trail (as calculated from

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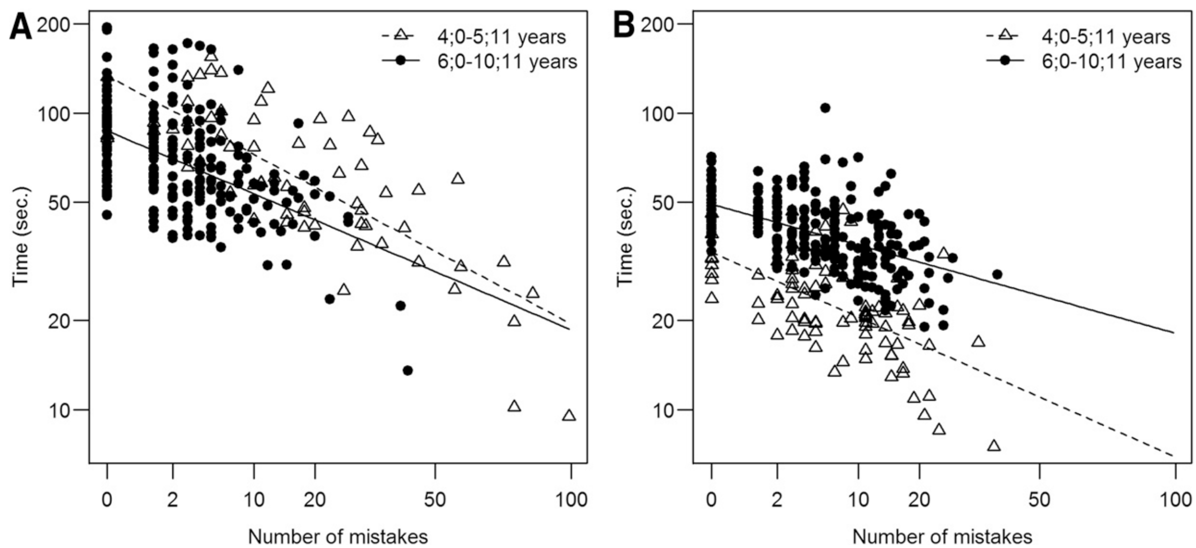
Figure 1. Time performance as a function of number of mistakes for children ages <6 yr and ≥6 yr on the (A) Developmental Test of Visual Perception, Second Edition, and (B) Zurich Graphomotor Test.



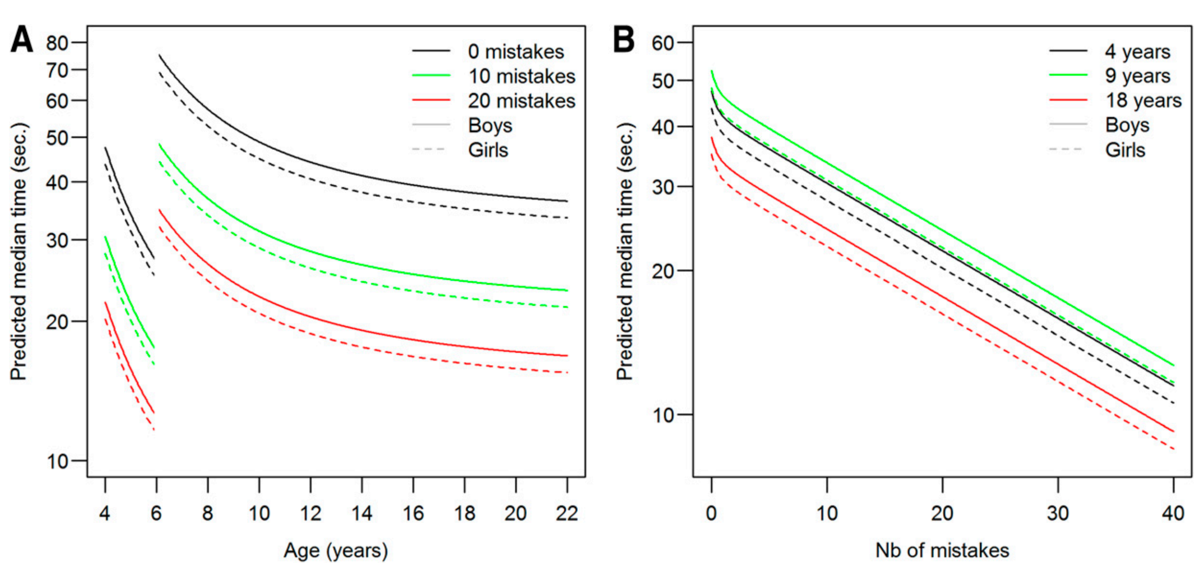
Note. Lines represent linear regressions within each age group (represented as years;months). A logarithmic scale is used for time; a square root transform has been applied to number of mistakes.

