■ORIGINAL ARTICLE

Motor Learning of Handwriting Using the Non-dominant Hand

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Abstract: To investigate the features associated with the mastery of neat and speedy handwriting, 23 healthy volunteers practiced writing with their non-dominant hand. The participants were randomly divided into two groups. One group (n = 12) started writing simple symbols such as dashes, circles, and triangles (−, ○, and △) and then after 1 week, advanced to writing individual characters. The other group (n = 11) started by copying entire sentences. The practice period lasted 4 weeks (7 days/week). Results showed no major differences between the groups in terms of handwriting learning effectiveness; however, there was a trade-off between the speed at which the participants wrote and the neatness of their writing. These findings suggest that the process of learning to master handwriting is consistent with the Fitts's law.

Keywords: non-dominant hand, handwriting, motor learning

Introduction

In the field of occupational therapy, patients who lose functionality in their dominant hand due to disease or injury are often provided with guidance regarding the transfer of hand-dominance. When the objective of such a therapy is to regain the ability to write, for example in cases where returning to work is expected or when writing is an essential method of communication, the motor learning of handwriting is frequently part of the therapy program.

Chinese characters (*kanji*) were imported to Japan from China via the Korean peninsula during the 5th and 6th centuries CE. Based on these characters, two types of syllabaries (*hiragana* and *katakana*) were developed in Japan around the 9th century CE. These three character types are commonly used in Japan. Thus, Japanese patients who need to learn handwriting have to master these three character types.

Mastering handwriting requires both speed and neatness. Generally, practice progresses in the steps of increasing difficulty, beginning with simple outlined shapes (such as −, |, /, ×, and ○), then advancing to *kanji*, which comprises straight lines (三, 川, 日, 田, and 目), and finally to more complex *kanji* and the *hiragana* syllabary. [1–3] An alternative approach is "random practice," one aspect of R.A. Schmidt's theory of motor learning;[4,15] this entails the simultaneous practice of tasks at different levels of difficulty. Although progress is generally slower, this method is considered to be more effective than the block practice method for the retention of skills and the transfer of skills to practical problems. [4, 5]

Many occupational therapists utilize block practice, which involves initiating practice with simple tasks such as coloring in outlines and then advancing to writing characters, because they have more experience with this method. [1–3] However, only a few studies have investigated effective methods for improving handwriting speed and neatness through practice. In the present study, we compared the motor learning efficacy using the block and random practice methods for the development of handwriting proficiency among individuals

undergoing hand-dominance transfer therapy. The aim of this investigation was to identify the factors which influences the motor learning of handwriting.

Methods

Participants

The study enrolled 23 healthy volunteers who used their right hand when performing common, everyday activities such as holding a pencil when writing, holding chopsticks when eating, or throwing a ball. None of the participants underwent hand-dominance transfer from their left to their right hands during childhood. Three participants were males and 20 were females. Their mean age was 20.7 ± 0.5 years. The participants were randomly assigned to two groups. The 23 participants began by writing symbols such as −, ○, and △. Subsequently, 12 subjects advanced to *kanji* (consisting of only three strokes), *hiragana*, and then sentence copying. As these tasks became increasingly difficult, these 12 participants were placed in the block practice group. Eleven participants were placed in the random practice group in which they were made to practice sentence copying from the beginning. Participants were randomly assigned to the groups.

This study was approved by the Institutional Review Board of the Kinjo University (no. 27−16). The participants were provided with the descriptions of study contents and methods. Moreover, the participants provided written informed consent before participation.

Procedures

Each day during the 4-week practice period, the participants wrote 200 characters in horizontal lines using HB pencils. The paper was lined with a grid of 1 × 1 cm squares. Because the study aimed to investigate the motor learning process when writing was practiced to gain speed and neatness, the participants were not provided with any instructions except for a description of the characters that were required to be practiced.

For the block practice group, the specific type of practice was changed according to pre-determined steps: during week 1, they practiced symbols (e.g., +, ×, and ○); during week 2, they practiced *kanji* involving strokes (e.g., 川, 三, and 口); during week 3, they practiced *hiragana*; and during week 4, they copied sentences on general topics (of a third grade elementary school level as indicated by the Japanese Ministry of Education, Culture, Sports, Science and Technology)6. In contrast, the random practice group practiced copying entire sentences on general topics throughout the practice period.

For both the groups, the sentences on general topics were of third grade elementary school level, as indicated by the Japanese Ministry of Education, Culture, Sports, Science and Technology, and included kanji with higher numbers of strokes. The level of difficulty of each task was determined by five occupational therapists and was based on the Japanese Ministry of Education, Culture, Sports, Science and Technology's Elementary School Curriculum for the Japanese Language.[6]

Outcome measures

The sentences on general topic of a sixth grade elementary school level, which included *kanji* with higher numbers of strokes, were practiced on paper lined with a 1 × 1 cm grid using HB pencils.

