Investigating Haptic Guidance Methods for Teaching Children Handwriting Skills

Wanjoo Park, Georgios Korres, Tania Moonesinghe, and Mohamad Eid

***Abstract*—Haptics technologies have the potential to considerably improve the acquisition of handwriting skills by providing physical assistance to improve movement accuracy and precision. To date, very few studies have thoroughly examined the effectiveness of various haptic guidance methods to leverage the acquisition of handwriting skills. In this paper, we examine the role of several methods for haptic guidance, namely full haptic guidance, partial haptic guidance, disturbance haptic guidance, and no-haptic guidance toward improving the learning outcomes of handwriting skills acquisition for typical children. A group of 42 children from Cranleigh School Abu Dhabi across two educational stages, namely Foundation Stage 2 (FS2, 4–5 years old) and Year 2 (6–7 years old), participated in this study. Results showed that disturbance haptic guidance was the most effective for high complexity handwriting tasks (such as writing the letters "o" and "g"), partial haptic guidance was the most effective for medium complexity handwriting tasks (such as "t," "r," "s," "e," "n," "a," and "b"), and full haptic guidance was the most effective for low complexity letters (such as "i"). Another interesting finding was that FS2 participants had statistically significant improvement in handwriting speed compared to the Year 2 group, demonstrated by a significantly shorter test completion time. Furthermore, female children performed statistically better than their male counterparts in partial guidance. These results can be utilized to build more effective haptic-based handwriting tools for typical children.**

***Index Terms*—Haptic interfaces, evaluation/methodology, psychology, user-centered design**

I. Introduction

Writing is a complex motor skill that requires combined physical and mental skills, which makes the learning process a slow, inefficient and difficult one. The acquisition of handwriting skill entails the combined visual characteristics and the physical (haptic) properties of the handwriting artifact. Therefore, in order to complete a handwriting task, the learner must develop haptic-visual integration skills. The accurate perception of visual and haptic properties of any handwriting task is critical for the development of handwriting skills [1]–[3]. Given the fact that many children are learning handwriting with a computer that involves only audio-visual modalities, technologies for teaching handwriting skills must consider engaging the human haptic system in the learning process [4].

A large body of research demonstrates that kinesthetic and/or tactile feedback plays a crucial role in learning and cognitive development, and may even be a constitutive factor in language development [5]. For instance, a brain imaging study shows that the specific hand movements involved in handwriting support the visual recognition of letters [6]. In a recent study, experiments in neuroscience and experimental psychology demonstrated that the haptic modality is a defining feature of handwriting skills acquisition, as well as an intrinsic factor contributing to reading skills such as letter recognition [5].

Haptic guidance methods are developed to support the acquisition of handwriting skills by engaging the haptic modality in the learning process; by physically moving the learners hand along a desired trajectory [7]. Previous research has investigated several types of haptic guidance, such as full haptic guidance and partial guidance [8], and disturbance haptic guidance [9]. The full haptic guidance implies that the haptic interface is generating the handwriting trajectory while the learner is passively following the movements. In the partial guidance, the learner performs the handwriting task while the haptic interface provides corrective force feedback only when the learner deviates significantly from the desired trajectory. The disturbance guidance utilizes full haptic guidance with sparks of vibration feedback rendered at strategic points along the reconstructed trajectory in order to maintain the learners attention.

The present study strives to evaluate various haptic guidance methods, namely full haptic guidance, partial haptic guidance, disturbance haptic guidance, and no haptic guidance in a classroom setup as a part of children daily activities with minimal interventions from the researchers. Comparative studies between various guidance methods are conducted regarding the complexity of the handwriting task (different characters of the English alphabets), the learning level (FS2 versus Year 2), and gender.

The remainder of the paper is organized as follows. Section II analyzes the related work for haptic guidance in learning

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TABLE I
PARTICIPANTS CHARACTERISTICS AND GROUP ASSIGNMENTS

	Male	Female	Total
FS2 (4-5 years old)	n=10 Full, 2; Partial, 2 Disturbance, 2; NoHaptic, 2 Control, 2	n=10 Full, 2; Partial, 2 Disturbance, 2; NoHaptic, 2 Control, 2	n=20 Full, 4; Partial, 4 Disturbance, 4; NoHaptic, 4 Control, 4
Year 2 (6-7 years old)	n=10 Full, 2; Partial, 2 Disturbance, 2; NoHaptic, 2 Control, 2	n=12 Full, 3; Partial, 3 Disturbance, 2; NoHaptic, 2 Control, 2	n=22 Full, 5; Partial, 5 Disturbance, 4; NoHaptic, 4 Control, 4
Total	n=20 Full, 4; Partial, 4 Disturbance, 4; NoHaptic, 4 Control, 4	n=22 Full, 5; Partial, 5 Disturbance, 4; NoHaptic, 4 Control, 4	n=42 Full, 9; Partial, 9 Disturbance, 8; NoHaptic, 8 Control, 8

handwriting skills. Section III presents the experimental method to evaluate different haptic guidance methods. In section IV, the results are presented and thoroughly analyzed. Section V presents general discussion points related to the study. Finally, Section VI summarizes the findings of the paper and provides directions for future work.