the model) depends on age (Panel A) and number of mistakes (Panel B) in the three subgroups of children. For any given fixed number of mistakes, we observed a marked developmental trend, with older children being faster than younger ones (see Panel A). The increase in ZGT trail length for children age 6 yr and older is evident in the time shift shown in the figure. Additionally, girls were slightly faster than boys who made the same number of mistakes ($p < .001$). Panel B indicates that at any given age, children who committed more mistakes generally completed the trail faster than those who committed fewer mistakes. The relationship between the logarithm of time and number of mistakes appears mostly linear. However, the slight curvature of the regression lines toward the left of the plot suggests that the relative gain in speed resulting from committing one mistake instead of zero may be larger than for any other consecutive number of mistakes.

Centile plots (with the 10th, 50th, and 90th percentiles) for time performance according to number of mistakes are presented in Figure 3, separately for boys (Panel A) and girls (Panel B). The figure suggests that the effect of committing more mistakes can be substantial compared with the age effect or the natural variability in time performance within a group of children who make the same number of mistakes.

Table 1 presents ICCs calculated for different subgroups of children based on a single trial or the average

Figure 2. Predicted median time to complete the Zurich Graphomotor Test trail for different subgroups (A) as a function of age and (B) as a function of number of mistakes.



Note. A logarithmic scale is used for time.

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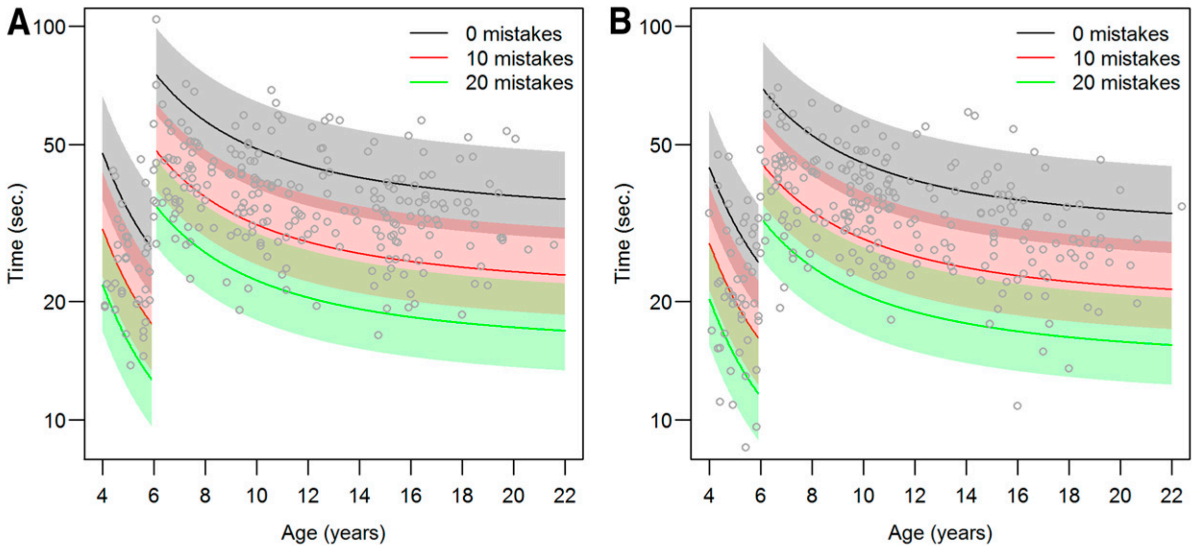
Figure 3. Centiles of time performance as a function of age in subgroups based on number of mistakes for (A) boys and (B) girls.



