Evaluation of Handwriting Skills in Children with Learning Difficulties

Wanjoo Park[1], Georgios Korres[1], Samra Tahir[2], and Mohamad Eid[1(✉)]

[1] Engineering Division, New York University Abu Dhabi, Saadiyat Island, Abu Dhabi, United Arab Emirates
{wanjoo,george.korres,mohamad.eid}@nyu.edu

[2] Child Clinical Department, American Center for Psychiatry and Neurology, Abu Dhabi, United Arab Emirates
s.tahir@americancenteruae.com

Abstract. Many children have physical, cognitive, motor, and other limitations that influence their ability to develop handwriting skills. Recently, haptic technology is gaining rising interest as an assistive technologies to improve the acquisition of handwriting skills for children with learning difficulties. In this paper, we introduce a method and an experimental protocol to evaluate the quality of handwriting for children with learning difficulties. We developed a copy work task comprising four categories of handwriting tasks, namely numbers, letter, shapes, and emoticons (a total of 32 tasks, covering low to high complexity handwriting tasks). Results demonstrated that shapes are more difficult to learn than emoticons, even though emoticons are more complex to construct. This is probably due to the fact that children are more familiar with emoticons than abstract shapes. Findings in this study are crucial for developing a longitudinal experimental study to evaluate the effectiveness of various haptic guidance methods to improve learning outcomes for children with learning difficulties.

Keywords: Haptic · Handwriting · Drawing, assistance · Learning difficulty

1 Introduction

Handwriting is a complex human activity that requires fine motor control, perceptual, and visual-motor integration skills [1,2]. Early writing skills is the ability to create easy-to-read text with minimal physical and mental effort. Generally, the fluency of handwriting skills improves with age and education [3]. Children usually acquire these skills as they grow over a long term of repetitive training. Also, for typically growing children, handwriting become automatic and therefore, text generation does not interfere with creative thinking process [4]. However, it is reported that the difficulty of handwriting in school-aged children varies from 10% to 34% [5]. Hamstra-Bletz and Blote defined "dysgraphia"

M. Antona and C. Stephanidis (Eds.): HCII 2019, LNCS 11573, pp. 150–159, 2019.
https://doi.org/10.1007/978-3-030-23563-5_13

as a disturbance or difficulty in the creation of a written language [6]. Writing difficulties are officially diagnosed as a part of Developmental Coordination Disorder [7]. There are many assistive technologies to support students with writing difficulties, but they all have their own practical limitations [8]. Drawing skill is also considered to be one of the important factor to evaluate learning process. In order to support students with handwriting learning difficulties, a workbook was created that include shapes, emoticons, numbers and letters in order to provide a wide range of handwriting skills complexity (starting from simple tasks such as numbers or characters to more complex shapes and emoticons). We also developed a haptic-based handwriting training system (Fig. 1) to provide haptic guidance for improving handwriting skills acquisition. Our previous work reported significant improvement in the acquisition of handwriting skills for adults using various haptic guidance methods (full and partial guidance) [9]. In this study, we designed an experimental protocol for students with learning difficulties to investigate if haptic guidance may improve further the learning outcomes. Before proceeding with the experimental study, We must evaluate the children's performance with paper-based copy work to verify the experimental protocol.

2 Materials and Methods

2.1 Participants

Twenty children with learning difficulties are recruited for this study (14 males and 6 females; age range, 4–12, all met our inclusion/exclusion criteria). The inclusion criteria were: (a) children who struggle with letter, shape formation and have moderate, mild and borderline intellectual deficits, (b) children who suffer from visual spatial skill deficits. The exclusion criteria were: (a) children who have no intellectual disabilities, (b) children who demonstrate normal executive and marking memory skills. The study was approved by the Institutional Review Board for Protection of Human Subjects in the American Center for Psychiatry and Neurology (Project # 0017) and New York University Abu Dhabi (Project # 101–2016).

