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# Handwriting Training with a Board Prototype: A Randomized Controlled Trial

**Yumi Suzuki[1]*, Yuuki Haba[3], Aoi Onodera[4], Yuuka Nakamura[5], Sakiko Nakamura[4] and Hiromi Fujii[1,2]**

[1]*Department of Occupational Therapy, Yamagata Prefectural University of Health Sciences, Japan*

[2]*Graduate School, Yamagata Prefectural University of Health Sciences, Japan*

[3]*PAS Corporation*

[4]*Department of Rehabilitation, Shonai Amarume Hospital, Japan*

[5]*Department of Rehabilitation,Yamagata Saisei Hospital, Japan*

***Corresponding Author**

Yumi Suzuki, Department of Occupational Therapy, Yamagata Prefectural University of Health Sciences, 260 Kamiyanagi, Yamagata-shi, Yamagata Japan.

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## Abstract

***Purpose****: This study investigated whether handwritten characters differ between letter tracing on a handwriting training system developed by the authors and letter tracing training on a paper. This study is registered in the UMIN Clinical Trials Registry (Trial registration number: UMIN000055578).*

***Materials and methods:*** *This study developed a training system in which patients traced lines and figures carved onto a board. A training board and a paper sheet with similar lines and shapes were prepared. In total, 62 randomly selected participants traced lines and shapes with their nondominant hand for 10 min daily for 2 weeks. Subsequently, an optical character recognition software (Yonn de CoCo! Personal v.4) was used to evaluate the shape of the characters. The writing pressure was assessed using Trace Coder, and the fixation numbers were assessed using SMI BeGaze (SensoMotoric Instruments).*

***Results:*** *The number of fixations decreased, whereas the change in writing pressure per unit time increased after intervention. The character shapes did not change after training on paper. However, the character shapes improved, and the average writing pressure increased after practicing on a board.*

***Conclusions:*** *Tracing lines and shapes carved on a board can effectively improve handwriting with the nondominant hand.*

**Keywords:** Handwriting Training, Writing Pressure, Handwriting Assessment, Nondominant Hand, Hemiplegia Rehabilitation

## 1. Introduction

Handwriting ability is still important despite the development of digital devices in recent years. Handwritten notes can range from simple shopping notes to signing contracts, verifying credit cards, and processing other types of identification Some reports have shown that handwriting skills can be used to evaluate diseases [1-4].

Several reports have revealed that many people experience handwriting difficulties [5]. For example, based on a previous study, some school-age children have developmental disabilities and handwriting difficulties. Another study revealed that some individuals experienced handwriting difficulties with their dominant hand due to injury or illness [6-9].

Several factors can be used to assess handwriting skills. To evaluate handwriting quality, Grosse et al. (1) utilized character distortion (2), inconsistent character size (3), inconsistent relative height of characters (4), correction of character forms (5), and bad character alignment within the word [10]. Coradinho et al. examined handwriting process characteristics such as number of strokes, reaction time, duration, relative pen-down duration, average writing pressure, vertical size, horizontal size, road length, and average absolute velocity [11]. Rettinger et al. (2022) showed that handwriting issues among children often involve inadequate pen grip and tip pressure [12].

Ahmed et al. defined handwriting as a low-level component, and background knowledge, reading comprehension strategies, reasoning, planning, editing, and revision as high-level components [13]. Pei et al. examined neural activity by assessing the significant associations between handwriting as well as language and hand skill, handwriting cognitive stages, and kinematics [14]. Thus, handwriting issues are complex as they involve cognitive, perceptual–motor, mental, and emotional components and precise motor processes [15-18]. Therefore, each parameter is associated with a different issue, and solving all issues can resolve handwriting problems. For example, if an individual cannot recall words or write characters, the process begins with recalling words [19]. Further, if someone's pen grip is weak, finger muscles should be strengthened [20].

Babushkin et al. found that handwriting mastery requires the coordination of motor, sensory, cognitive, memory, and language skills. In addition, the degree to which these processes are involved is based on the complexity of the handwriting task [21]. Therefore, complex training is often required. The effects are interesting, and handwriting ability has a synergistic effect. For example, an individual can learn to read [22-25]. Hsiao et al. showed that Chinese calligraphy handwriting improved emotional stability, concentration, hand movement, memory, and speech in patients with mild dementia [26].