II. RELATED WORK

Little literature concerning the integration of haptic feedback in multimedia handwriting learning platforms exists. Shuto et al. [10] developed an e-learning system that utilizes haptic feedback to teach handwritten characters. The system comprises a haptic recorder that the instructor uses to record a handwriting task while a haptic player presents the play-back of these tasks to the learners. Experiments demonstrated that the proposed system improves the learning outcomes. A subsequent work [11] verified the realism of calligraphy training and the efficiency to support brush-stroke calligraphy practices via subjective evaluation. Both studies utilized full haptic guidance.

Various methods of haptic guidance, and their effectiveness to improve learning outcomes, are also studied in the literature [12], [13]. The study in [12] found that the addition of haptic information in the form of force coordinates plays a crucial role on the visuo-manual tracking of new trajectories. [13] concluded that haptic guidance can benefit short-term learning of a steering-type task of a simulated vehicle and improve performance during training. Neither studies addressed handwriting skills development in particular.

A recent study investigated the effectiveness of full and partial haptic guidance towards improving learning outcomes (measured quantitatively as the quality of handwriting) [8]. Interestingly, results have shown that combining full and partial haptic guidance improves further the learning outcomes, compared to merely full or partial haptic guidance; in particular, starting with partial guidance at early stage of the learning process then utilize full guidance at an intermediate/advanced stage [14]. It is concluded that partial haptic guidance is more effective to learn the gross shape of the handwriting task while full guidance is more effective to learn the fine details of the handwriting task.

Another study introduced the concept of disturbance haptic guidance, in the form of arousing and noise-like forces [9], [15], [16]. Results showed a great potential for haptic disturbance for expediting motor learning process, especially in memorization. It was found that progressive haptic disturbance worked best to track accuracy, whereas noise-like haptic disturbance worked better for retention tests. However, disturbance haptic guidance has not been applied to handwriting learning. Thus, we want to study the effects of disturbance haptic guidance, and how it would be combined with full and/or partial guidance, towards improving learning outcomes.

A recent approach for haptic guidance combines manual control inputs of an operator with haptic guidance from an automated system, commonly known as haptic shared control [17]. The operator-guidance system interaction is modeled as a virtual spring, with a stiffness defined to match the desired level of shared control while allowing sufficient control for the operator [18]. The stiffness is determined based on performance [19], [20] or the operator's neuromuscular properties [21], [22]. The challenge in this approach is to define the stiffness property (or set of properties) that maximizes the learning outcome [23]. Furthermore, the approach is not evaluated with handwriting [24].

Meanwhile, previous research has demonstrated significant effects of gender and age group on handwriting skills acquisition. Whereas some studies report a significant female advantage ([25]–[27]), others do not ([28], [29]). Such inconsistencies emphasize the importance of assessing the quality of handwriting learning on the basis of gender and age group differences. Motivated by these studies, we intend to investigate the effectiveness of haptic guidance methods across gender and age groups for improving learning outcomes of handwriting skills.

The following hypotheses are examined in this study:

(i) The effectiveness of haptic guidance depends on the type of haptic guidance method,
(ii) The effectiveness of haptic guidance also depends on the complexity level of the handwriting task to be learned,

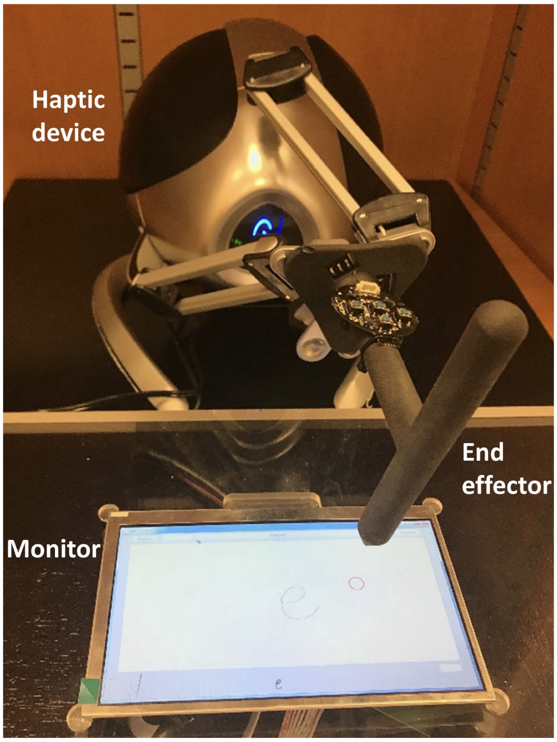

Fig. 1. Experimental setup. Novint's Falcon haptic device is used to provide haptic guidance. End-effector is designed for right-handed users. The monitor show a trajectory of letter 'e' and red dash circle indicated the projected location of the end-effector.