Note. Colored areas represent the 10th and 90th percentiles, and solid lines represent the 50th percentile. Observed data are overplotted as gray dots. A logarithmic scale is used for time.

of results from three successive trials. Results for a single trial showed modest ICCs of about .50 that differ only slightly in younger and older children. Larger ICCs were obtained for average results over three trials; for example, for children age 6 yr and older, the estimated ICC reached .76. However, we did not observe any practical gain in test–retest reliability for children younger than age 6 yr after averaging the results of three trials.

We found a positive association between the HISEI, a measure of socioeconomic status, and SDSs of the ZGT. However, this association did not reach significance and was weak in magnitude, with an estimated increase of 0.14 SDS ($p = .077$) in graphomotor performance when the HISEI increased by 30 points (corresponding to the IQR) after adjusting for age and sex. Similarly, SDSs of the ZGT were only weakly associated with SDSs on the fine motor component of the ZNA–2 (rank correlation $r = .22$, 95% confidence interval [CI] [.13, .30]) or with SDSs on the Pegboard and Bolts tasks in the dominant hand only ($r = .21$, 95% CI [.13, .30]).

Discussion

In this article we present the ZGT, a new and easily administered assessment of graphomotor skills in children, adolescents, and young adults that incorporates the two most important elements of handwriting performance: speed and quality. We found that children who committed more mistakes completed the trail task at a faster rate than those making fewer mistakes, a pattern seen with both the ZGT and DTVP–2, even though the DTVP–2 does not involve time pressure. We also observed a marked developmental trend, with older children being faster than younger ones. Girls were slightly faster than boys who made the same number of mistakes. ICCs were modest, but larger ICCs were obtained after averaging the results of three successive trials.

Table 1. Test–Retest Reliability of Standard Deviation Scores for the Zurich Graphomotor Test

Participant Group	ICC [95% CI]	
	1 Trial	Average of 3 Trials
All children	.50 [.36, .63]	.67 [.53, .78]
Children ages <6 yr	.47 [.15, .69]	.52 [.22, .72]
Children ages ≥6 yr	.52 [.34, .65]	.76 [.59, .86]

Note. CI = confidence interval; ICC = intraclass correlation.

In our modeling approach, we treated time as the dependent variable and number of mistakes as a predictor. Although an equally valid approach would be to treat number of mistakes as the dependent variable and time as a predictor, we chose to use time as the primary outcome because it is a continuous variable, for which it is easier to construct reference norms, whereas number of mistakes is a discrete variable. The idea of penalizing time performance by number of mistakes is not new; it is used in sports involving both speed and precision such as biathlon, in which an athlete's time performance is penalized for each miss during rifle shooting sessions. Similarly, the ZNA–2 assesses motor performance with regard to timed performance and movement quality (i.e., contralateral associated movements), yielding a global motor proficiency score.

Children who performed faster on the ZGT committed more mistakes on average than those who performed slower. This finding is consistent with the features of the SAT (Bogacz et al., 2010; Heitz, 2014). When performing the ZGT task, children confront the complex relationship of speed and quality by choosing

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between drawing slowly and making relatively few mistakes or drawing quickly while making relatively more mistakes. Although the DTVP–2 does not put children under time pressure to complete the exercise and focuses only on the number of mistakes, we recorded the completion time for the DTVP–2, which revealed that the DTVP–2 also is affected by the SAT. This finding strongly supports the idea that both speed and quality should be considered when assessing graphomotor performance, regardless of whether or not children are instructed to perform as quickly as possible. Indeed, even handwriting intervention programs for students struggle with the impact of the SAT. A review by Engel et al. (2018) found that handwriting programs improved legibility but not speed. The authors even highlighted a decline in speed with improved legibility and noted that children need additional practice to develop handwriting speed after quality improvement.