Handwriting has been evaluated from various perspectives. Lee et al. reviewed handwriting based on literature on occupational therapy and education and examined interdisciplinary approaches [27]. Previous studies have explored strategies that can help easily develop the handwriting skills of patients with hemiplegia who cannot write well. In particular, if the dominant hand becomes paralyzed, the nondominant hand must assume the role.

In Japan, some tasks, such as writing with the nondominant hand, using chopsticks when eating, and tying strings when changing clothes, are challenging to accomplish with the nondominant hand. Children who have writing difficulties often undergo handwriting training [28-30]. Some reports have presented training methods for patients with hemiplegia. However, the number of participants is small [31].

After a stroke, psychological symptoms, in addition to physical symptoms, worsen [32, 33]. These symptoms directly and indirectly affect the activities of daily living and quality of life of patients with hemiplegia [34]. For example, feelings of fatigue experienced by patients with hemiplegia are also experienced by anyone who interacts with them [35, 36]. As fatigue increases, their motivation for rehabilitation often decreases. Christensen et al. reported that high fatigue levels were associated with poorer functional outcomes [37].

In relation to these findings, the current study used easy and effective methods for writing training in patients with hemiplegia. In another study, children required 20 sessions of handwriting training at least twice a week [38]. These sessions focus on tracing, copying, and direct writing [10, 39]. It was hypothesized that training that can promote upper limb stability and finger dexterity is required to create a foundation for handwriting [40, 41].

Mugari et al. reported that some exercises can improve hand dexterity when using a pen. However, the continuous performance of these exercises does not guarantee that an individual can be a better writer [42]. Therefore, for handwriting training, experience in pen holding and writing is necessary. Danna et al. have revealed that visual, proprioceptive, and auditory feedback are effective sensory functions for handwriting [43]. Based on this principle, some studies have proposed methods that can supplement the senses that a participant lacks in handwriting [12, 29, 30, 44, 45]. Therefore, the authors searched for tasks that could be easily tackled, focusing on tracing and copying. As a result, plywood was used to make indented lines traceable. This design allows people to draw a line without looking at the line by simply moving their hand in accordance with the line carving, and they can feel resistance from the pen in their hand. Several Japanese characters are a combination of curved lines in hiragana and straight lines in katakana and kanji. The authors believe that if they included that element in the line to be traced, several characters can be handled. The effects of these exercises were investigated by examining changes in character shape, writing pressure, and eye movement.

The shape of a character determines whether it is easy to read or not [46]. In addition, the number of fixations was calculated to determine changes in visual information due to pen operations. The writing pressure is the pressure of the pen tip relative to the paper surface. The state of pen operation can be assumed from the degree of variation in the writing pressure [47]. Based on reports showing that the degree of variation in writing pressure significantly contributes to pen operation skills, the variation of writing pressure per unit of time was calculated using continuous writing pressure data [48].

The current study aimed to investigate whether there is a difference in handwritten characters when comparing tracing training with a device created by the authors and tracing training on paper in healthy adults. The method used compared the character shape, writing pressure, and number of fixations between paper and board training at the start and end of the training. The authors hypothesized that practicing on a board can make it easier to feel pen tip resistance, improve the character shape, stabilize writing pressure, and reduce the number of eye fixations.

## 2. Methods

### 2.1 Settings

This randomized controlled trial was conducted at Yamagata Prefectural University of Health and Medical Sciences from August 1, 2022, to November 30, 2022. It included 62 adults between 20 and 21. The participants were right-handed, had good eyesight, and had the time to continually perform the same exercises every day for 2 weeks. The exclusion criteria were as follows: individuals with a history of major eye or brain disease and those who had handwriting training with their nondominant hand at least once in the past.