2.2 Design of the System

We have developed a haptic-based handwriting platform for physically guiding the children along a trajectory of handwriting task [9]. The platform has been extensively revised and calibrated, in collaboration with the therapists, for children with learning difficulties. A seven inch display was mounted on a base under the revised pen-shaped end-effector in order to act as a writing pad. Subsequently, the haptic device had to be calibrated with respect to the monitor so that the end-effector tip of the stylus matches accurately the trace path when a letter is written. The revised design of the end-effector stylus was more robust and ergonomically efficient in comparison to the previous one (verified through

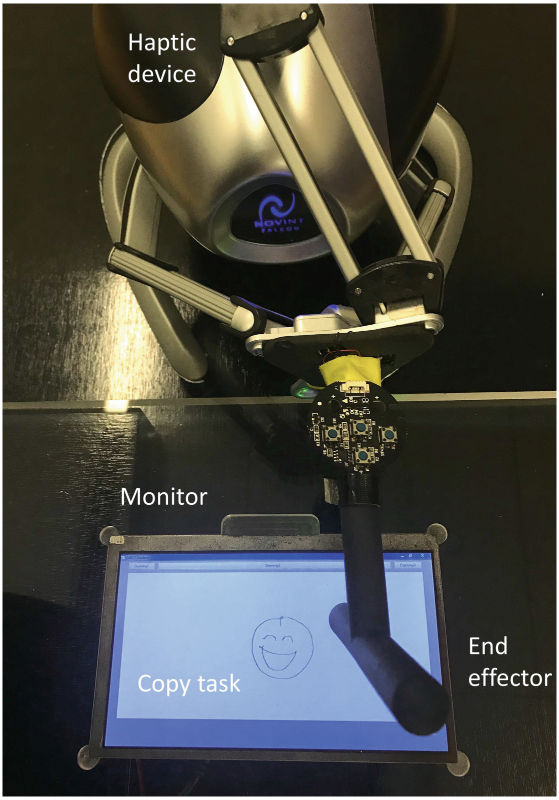

Fig. 1. Haptic handwriting assistance system.

several trials with the therapist). It provides a firm grip and thus a better coupling between the end-effector stylus and the Novint Falcon haptic device [10]. A firm coupling minimizes errors in haptic playback and thus provides accurate reconstruction of handwriting tasks. The revised experimental setup is presented in Fig. 1.

The handwriting system is capable of delivering three different modes of haptic guidance namely full guidance, partial guidance and disturbance guidance. In the full guidance mode which is described by Eq. 1, the force applied by the haptic device is derived from the maximum stiffness provided (K_{max}) times the point-to-point displacement (δu). For the partial guidance mode, a Proportional-Integral-Derivative (PID) controller was used as described in Eq. 2 whereas $\mathrm{C_p}$, $\mathrm{C_i}$ and $\mathrm{C_d}$ are the gains for the proportional, integral and derivative components of the controller respectively. e(t) is the error set by the difference between current position ($\mathrm{x_{cur}}$) and desired position ($\mathrm{x_{des}}$). Motivated by Lee's work on motor learning through cognitive effort [11], we designed the disturbance haptic guidance mode so that the haptic device would cause the stylus end-effector to provide vibration patterns at strategic positions along the hand-

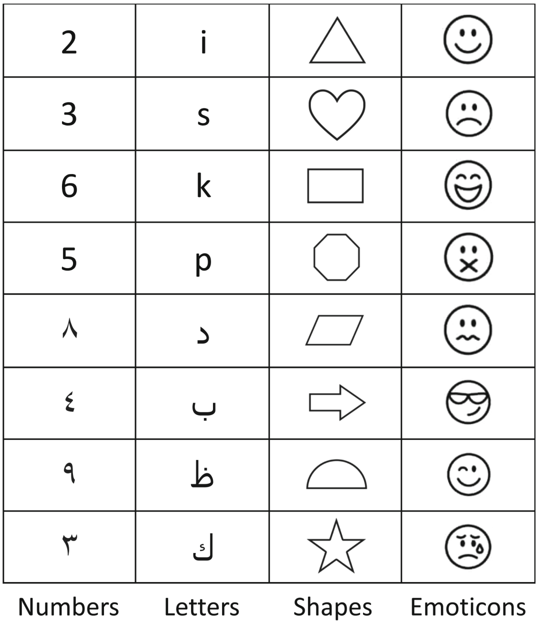

Fig. 2. Four types of task for the students' copy work.

writing trajectory, with the intention to increase the participants attention to the task at hand. This impulsive behaviourforce of the haptic device is randomly activated and deactivated by a set of predefined parameters while the task is performed. Finally, a No-Haptic guidance mode was also designed by driving the haptic device in high admittance in which there is no haptic feedback and the participant can freely move the end-effector stylus in any direction.