(iii) Age group and gender plays a tangible role in defining the effectiveness of a respective haptic guidance method.

III. Methods and Materials

A. Participants

A group of 42 students (20 students in FS2 class, 4-5 years old, 10 females; 22 students in Year 2 class, 6-7 years old, 12 females) were recruited from Cranleigh School Abu Dhabi, United Arab Emirates. The two groups (FS2 and Year 2 students) have already learned how to hold and use the pencil effectively. FS2 students have just started learning the alphabet. Year 2 students have developed some handwriting skills but continue to develop improved handwriting.

Participants are divided into 5 groups: full guidance, partial guidance, disturbance guidance, no-haptic guidance, and the control group. Table I shows the characteristics of the participants and the group assignments. 9 students were assigned to the full-guidance group, who trained with full haptic guidance, 9 students were assigned to the partial-guidance group using partial haptic guidance, 8 students were assigned to the disturbance-guidance group who utilized disturbance haptic guidance for learning, 8 students were assigned to the no-haptic guidance group who used the handwriting platform but with no-haptic feedback, and 8 students were assigned to the control group that did not use the handwriting platform at all and exercised with what the school was providing as learning tools for handwriting. All participants except the control group were right-handed since the end-effector in Fig. 1 is created for right-handed learners. The study was carried out with an approved protocol by New York University Abu Dhabi Institutional Review Board (FWA: 00018425).

B. Experimental Setup and Haptic Guidance

The experimental setup has undergone some considerable changes since our previous work [8]. In the current version, a seven inch monitor was placed underneath the pen-like end-effector to simulate a writing surface, and both the monitor and the device were calibrated in such a way so that the tip of the pen-like end-effector would match exactly the trace formation when a letter is written. The pen-like end-effector was redesigned in order to increase its robustness and usability (particularly to provide a better grip). For instance, the new design provides a more firm grip than the previous design due to better coupling between the pen-like end-effector and the Novint device. This aims to eliminate potential evaluation errors occurring from its material flexibility. A snapshot of the final experimental setup is shown in Fig. 1.

To compare the effectiveness of haptic guidance methods, we designed four haptic guidance methods. Full haptic guidance is described by equation (1) where **F**(t) is the calculated force, $\mathrm{K}_{\mathrm{max}}$ is the stiffness of the haptic interface and is equal to 2.31 N/mm and **Δu** is the displacement. Equation (2) outlines how the partial guidance force is calculated, where C_{p}, C_{i} and C_{d} are the proportional, integral and differential gains respectively, and are set to values 0.5, 0.3, and 0.2 respectively. e(t) is the error between the current position ($\mathrm{x}_{\mathrm{cur}}$) and the desired position ($\mathrm{x}_{\mathrm{des}}$). Full and partial haptic guidance methods are explained in more details in our previous work [8].

We also developed disturbance haptic guidance using impulsive force feedback. Algorithm 1 shows the pseudo code of the disturbance guidance. Driven by the fact that more cognitive effort leads to greater motor learning [30], the disturbance haptic guidance was designed to make the pen-like end-effector suddenly hold or push in the direction of movement, in order to keep the participants more focused on their writing task. In addition, the impulse noise is activated with a small probability (through the parameter *b* in Algorithm 1) and deactivated with a large probability (through the parameter *a* in Algorithm 1), thus an impulsive force is created. In case of the no-haptic guidance, the system does not provide any force feedback. However, the participants grasp the end-effector and and exercise handwriting with visual guidance only. The visual guidance is also provided for all other haptic guidance methods.

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

$$\begin{aligned} \mathbf{F}(t) &= \mathbf{C}_{\mathrm{p}}\mathbf{e}(t) + \mathbf{C}_{\mathrm{i}}\int_{\Delta \mathrm{T}}\mathbf{e}(t)\mathrm{d}t + \mathbf{C}_{\mathrm{d}}\frac{\mathrm{de}(t)}{\mathrm{d}t} \\ \mathbf{e}(t) &= \mathbf{x}_{\mathrm{cur}} - \mathbf{x}_{\mathrm{des}} \end{aligned} \tag{2}$$

Note that the control group trained with what the school offered for handwriting skills development and did not train with our system at all.