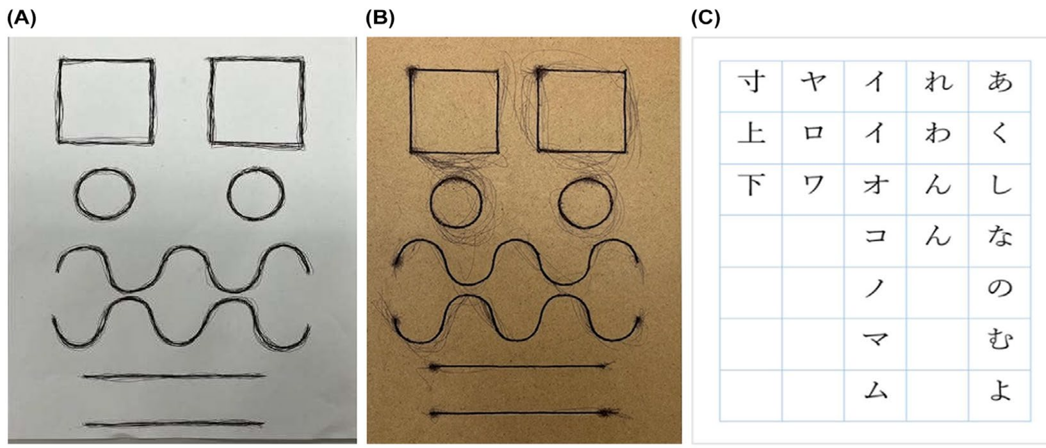


**Figure 1:** The figures used in the participants' training and the character types evaluated "A" and "B" are the figures used in the participants' training, taken at the end of the day. "A" presents paper training, "B" represents board training, and "C" presents the character type used for evaluation. For board training, tracing lines are engraved approximately 3 mm into the board

The sample size was set as an effect size dz of 0.5, an α err prob of 0.01, and a power (1-β err prob) of 0.8 using the G*power statistical tool. The minimum sample size was 26 individuals per group.

The Ethics Review Committee of Yamagata Prefectural University of Health Sciences approved this study (approval no. 2208-14). The participants were informed about the study details and provided a written informed consent before joining the experiment.

### 2.2 Experimental Equipment

An upper limb coordination evaluation system (Trace Coder, SYSNET Co., Ltd.), a stylus pen (Microsoft Corporation), a personal computer tablet (Surface Pro, Microsoft Corporation), and a web camera (HD Webcam C615n, Logitech) were used to measure writing pressure. The resolution and pitch of the tablet used for writing pressure were 10.6 in/1920 × 1080 pixels and 0.122 mm, respectively.

The time resolution of Trace Coder was 25 Hz, and the measurements reached up to 5 N. Its temporal resolution was 30 Hz, and its writing pressure resolution was 0.1 g. A glass-type eye movement measurement device (SMI EYE Tracking Glasses [SMI ETG] for Smart Recorder, SensoMotoric Instruments) was used to measure eye movements. A scanner (EPSON DS-860) and the optical character recognition (OCR) software Yonn de CoCo! Personal Ver. 4.0 were used to read the text.

### 2.3 Procedure

Before the experiment, 20 nonparticipants wrote 51 Japanese characters each in hiragana and katakana and 15 kanji characters with their dominant hand. Then, an OCR analysis was conducted. In total, 25 characters with a reading rate of ≧80% were extracted. One set of characters included 12 hiragana characters, 10 katakana characters, and 3 kanji characters. These characters were selected to evaluate differences in reading rates based on the characters.

The participants performed the Edinburgh handedness test during the first experiment to validate their handedness [49]. Then, they took a pen in their right hand and copied one set of 25 characters onto the paper (figure 1[1] ). Similarly, they copied the same set three times with their left hand. Next, they put on the SMI ETG and sat in front of a desk that is approximately 70-cm high.

Then, the Trace Coder and stylus pen were placed in front of the participants' eyes, and a web camera was placed on the side to examine eye movements during handwriting. After calibration with SMI ETG, the participants held a pen in their left hand and drew 10 lines with a distance of 10 cm from left to right on the Trace Coder. Most Japanese characters were lines drawn from left to right. Hence, in this experiment, the participants were instructed to draw lines from left to right. The issues encountered when measuring eye movements were identified because eye movement changes during handwriting with the nondominant hand were examined. Further, eye movement changes based on the type of characters should be prevented.