It is highly questionable whether tools like the DTVP–2 that consider only one factor are able to identify children at risk for graphomotor problems with sufficient precision (a Practical Example is reported in S4 in the Supplemental Material). As Vandierendonck (2021) noted, "If speed and accuracy correlate negatively in a particular task setting, it seems plausible to assume that the higher score contributed by one task property (e.g., speed) is—to some extent—compensated by a lower score contributed by the other property (e.g., accuracy)" (p. 2). Tests such as the DTVP–2 may instead measure a child's temperament or strategy used. In fact, Nagengast et al. (2011) supported this suggestion, positing that individual risk sensitivity is an important factor in motor tasks influenced by the SAT.

At any given number of mistakes and controlling for trail length, ZGT results feature a marked developmental trend, with older children completing the trail faster than younger ones. Children undergo constant developmental changes in motor proficiency as they grow from early childhood into adulthood. Despite large interindividual variations, motor proficiency improves throughout the entire period in speed and quality, with some reaching a plateau earlier (Kakebeeke et al., 2013, 2018; Largo et al., 2001a, 2001b). We also found that girls were slightly faster than boys of the same age after adjusting for number of mistakes. Many studies have found that girls tend to show better fine motor skills (Morley et al., 2015) and drawing skills (Morović et al., 2015) than boys, although some studies have found no gender differences (Weil & Amundson, 1994).

There was no relevant association between HISEI, a marker of socioeconomic status, and standard deviation scores on the ZGT. SDSs correlated only weakly with the fine motor component of the ZNA–2, including the Pegboard task. Tests of graphomotor performance may measure a group of skills different from those of other typical fine motor tasks; Dinehart and Manfra (2013) proposed considering fine motor object manipulation skills and fine motor writing skills separately. Object manipulation skills are used in performing tasks with objects, such as stacking blocks or placing pegs on a pegboard. Fine motor writing skills involve the use of a writing utensil to produce and replicate symbols, numbers, and letters. Studies have shown that only certain fine motor writing skills in preschool-age children are predictors for later academic achievement (Dinehart & Manfra, 2013; Grissmer et al., 2010). Thus, fine motor writing skills have a stronger predictive value than fine motor object manipulation skills, and graphomotor performance should always be considered separately when assessing fine motor skills.

Despite its appealing properties, the ZGT suffers from limited test–retest reliability, with an overall ICC of only .50. This modest performance is in fact a direct consequence of the SAT. Because time performance and number of mistakes are negatively correlated, the combined score inevitably displays lower test–retest reliability than either dimension considered separately. This issue can be overcome by repeating the ZGT several times and averaging the results. In principle, SDSs from successive trials will be positively correlated, so averaging the results of multiple trials will increase the test–retest reliability. Although doing so lengthened the total assessment duration, averaging the results over three successive trials increased the overall ICC to .67 and to .76 for children older than 6 yr. However, we did not observe a substantial improvement of the ICC after three trials in children younger than age 6 yr.

Implications for Occupational Therapy Practice

The results of this study have the following implications for occupational therapy practice:

- Compared with existing tools, the newly developed ZGT provides occupational therapy practitioners with more realistic information on graphomotor skills in children and adolescents.
- The ZGT offers insights into how children cope with demands on their graphomotor skills in the school setting to produce legible texts within a reasonable time. By exploring how children cope with the ZGT's SAT, occupational therapy practitioners can develop interventions to promote graphomotor skills.
- Occupational therapy practitioners, parents, and teachers can use the ZGT to easily assess a child's graphomotor skills during developmental examinations, diagnostic procedures for suspected graphomotor problems, and therapy progress assessments.
- The ZGT does not require writing or language skills, and norms are provided (see Figures 1–3) for children age 4 yr and older.

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Conclusion

For a realistic assessment of graphomotor skills in children, adolescents, and young adults, tests need to take both speed and quality into account. The ZGT combines these two developmental aspects of graphomotor skills into one score, providing important information on a child's graphomotor skills and insights into how the child copes with the demands on their graphomotor skills at school. Other tools affected by the SAT do not take speed as well as quality into account.

To extend the utility of the ZGT, future studies should investigate whether the ZGT can distinguish between children with and without graphomotor difficulties (e.g., developmental coordination disorder). Finally, longitudinal studies would reveal whether ZGT scores are able to predict children's later success in school.

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