Algorithm 1: Disturbance guidance, a and b indicate chance levels for activation and deactivation, respectively. a should be an integer larger than 2, but not a big number. b should be a big integer. c and d indicate the gain of the impulse noise. c should be a float type and almost zero. d also should be a float type and larger than 1. We set the values of coefficients a, b, c, and d as 9, 2, 1.2, and 1.05 respectively.

```
if flag then
  if (randomNumber mod a) < 1 then
    Deactivation
    flag = 0
  else
    Equations of the force feedback
    force.x = force.x * impulseGain
    force.y = force.y * impulseGain
    force.z = force.z * impulseGain
  end if
else
  if (randomNumber mod b) < 1 then
    Activation
    flag = 1
    if type then
      type = 0
      Hold mode
      impulseGain = c
    else
      type = 1
      Push mode
      impulseGain = d
    end if
  end if
end if
```

C. Procedure and Evaluation Metrics

The experiment was designed as a nine-weeks longitudinal study. Before the experiment, students participating in the study (except the control group) spent time to get acquainted with the system. Ten characters are considered in the study: the eight alphabet letters (e, a, r, i, o, t, n, and s) that are the most frequently used letters in the English alphabet [31], as well as two additional characters suggested by the teachers, b and g. Teacher's observation is that students are commonly confused about these two specific letters (b and g) particularly for the stroke sequence. All students completed a paper-based handwriting test for the ten letters before the experiment and each letter was evaluated by three teachers using five evaluation aspects: starting point, orientation, positioning on the line, fluency, and regularity (neat and proportionate). During a teacher's evaluation, the student's name and the scores of other teachers were hidden to avoid influencing each other. We also measured the time students spent writing the ten letters, but students were prompted not to rush writing them.

Students were assigned to five groups based on the their test scores so that students with similar level of handwriting abilities are grouped together. All students, excluding the control group, completed three training sessions per week. One training session consisted of five repetitions for each letter with the assigned haptic guidance method. Thus, the students practiced handwriting for a total of 50 times per session and took about 15 minutes to complete a training session. At the last training session of every week, the students also took the paper-based test. In the paper-based test, the students grasped a real pencil and copied ten letters on the paper sheet. The test generally took less than two minutes. The control group students took only the paper-based test once a week. Every week the students' paper-based tests were evaluated by three teachers and each letter was scored on a scale from zero to five. It was hypothesized that the appropriate haptic guidance method would vary depending on the difficulty of the letter and/or the age of the student. Therefore, we observed how students' handwriting scores improved as function of the haptic guidance method and the complexity of the letters. We also examined if age and gender influence the effectiveness of the haptic guidance method for the handwriting acquisition process.

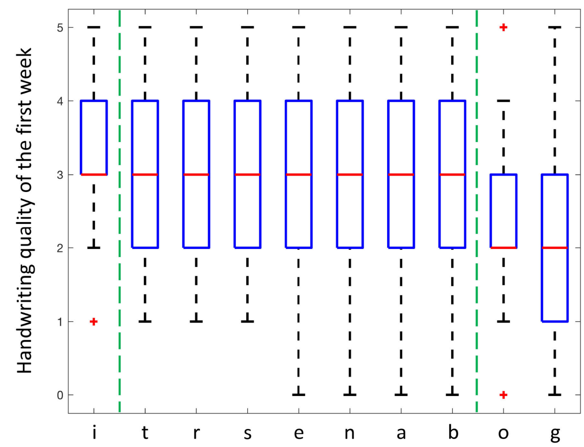

Fig. 2. The handwriting quality (out of five) for 10 letters at the end of the first week. The middle red line of the blue box indicates a median value and the bottom and top edges of the box indicate the 25th and 75th percentiles, respectively. Green dash lines divide three letter groups by the handwriting quality score.

IV. Results

We used the first week's handwriting quality scores as the baseline of the students' handwriting ability. Figure 2 shows the box plot of the handwriting quality (out of five) for each letter at the end of the first week. Based on this result, we divided the ten letters into three difficulty levels: low complexity, including the letter i; medium complexity, comprising the letters t, r, s, e, n, a, and b; and high complexity including the letters o and g. We hypothesized that the difficulty of the handwriting task influences the effectiveness of the haptic guidance methods.