An independent collaborator enrolled participants using a random number table generation computer program (Reach Randomizer, https://www.randomizer.org/). At the same time, the Randomizer performed block randomization, dividing participants into blocks of two. Group assignments were not revealed to the investigators until the end of the analysis.

Each participant in the paper group was provided with 14 training sheets. Each participant in the board group was provided with one training board. After completing the pre-training assessment, participants were instructed by the collaborator to take home an envelope containing either a training sheet or a training board, which was placed on a small table. The contents of the envelope became the participant's training assignment.

Lines and figures of the same length and shape were drawn on the board and paper. However, lines on the board were carved at a depth of approximately 3 mm. The participants were instructed to spend 10 min each day on the given task, hold a pen in their left hand, and trace the shapes. After 2 weeks, the participants repeated the same test after practicing each task.

The content of participants' home training was anonymized, kept confidential, and hidden from the experimenters. The criterion for participants to drop out of the trial was not to training for a total of 2 days or more.

### 2.4 Analysis

The shape of the participants' characters, the number of fixations during line drawing, the average writing pressure, and the variation in writing pressure per unit of time were analyzed.

The character shapes were examined with OCR and compared based on the number of reads. The characters written by the participants were read with a scanner (EPSON DS-860) at a resolution of 200 dpi and converted into tiff files.

The characters were then read using the OCR software Yon de Coco! Personal Ver. 4.0, and the number of correctly read characters was used for comparison [50]. The OCR analysis separates a character into four components, which were as follows: vertical, horizontal, and diagonal. Moreover, it compresses the four components to approximately 7 × 7, thereby extracting the features of each character and performing character recognition. The number of fixations during line drawing was calculated using BeGaze by calculating the number of fixations per each line when 10 lines were drawn.

The average writing pressure was calculated by dividing the writing pressure when drawing one line measured by Trace Coder by the unit of time. Thereafter, the average of 10 measurements per participant was calculated. In addition, the amount of change in writing pressure per unit of time was calculated by subtracting the next measurement from the writing pressure measurement for each line and by calculating the amount of change between measurements. This amount of change was integrated over the number of measurements for one line and then divided by the measurement time and average.

### 2.5 Statistical Analysis

Multiple comparisons via the OCR analysis of the characters written by the participants with their left hand were performed. Similarly, multiple comparisons of eye movements and changes in writing pressure per unit of time were performed. The number of fixations had a normal distribution. However, the duration of each fixation was not constant. Therefore, the nonparametric test could be used for analysis. Using writing pressure data, one-way analysis of variance was used, and multiple comparisons were performed before and after training in the paper and board groups. All risk rates were set to <5%.

## 3. Results

### 3.1 Participants

In total, 64 participants responded to the invitation to join the study. Table 1 shows the characteristics of the participants. The participants were randomly divided into the paper and board groups (n = 32 each). However, two participants in the paper group dropped out because they did not train for 2 consecutive days during the study (figure 2).

**Table 1:** Participant Demographics

| | | All | Paper training | | Paper training | | p-value |
|---|---|---|---|---|---|---|---|
| | | | **Pre-training** | **Post-training** | **Pre-training** | **Post-training** | |
| Participants (male: female) | | 64(8:56) | 32(4:28) | 30(4:26) | 32(4:28) | 30(4:26) | —— |
| Age | | 21.5±0.7 | 21.2±0.8 | 21.8±0.7 | 21.5±0.6 | 21.5±0.6 | —— |
| Total time | (msec) | 1457±511 | 1382±405 | 1309±484 | 1621±531 | 1425±409 | 0.000 |
| Character shapes | (count) | non dominant hand 46±11 | 42±12 | 46±10 | 44±10 | 51±11 | 0.046 |
| Average number of fixation | (time) | 3.8±1.3 | 4.0±1.5 | 3.5±1.3 | 4.0±1.4 | 3.8±1.5 | 0.008 |
| Average writing pressure | (g) | 54.3±18.5 | 56.1±19.5 | 62.1±24.0 | 52.4±20.8 | 60.7±29.6 | 0.002 |
| Changes in writing pressure per unit of time | (g/msec) | 0.6±0.4 | 0.6±0.3 | 0.7±0.4 | 0.5±0.3 | 0.6±0.3 | 0.000 |