$$\mathbf{F}(t) = K_{max} \Delta \mathbf{u} \tag{1}$$

$$\begin{aligned} \mathbf{F}(t) &= C_p \mathbf{e}(t) + C_i \int_{\Delta T} \mathbf{e}(t) dt + C_d \frac{d\mathbf{e}(t)}{dt} \\ \mathbf{e}(t) &= \mathbf{x}_{cur} - \mathbf{x}_{des} \end{aligned} \tag{2}$$

2.3 Experimental Tasks

We developed a copy work task comprising of numbers, letters, shapes, and emoticons. These four categories represent cognitive and academic tasks. In this task, we are able to evaluate visuomotor and fine motor skill in the ability of students to recognize tasks and copy works. We also designed various difficulties of tasks to evaluate the students' fine motor skills. Figure 2 shows 32 tasks for the students' copy work with four types of categories. In case of numbers and letters, we included Arabic numerals and letters, since these are handwriting tasks the children are currently learning. We selected not only simple shapes such

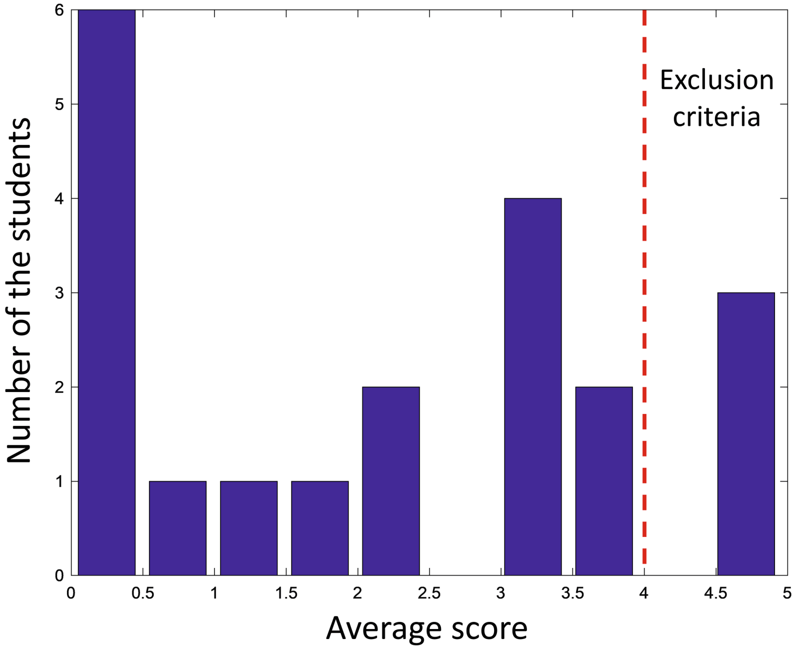

Fig. 3. Histogram.

as triangle and square, but also difficult shapes such as arrow and star. We have added emoticons, four positive and four negative emotional expressions, in the copy work to investigate the students' recognition and development depending on emotional expressions.

2.4 Evaluation of the Experimental Protocol

To verify the longitudinal experimental protocol, we asked the candidates to perform the 32 copy work task on a sheet of paper. Three therapists evaluated individual copy work tasks on a scale 0–5 points. The scores were calculated as the average of three experts' evaluations. We checked distribution of average score and differences between/within the four categories. We designed various difficulties, thus we investigated if there are significant differences of score among all copy work tasks. We also checked the correlations between age/gender and average scores.

3 Results

First of all, we analyzed histogram of average scores. Seven students achieved a very low score of 1 or less on average. four and six students achieved 1 to 2.5 and 3 to 4 points respectively, as shown in Fig. 3. Unexpectedly, three students achieved