A. Low Complexity

The range of distribution box of the letter 'i' in Fig. 2 is from 3 to 4. It means that letter 'i' is the easiest letter among the ten letters. Figure 3 shows the improvement in handwriting quality during the nine weeks. Five different shape points indicate the

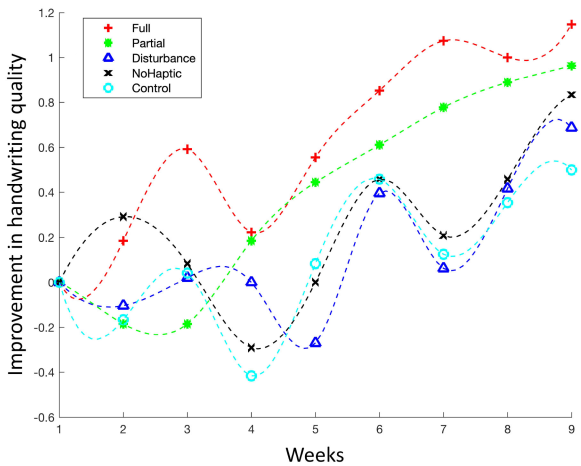

Fig. 3. Improvement in handwriting quality (score out of five) during nine weeks for low complexity handwriting tasks (letter i).

average score of the handwriting test for the five groups participating in the study, and the dashed line is the spline interpolation between average data points. Even though the graphs look fluctuating, the general trend is clearly increasing over time. The full guidance group show the best performance among the five groups, however that difference is not statistically significant even after the ninth week. Since the number of participants of each group is eight or nine, a non-parametric statistical method is utilized, namely the Wilcoxon signed rank test in order to examine statistical significance between a subsequent week and the first week. Table II shows p-values of Wilcoxon signed rank tests between the first week and each following week. The full guidance group shows significant improvement at week 3 as well as weeks 6 to 9 ($p < 0.05$). In particular, there is very significant improvement starting at the eighth week ($p < 0.01$). On the other hand, significant differences are achieved at eight/ninth week for partial haptic guidance and only ninth week for no-haptic guidance. It means that the full haptic guidance is more useful than others when the students learn and practice an easy letter.

B. Medium Complexity

We consider letters 't' to 'b' of medium level complexity handwriting tasks when it comes to acquiring handwriting skills since the the handwriting quality for these letters range between 2 and 4 (as shown in Fig. 2). Figure 4(a) shows improvement of the handwriting quality over the 9 weeks. The dashed lines are again fluctuating over the weeks. However, the students' handwriting score were increasing from the fifth week onward. From the seventh week, the full and partial guidance group produced a better outcome with a higher statistical significance compared to other groups (Wilcoxon rank sum test, $p < 0.05$). Wilcoxon rank sum test, being a non-parametric statistical method, is utilized to compare different groups due to the data size (8-9 participants per group).

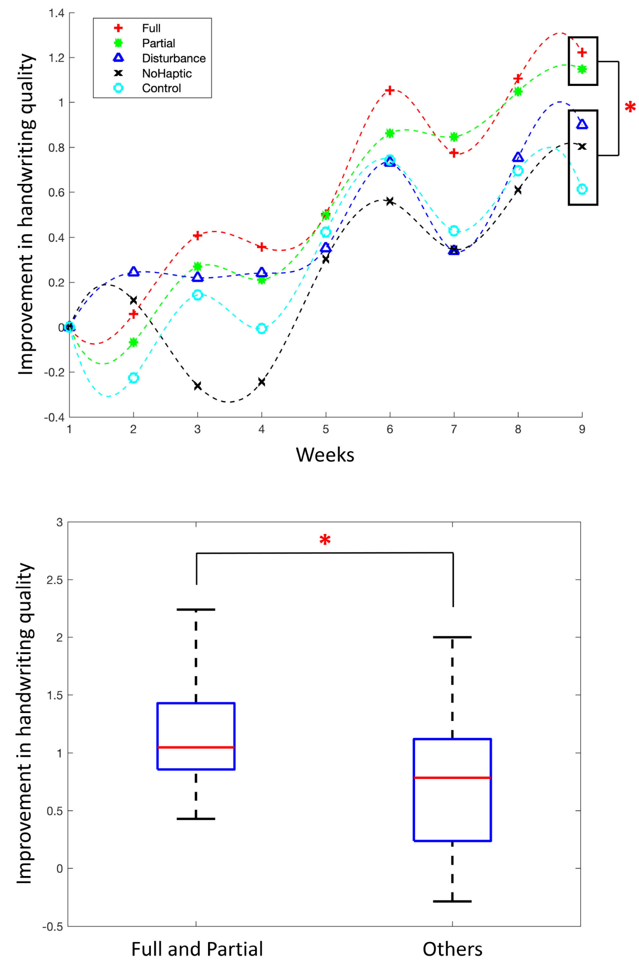

Fig. 4. (a) Improvement in handwriting quality (score out of five) after the ninth week in case of medium complexity letters. (b) The full and partial haptic guidance groups show greater improvement in handwriting score compared to other groups at the end of week 9. Wilcoxon rank sum test, $^*p < 0.05$.

Figure 4(b) shows the improvement in handwriting quality of the full and partial guidance groups compared to other groups after week 9. The full and partial haptic guidance groups (1.18 $\pm$ 0.53) show greater improvement of handwriting score than the other groups (0.77 $\pm$ 0.53). It is also statistically verified by the Wilcoxon rank sum test ($p < 0.05$).