Seven assessments were conducted: at the baseline (T0), at the end of each week during the practice period (T1, T2, T3, T4; total 4 h), a week after the end of the practice period (T5), and 2 weeks after the end of the practice period (T6) (Figure 1).
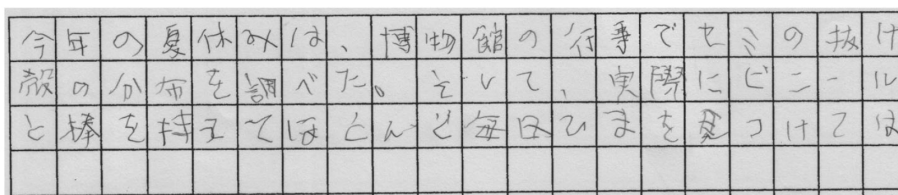
There were two outcome measures: the number of
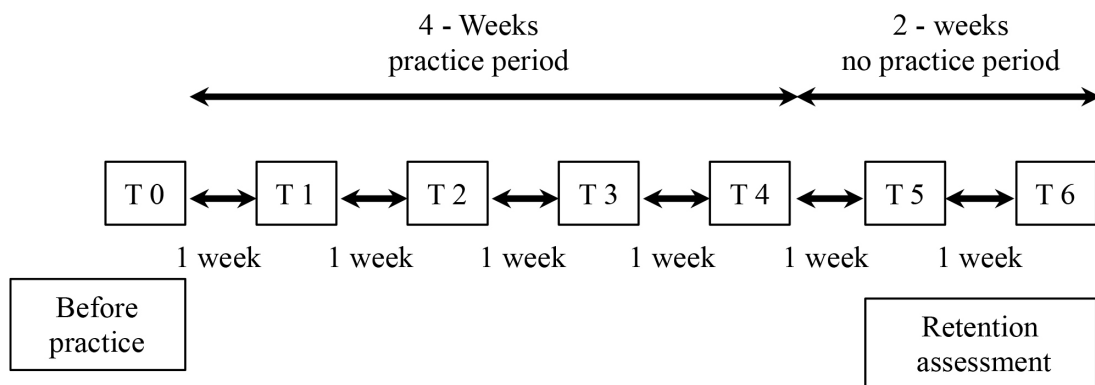
Figure 1. Writing practice period and assessment points.

The assessment was carried out seven times; before practice (Time0: T0), the end of each week (T1, T2, T3, T4, total four hours), a week after the end of the practice (T5), and two weeks after the end of the practice (T6).

Table 1.　An example of character neatness scores

		Evaluator1	Evaluator2
hiragana	overlappong of lines	5	4
	wobbly lines	2	2
	correct usage of "stops" and "upward turns"	3	3
	downward sloping characters	3	3
	balance between *kanji* and ather characters	3	3
katakana	overlappong of lines	4	4
	wobbly lines	3	3
	correct usage of "stops" and "upward turns"	2	2
	downward sloping characters	4	3
	balance between *kanji* and ather characters	3	3
kanji(comprising≤7 strokes)	overlappong of lines	4	4
	wobbly lines	3	3
	correct usage of "stops" and "upward turns"	2	2
	downward sloping characters	2	2
	balance between *kanji* and ather characters	3	3
kanji(comprising≥8 strokes)	overlappong of lines	2	2
	wobbly lines	2	2
	correct usage of "stops" and "upward turns"	2	2
	downward sloping characters	3	3
	balance between *kanji* and ather characters	2	2
Character neatness scores : total		57	55
Character neatness scores: mean		**56.0**	

The baseline (T0) evaluation results of female (21 years old) in the random practice group are shown. Each of these features were scored from 1 to 5 (5 = good), and the total scores were calculated. The number of characters that this subject could write within the evaluation time was 30.

characters written and the neatness with which the characters were written.

　The number of characters written was assessed by counting the number of characters the participants were able to copy within a time limit of 150 s. Character neatness was assessed using a method that was devised by us and was based on the Elementary School Curriculum for the Japanese Language of the Japanese Ministry of Education, Culture, Sports, Science and Technology.[6] The characters were divided into the following four groups for assessment: *hiragana*, *katakana*, *kanji* comprising ≤7 strokes, and *kanji* comprising ≥8 strokes. The assessments were based on the following features: the overlapping of lines; wobbly lines; the correct usage of "stops" and "upward turns"; downward sloping characters; and the balance between *kanji* and other characters, examining whether the *kanji* were more prominent than

others. Each of these features were scored from 1 to 5 (5 = good), and the total scores were calculated. The maximum total score was 100. Higher scores indicated that the characters were neatly and skillfully written.

　Table 1 shows the example of scoring. This subject was a 21 years old female in random practice group, copied 30 hand writing characters at baseline (T0) evaluation.