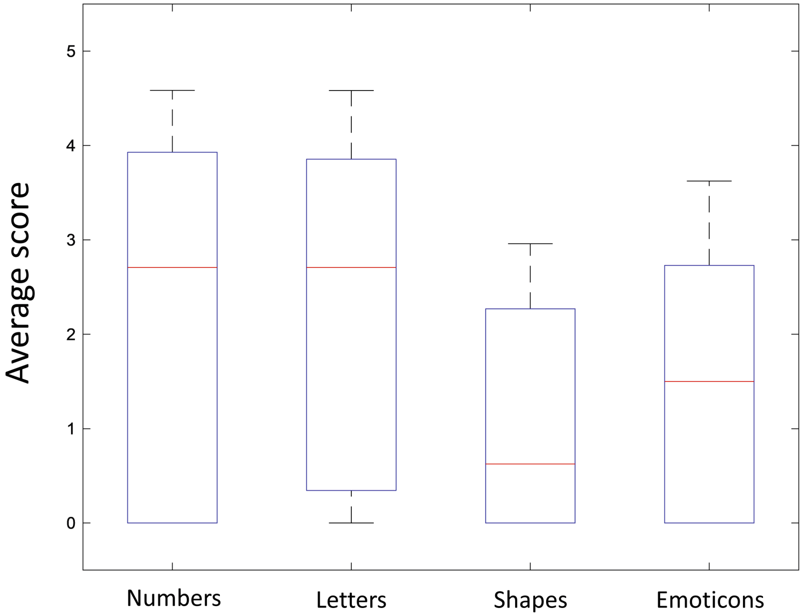

Fig. 4. Distribution of average scores according to four types of copy work.

a very high score of 4.5 or higher. They are excluded from the longitudinal study because they no longer have room for improvement.

Figure 4 shows the average of scores for the four categories of handwriting tasks. As expected, the average scores are higher for numbers and letters than shapes and emoticons, but these differences are not statistically significant. Figure 5 shows the distributions of the average scores of eight copy work tasks in each category. There are no significant difference among the eight copy work tasks in each category. We expected Arabic numbers and letters (tasks 5 to 8) to be a little more difficult than others. However, there are no significant differences. Also, we found no significant differences in the average scores of copy work of emoticons according to the positive and negative emotional expression.

We investigated significant difference in the average scores among the 32 copy work tasks. Figure 6 shows the comparison intervals of Kruskal-Wallis test, showing significant differences between the letter 'i' and the arrow/star shapes (Kruskal-Wallis test, $p < 0.01$; ad-hoc, Bonferroni). This result shows that we have designed a wide spectrum of handwriting tasks, varying from very difficult to very easy, and that is shown to be statistically valid.

We also investigated whether there is a correlation between average score and gender/age, but there is no significant correlation.

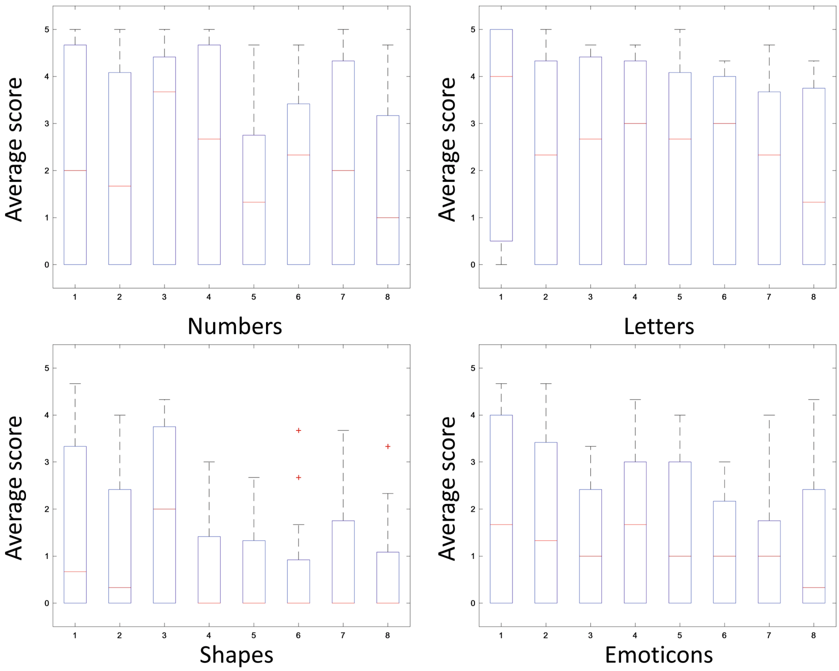

Fig. 5. Distribution of average scores in each category of copy work

4 Discussion

As shown in the histogram in Fig. 3, students with diagnosed learning difficulties showed significant differences in ability to copy work. It will be interesting to see how the improvements during the longitudinal training depending on their initial ability of the copy work. We also added this condition to the exclusion criteria for the longitudinal study because high scores with a score of 4 or higher have little room for improvement and do not need to be trained in copy work.