TABLE II
P-VALUES, WILCOXON SIGNED RANK TEST, $^*P < 0.05$, $^{**}P < 0.01$

Week	2	3	4	5	6	7	8	9
Full	0.8008	0.0156*	0.4531	0.0703	0.0117*	0.0156*	**0.0078****	**0.0039****
Partial	0.8281	0.5742	0.7656	0.3125	0.1094	0.0977	0.0391*	0.0156*
Disturbance	0.7188	1.0000	0.8438	0.6250	0.3750	0.8750	0.2188	0.1562
NoHaptic	0.5156	1.0000	0.2656	1.0000	0.2969	0.6562	0.0625	0.0312*
Control	0.7031	1.0000	0.1406	0.9922	0.2656	0.8750	0.3750	0.2500

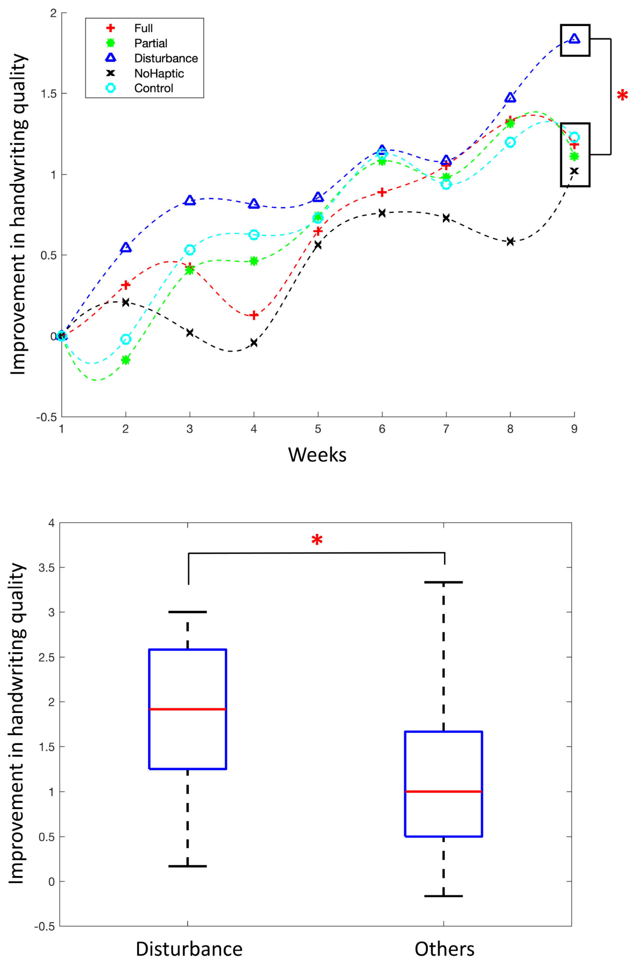

Fig. 5. (a) Improvement in handwriting quality (score out of five) during the nine weeks in the case of hard level letters, o and g, to do handwriting. (b) The disturbance haptic guidance shows greater increments of handwriting score than others at the end of week 9. Wilcoxon rank sum test, $^{*}p < 0.05$.