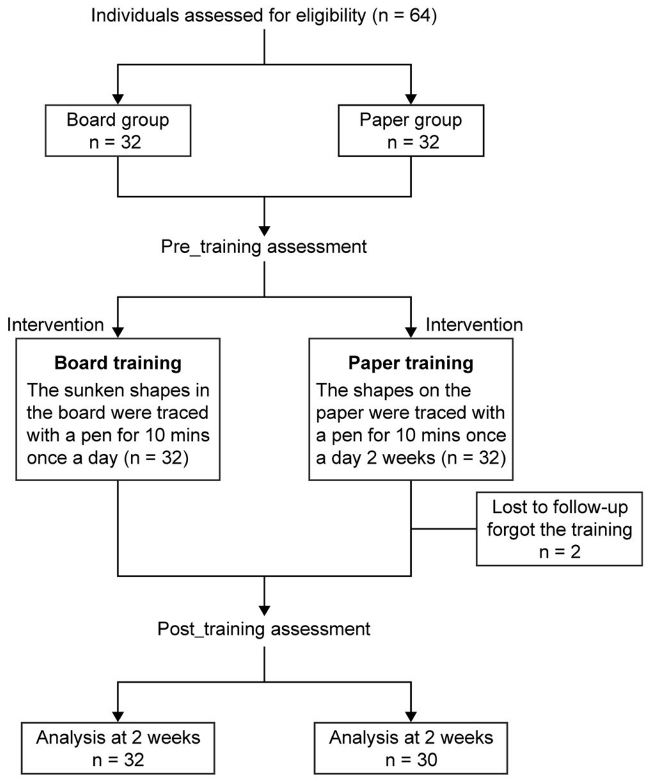


**Figure 2:** Overall Flow Diagram of the Trial

### 3.2 Character Shapes

The number of characters read via OCR analysis was 51/75 after 2 weeks of board training. This result differed from the value before training (p = 0.0036) (figure 3).

### 3.3 Average Number of Fixations

The average number of fixations during line drawing decreased from before training only in the paper group 2 weeks after training, with a median of 3 times, a minimum of 1, and a maximum of 7 (p = 0.009) (figure 4).

### 3.4 Average Writing Pressure

The change in the average writing pressure was more evident than before training in the board group (p = 0.01) (figure 5).

### 3.5 Changes in Writing Pressure Per Unit of Time

The change in writing pressure per unit of time did not change in the board group compared to before training. However, it increased in the paper group (p = 0.002) (figure 6).