An interesting result of distribution analyzing among four categories of copy work is that the average scores of shape had the lowest scores. We expected the copy of emoticons to be the most difficult task since emoticons have far more complex construction trajectories. It is presumed that the face is a picture that young children draw well. Especially happy face is a psychologically familiar emoticon because it is their favorite emotion. It is likely that the familiarity, in addition to the complexity of the copy work task, plays a significant role in defining what makes a difficult task.

Although there was no significant differences among the four categories of copy work tasks and the eight tasks in each category, it is necessary to investigate their effects during the following longitudinal experiment. There could be significant improvements in the students' performance in relation to the assigned copy work task. In addition, it will be interesting to examine how task difficulty influences the development of handwriting skills for children with learning difficulties.

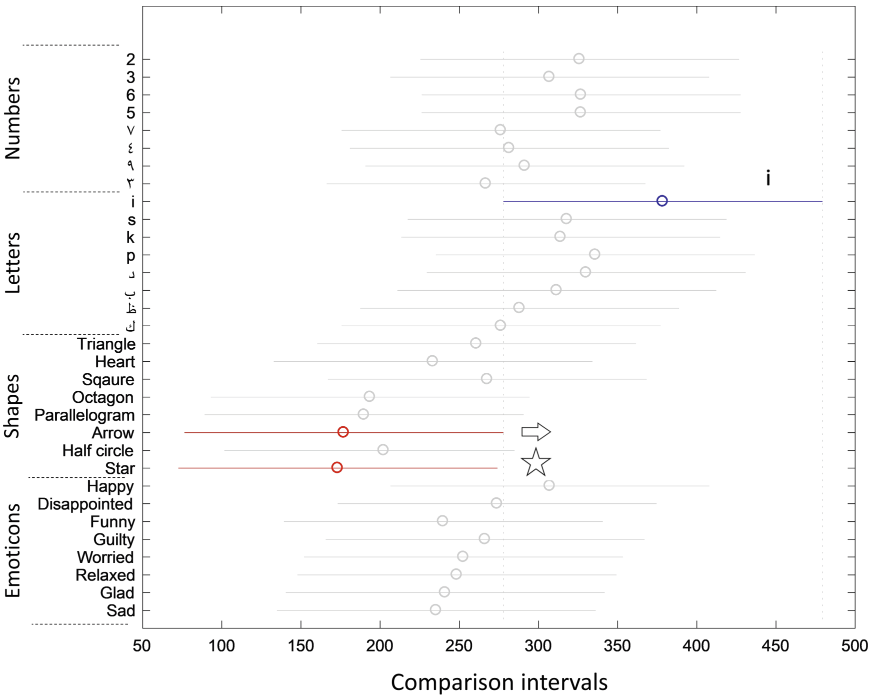

Fig. 6. Comparison intervals. The blue and red lines indicate that scores of the first letter, 'i' are higher than scores of the sixth and eighth shapes, arrow and star. (Kruskal-Wallis test, $p < 0.01$; ad-hoc, Bonferroni) (Color figure online)

In general, it is natural that the ability of copy work varies according to age, however we could not find a significant correlation of average scores of copy work according to age. Previous studies showed that implicit learning has not been correlated with age [12]. It is presumed that the copy work which is not familiar to the children with learning difficulties could not have a correlation with the score according to age because it is a new task requiring visual recognition, visual-motor function, and fine motor function. On the other hand, there is no significant correlation between age and copy work (Pearson correlation coefficient, $r = 0.44$, N.S.), but there is a trend to improve the score according to age as shown in Fig. 7. Therefore, the assignment of treatment/control groups for the following longitudinal study should be adjusted to match the age group balance.