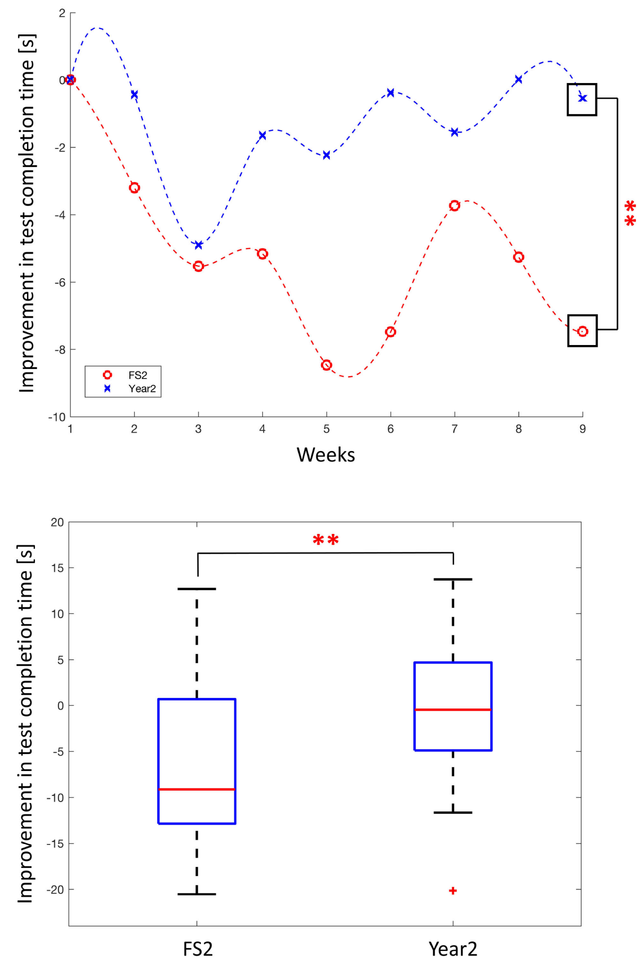

Fig. 6. (a) Improvement in the test completion time to write 10 letters at the end of every week for FS2 and year 2 groups. (b) The improvement in the test completion time to write ten letters at the end of week 9, compared to week 1, for FS2 and Year 2 groups. Wilcoxon rank sum test, $^{**}p < 0.01$.

C. *High Complexity*

The letters 'o' and 'g' belonged to the high complexity level. It was observed that the circular movement in these letters would cause confusion about the starting point and stroke sequence. Therefore, the quality of handwriting scores at the first week were lower than the other eight letters (see Fig. 2). Figure 5(a) shows the improvement in handwriting quality over the nine weeks for the high complexity letters. In this case, the disturbance guidance group has performed the best (with most stable/steady improvement). Figure 5(b) shows the improvement in handwriting quality of the disturbance guidance group and the other groups at the end of week 9. The disturbance haptic guidance group (1.83 $\pm$ 0.94) showed greater improvements of handwriting acquisition compared to the other groups (1.14 $\pm$ 0.84). This was statistically verified by Wilcoxon rank sum test ($p < 0.05$).

D. *Age and Gender Effects*

We also investigated the age and gender effects, since we had a hypothesis that not only the difficulty of the handwriting task but also the users' age and/or gender could influence the effectiveness of haptic guidance methods. We compared the performance of the FS2 and Year 2 age groups. No significant differences were found between FS2 and Year 2 age groups in terms of improvement in the handwriting quality. However, in the time spent to complete the handwriting test, we found significant differences based on the age group. Figure 6(a) shows a significant drop in the test completion time for FS2 age group. The data points indicate the averaged differences of test completion time for the ten letters for all the groups at the end of every week, compared to week 1. There are significant differences between the two age groups starting from week 4 (Wilcoxon rank sum test, $p < 0.05$). At the third week, the test completion time for Year 2 students decreased to a minimum and then increased again. In case of FS2 students, the result showed a steady decline in the test completion time even with some fluctuations. At week 9, the improvement in test completion time of FS2 students (-7.18 $\pm$ 9.96) was significantly higher than Year 2 students (-0.44 $\pm$ 8.17) as shown in Fig. 6(b).

As for the gender effect, we found an interesting result. Figure 7(a) shows improvements in handwriting quality across the two genders for all letters including the two age groups in

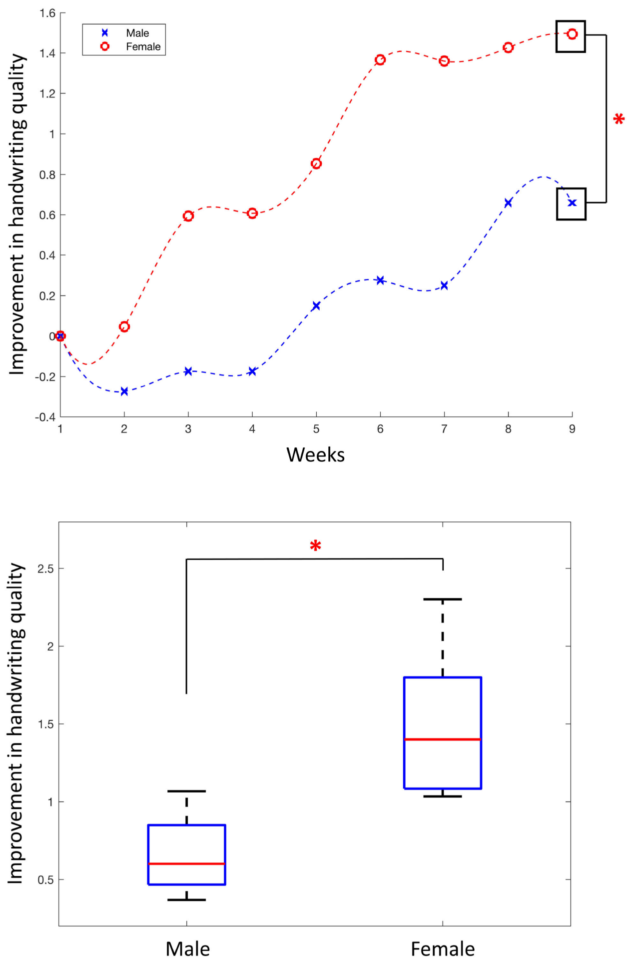

Fig. 7. (a) Improvement in handwriting quality (score out of five) by gender in partial haptic guidance group for all letters. (b) The improvement in the scores in partial haptic guidance group for all letters after week 9. Wilcoxon rank sum test, $^{*}p < 0.05$.