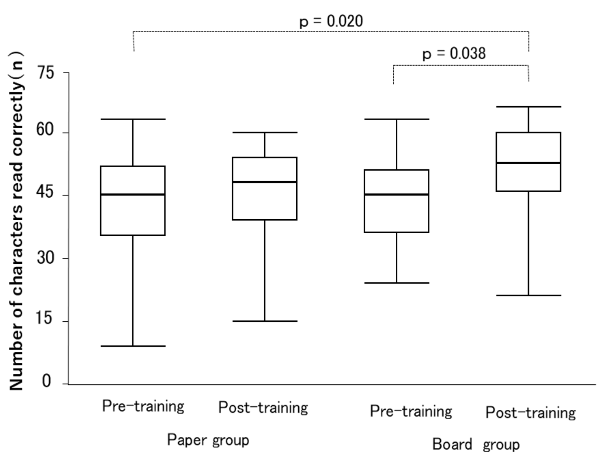


**Figure 3:** Comparison of Number of Characters Read Correctly

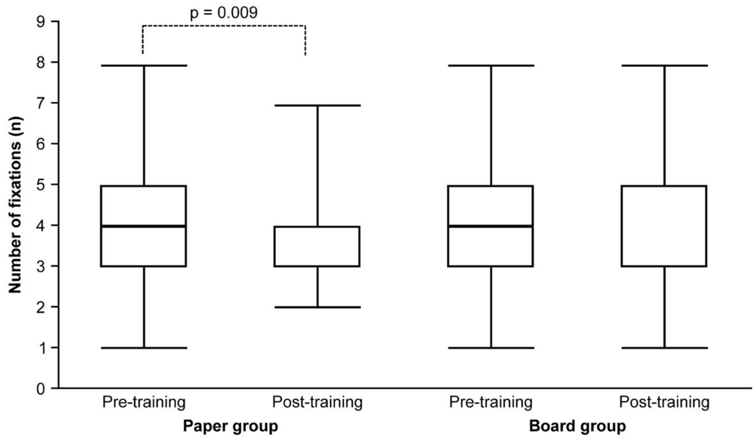


**Figure 4:** Comparison of Number of Fixations

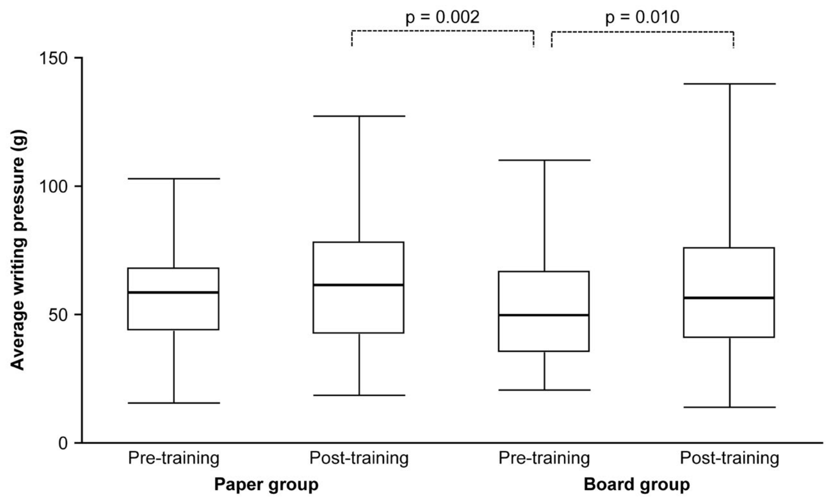


**Figure 5:** Comparison of Average Writing Pressure Values

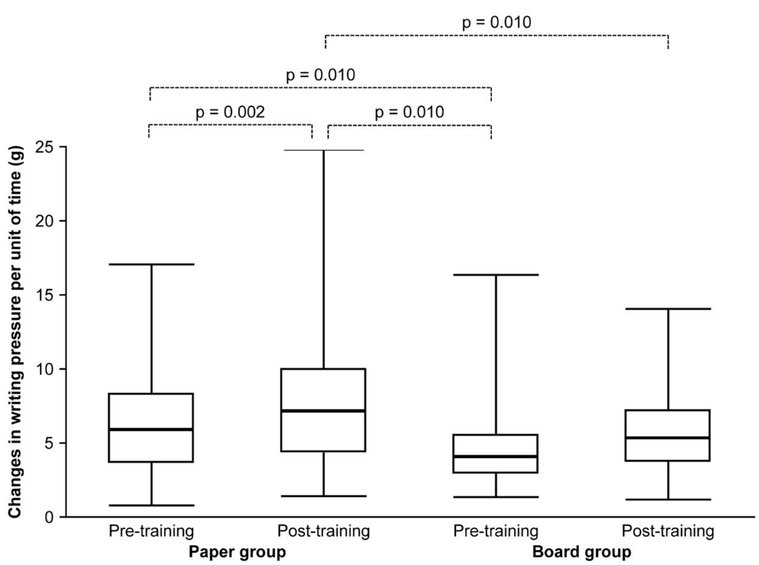


**Figure 6:** Comparison of Changes in Writing Pressure Per Unit of Time

## 4. Discussion

This study investigated differences in the shape of characters, eye movements, and writing pressure when tracing training with the nondominant hand was performed on a paper and board with carved lines. The following survey item was considered:

### 4.1 Character Shape

If the shapes of the characters were analyzed using OCR, the number of readings in the board group was higher after 2 weeks of training. Hong et al. showed that if the kinesthetic sense is higher, handwritten texts are easier to read [51].