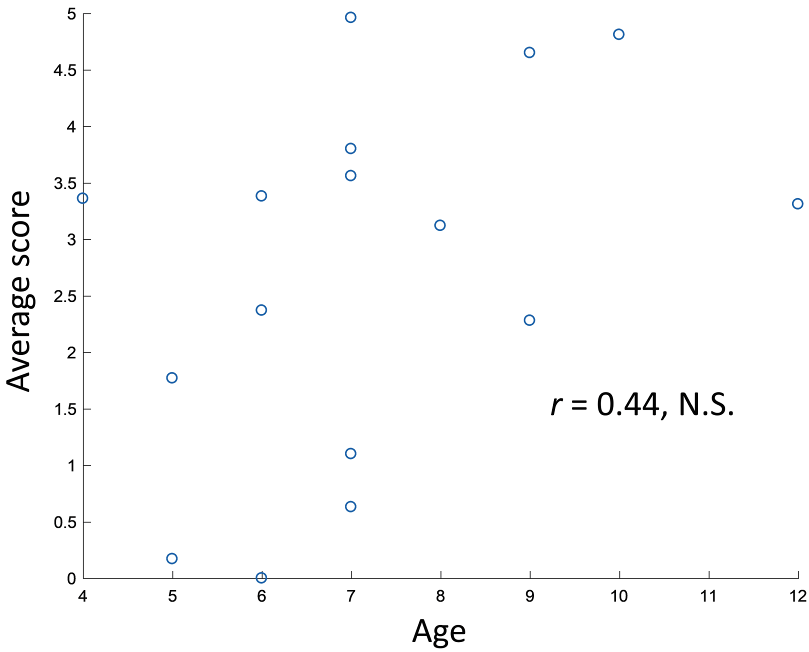

Fig. 7. Correlation analysis between age and average scores of copy work.

5 Conclusion

This study introduced a methodology and copy work for evaluating the handwriting skills of children with learning difficulties. The proposed method can be used to define appropriate tasks, depending on the complexity of the task and the abilities of the learner, to maximize the learning outcomes. This may also be used as a pre-test to place learners in different groups for comparative studies. Our immediate future work is to form balanced groups of students, based on their abilities, that will train with the haptic-based handwriting platform. We would like to study the effectiveness of various haptic guidance methods (partial, full and disturbance) towards improving the acquisition of handwriting skills.

Acknowledgments. This work has been supported by the ADEK Award for Research Excellence (AARE) 2017 program (project number: AARE17–080).

References

1. Bonny, A.: Understanding and assessing handwriting difficulties: perspective from the literature. Aust. Occup. Ther. J. **39**(3), 7–15 (1992)
2. Reisman, J.E.: Development and reliability of the research version of the minnesota handwriting test. Phys. Occup. Ther. Pediatr. **13**(2), 41–55 (1993)

3. Hamstra-Bletz, L., Blöte, A.W.: Development of handwriting in primary school: a longitudinal study. Percept. Motor Skills **70**(3), 759–770 (1990)
4. Scardamalia, M., Bereiter, C., Goelman, H.: The role of production factors in writing ability. What Writers Know: Lang. Process Struct. Written Discourse **3**, 173–210 (1982)
5. Smits-Engelsman, B.C., Niemeijer, A.S., van Galen, G.P.: Fine motor deficiencies in children diagnosed as DCD based on poor grapho-motor ability. Hum. Mov. Sci. **20**(1–2), 161–182 (2001)
6. Hamstra-Bletz, L., Blöte, A.W.: A longitudinal study on dysgraphic handwriting in primary school. J. Learn. Disabil. **26**(10), 689–699 (1993)
7. Diagnostic and Statistical Manual of Mental Disorders, 5th edn. DSM-5. American Psychiatric Association, Washington, DC (2013)
8. Kivisto, L.R.: The use of assistive technology in school-aged children with learning disorders. Electronic theses and Dissertations 7270 (2017)
9. Teranishi, A., Korres, G., Park, W., Eid, M.: Combining full and partial haptic guidance improves handwriting skills development. IEEE Trans. Haptics **11**(4), 509–517 (2018)
10. Martin, S., Hillier, N.: Characterisation of the novint falcon haptic device for application as a robot manipulator. In: Australasian Conference on Robotics and Automation (ACRA), pp. 291–292. Citeseer (2009)
11. Lee, T.D., Swinnen, S.P., Serrien, D.J.: Cognitive effort and motor learning. Quest **46**(3), 328–344 (1994)
12. Vinter, A., Perruchet, P.: Implicit learning in children is not related to age: evidence from drawing behavior. Child Dev. **71**(5), 1223–1240 (2000)