the partial haptic guidance group. It is observed that female learners performed statistically better than the their male counterparts when partial haptic guidance method was used. We could not find any significant difference between male and female students in all the other groups. Therefore, it seems that partial haptic guidance method is more suitable for female students. Figure 7(b) shows the improvement in handwriting quality at the end of the last week for the partial haptic guidance group for the two genders. The improvement in handwriting quality for female students (1.49 ± 0.51) is much bigger than for the male students (0.66 ± 0.29). This was also statistically verified using Wilcoxon rank sum test, $p < 0.05$.

V. Discussion

Results of this study demonstrated that there is no preferable haptic guidance method that would be most effective for all kind of users/tasks. For instance, in the case of high complexity letters, disturbance haptic guidance resulted in the highest improvement in handwriting skills. As for medium complexity letters, full and partial haptic guidance methods gave the best performance. Finally, for low complexity letters, full haptic guidance was the most effective. Furthermore, even for high complexity letters where improvement is expected to be the worst compared to medium or low complexity tasks, disturbance haptic guidance resulted in the highest improvements (1.83 ± 0.94), compared to medium complexity (1.18 ± 0.53) or low complexity tasks (1.15 ± 0.85).

In the case of high complexity letters, it seems that disturbance guidance stimulated the students to better concentrate. Also, as in letter 'i', the disturbance function may not work well in straight-line structures. The full and partial haptic guidance are the most common methods and thus are expected to outperform other guidance methods for medium complexity tasks. Finally, full haptic guidance with the simplest letter, such as the letter 'i', gave the best outcome in the same line that the partial-full guidance combination gave the best outcome in previous studies [8]. In other words, at an intermediate/advanced stage of the learning process, it is more effective to use full haptic guidance to teach the fine details of the handwriting skill.

An interesting, consistent observation in the improvement in handwriting quality is the u-shaped fluctuations over the 9 weeks. These patterns are typical for physical, artistic, and cognitive skills development [32], and also reported with motor skills development [33]. The handwriting skill starts out at a high performance level and over time the skills descend to a lower value. After another period of time the skill once again ascends to a higher value, and so on. We believe that these fluctuations in the performance are due to the already known U-shaped learning process.

The learner's age also plays a role in defining the most effective haptic guidance method. This can be explained by the high level of correlation between fine motor skills and handwriting legibility [34]. In the current study, Year 2 participants were 2 years older that FS2 participants. This implies Year 2 participants had more comprehensive abilities of various sensorimotor systems, more developed large/small muscles, better visual perception, finer motor skills, and more accurate in-hand manipulation skills [35]. This justifies the statistically significant difference in the test completion time between FS2 and Year 2 participants since FS2 group had larger margin to improve handwriting speed than year 2 group.

Another interesting finding is the gender effect. It seems gender plays an important role in defining what haptic guidance would be most effective. It was found that female participants performed statistically better than their male counterpart with partial haptic guidance. This is probably due to the fact that partial haptic guidance provides cooperative learning, compared to all other haptic guidance methods. This conclusion is also supported by previous research demonstrating that female learners interact in a cooperative, caring, and sharing manner when learning fundamental motor skills, compared to male counterparts who were found to interact in a competitive, individualized, and egocentric manner [36].

Another point worth mentioning in this study is the transformation of handwriting experience from the digital world (handwriting pen-like stylus and screen) to paper-based handwriting [37]. The current study accounted for this transformation by evaluating the children's ability to write on a piece of paper with a pencil (all the evaluation is made through the paper-based evaluation). Therefore, the results we obtained represent the net transferred skill from digital to paper-based handwriting.

VI. Conclusions

We investigated the effectiveness of four haptic guidance methods including full haptic guidance, partial haptic guidance, disturbance haptic guidance, and no-haptic guidance, in comparison to a control group that practiced with traditional tools currently used at schools. Forty-two students participated in the nine week longitudinal experiment. The results showed that the disturbance haptic guidance was most effective for high complexity handwriting. The full and partial haptic guidance gave the best performance for medium complexity letters. In the case of low complexity letter, the full haptic guidance gave the best performance. As for the test completion time, FS2 students showed a significant decrease in the test completion time, compared to Year 2 students. In addition, female children performed remarkably better than their male counterparts when partial haptic guidance was utilized. Therefore, the decision of what haptic guidance method would be most effective depends on the difficulty of the handwriting task, the age group and gender of the learner.

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