During board training, the carved lines guide the direction of the pen's movement. Danna et al. described an induction as supplicative feedback, an external stimulus: The teachers hold the children's hands and move them along the correct orbit [43]. It uses the upper arms, forearm, muscles of the hand with a pen, and unique sense of proprioceptive receptors in the skin.

In contrast, the paper group could not trace accurately with their nondominant hand without visual feedback. They had no choice but to conduct training in which visual feedback was significant. Considering the age of the participants, handwriting was associated with working memory [16].

Pen control is important for participants to write well-shaped characters. The board training, which obtained more proprioceptive information from the writing surface, was more effective. This result is similar to that of in the study of Palluel-Germain et al., which was obtained after controlling the upper limbs using forced feedback referred to as Telemaque and writing characters on a horizontal surface with a pen [52].

### 4.2 Number of Fixations

Visual fixation is an important position where fingertip movements and identified objects are coordinated, supporting the hand exercise plan [53]. The number of fixations decreased after training in the paper group. However, it did not change in the board group.

Visual information is important to trace lines on papers. However, the number of fixations decreases as the movement becomes more skilled. Hacques et al. revealed that visual control is used significantly during the learning process. However, it gradually decreases and shifts to more automatic control, changing the balance between visual and proprioceptive control [54]. By contrast, the board group received more information from the board surface, indicating that they were less dependent on visual information [43].

### 4.3 Average Writing Pressure

The average writing pressure became stronger after training in the board group alone. The participant drew a line on the tablet's surface. Thus, the participant's tablet was only in contact with the tip of the pen. In this posture, the upper limbs must be raised, and the main action muscles are the scapular elevation muscles, such as the trapezius, and the shoulder joint flexors, such as the deltoid muscle [55,56]. These muscle groups can be strongly active if the participant is not using his/her left hand. However, their activity gradually decreases after a period of training [57]. Therefore, the muscle activity of the shoulder girdle and muscles around the shoulder joint becomes stable with training. A certain weight of the upper limb can be applied on the tablet, and a line can be drawn, which increases the writing pressure. It was hypothesized that the board training, which applies more pressure to the pen tip to reduce the resistance created by rubbing the board, resulted in a stronger writing pressure after the training.

### 4.4 Change in Writing Pressure Per Unit of Time

There was no difference in the change in writing pressure per unit time between the board groups. However, the change in writing pressure per unit time after training was greater than that before training between the paper groups.

A significant change in writing pressure per unit time indicates an insufficient force control during handwriting. Based on the results of average writing pressure, the board group had a higher writing pressure after training. By contrast, since there was no change in the number of fixations during board training, the training did not incorporate visual information. Therefore, the movement was based on proprioceptive information sensed by the pen tip and hand, and writing pressure was easier to control than movements that used a lot of visual information. In relation to this, board training improves the shape of the characters and increases the writing pressure in stable writing.

However, Takamuku et al. revealed that watching and paying attention to moving objects can help people adjust their grip strength to match the direction of the moving object [58]. Therefore, it is more effective to apply creative training methods that incorporate appropriate use of visual information rather than simply changing the written surface.

The current study had limitations. This study only included healthy men and women in their 20s. Healthy people of this age can easily get used to the movements of their nondominant hand. Thus, this result cannot be immediately applied to older individuals or those with disability. The training was performed at home. Thus, the training environment was not standardized. However, the authors believed that the training environment can be standardized if the training was held in a limited location. Notably, this experimental method could not be considered for a fully randomized controlled trial because the participants knew the training method.

## 5. Conclusion

In this study, the participants trained in tracing lines on paper and traced the same lines on an engraved board to facilitate writing with the nondominant hand. Further, the shape of the characters, the number of fixations, the average writing pressure, and the variation in writing pressure per unit of time were compared. The number of fixations decreased, and the variation in writing pressure per unit of time training increased. However, the shape of the characters did not change when training on paper. The shape of the characters improved, and the average writing pressure increased. However, the number of fixations and the variation in writing pressure per unit of time did not change when training on a board.


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## Conflicts of Interest

The authors have no conflicts of interest to report.

## Data Availability

The Excel file containing the data used to support the findings of this study is available from the corresponding author upon request.


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