　Two evaluators independently assessed character neatness, and the final character neatness scores were the mean scores of the two evaluators. The degree to which the two evaluators' scores matched was investigated by calculating intraclass correlation coefficients for each time point.

Statistical analysis

　The character neatness scores of the two groups

at each time point were compared using the Mann–Whitney U test. Chronological changes were examined using the Friedman and Wilcoxon rank sum tests. In addition, the relationship between the number of characters written and character neatness was examined using the Spearman rank correlation coefficient analysis. The level of statistical significance was set at $p < 0.05$. The analyses were performed using Microsoft Excel for Mac 2016 (Microsoft) and JMP 14.0 MAC (SAS Institute Inc.).

Results

There was good correlation between the scores of the two evaluators for character neatness at each time point, with intraclass correlation coefficients between 0.67 and 0.82 (Table 2). Also, there was not significant difference between the scores of the two evaluators at each time point.

Comparisons of the number of characters written within 150 s and character neatness scores at each time point showed a significant difference between the two groups only in the number of characters at week 1 (Tables 3). No other significant differences were observed between the groups at any other time points (Tables 4).

In both groups, the number of characters written in 150 s increased gradually from the baseline to the final retention assessment ($p < 0.05$; Table 3). Character neatness scores in the block practice group showed a significant difference only between the week 4 assessment and the final retention assessment ($p < 0.05$), with no significant differences observed between any other time points (Table 4). In the random practice group, there were significant differences in character neatness scores between the week 1 and week 4 assessments and

Table 2. ICC between two evaluators on the results of the neat of characters which the leaners wrote

	Evaluator A		Evaluator B		
	Minimum ~ Maximum	Median	Minimum ~ Maximum	Median	ICC
T0	42 ~ 79	60	35 ~ 78	61	0.67
T1	43 ~ 91	60	35 ~ 81	56	0.72
T2	47 ~ 79	65	32 ~ 82	64	0.82
T3	41 ~ 91	68	33 ~ 94	59	0.77
T4	42 ~ 93	71	45 ~ 92	61	0.80
T5	40 ~ 83	67	35 ~ 92	60	0.77
T6	40 ~ 81	63	45 ~ 91	57	0.77

The values represent average of the scores determined by the two evaluators.

Table 3. The change with time on the numbers of characters which the learners wrote about two practice groups

		Block practice group		Random practice group		Both groups comparison
		Minimum ~ Maximum	Median	Minimum ~ Maximum	Median	
Before practice	T0	26 ~ 50	40	25 ~ 60	42	n.s.
	T1	25 ~ 59	45	33 ~ 71	57	p<0.05
	T2	34 ~ 63	53	40 ~ 72	62	n.s.
	T3	26 ~ 72	52	29 ~ 73	63	n.s.
	T4	37 ~ 68	56	33 ~ 74	64	n.s.
	T5	29 ~ 82	56	32 ~ 84	66	n.s.
Retention assessment	T6	32 ~ 78	58	35 ~ 83	63	n.s.

Values indicate the numbers of characters which by participants.
(* : p < 0.05   n.s. : not significant)

Table 4. The change with time on the neat of characters the learners wrote on two practices groups

|		Block practice group		Random practice group		Both groups comparison
		Minimum ～ Maximum	Median	Minimum ～ Maximum	Median	
Before practice	T0	43.5 ～ 77.0	61.0	44.5 ～ 74.5	57.5	n.s.
	T1	42.5 ～ 85.5	64.5	45.0 ～ 77.5	58.5	n.s.
	T2	45.0 ～ 79.0	66.5	39.5 ～ 77.0	55.5	n.s.
	T3	52.0 ～ 81.5	66.3	37.0 ～ 92.5	61.0	n.s.
	T4	52.0 ～ 79.0	66.3	45.0 ～ 92.5	62.0	n.s.
Retention assessment	T5	43.5 ～ 78.5	64.0	37.5 ～ 86.0	60.0	n.s.
	T6	41.0 ～ 83.0	60.3	40.0 ～ 83.5	56.5	n.s.

Values indicate the neatness of characters written by participants.
(＊ : $p < 0.05$　　n.s. : not significant)

between the week 4 assessment and the final retention assessment ($p < 0.05$), but there were no significant differences between any other assessments (Table 4).

The mean numbers of characters written in 150 s and character neatness scores in the two groups were subtracted from each case and the relationship between the scores at each time point was investigated. Scatter plots of these individual values showed that many individual scores at the baseline were in the vicinity of the mean scores and that the participants with a gradual increase in the number of characters written in 150 s showed a decrease in the rate of improvement in their character neatness scores. On the contrary, participants whose rate of increase in the number of characters declined showed a tendency toward improvement in their character neatness scores (Figure 2). There was no difference between the groups in this trend.

The correlation analysis resulted in the following
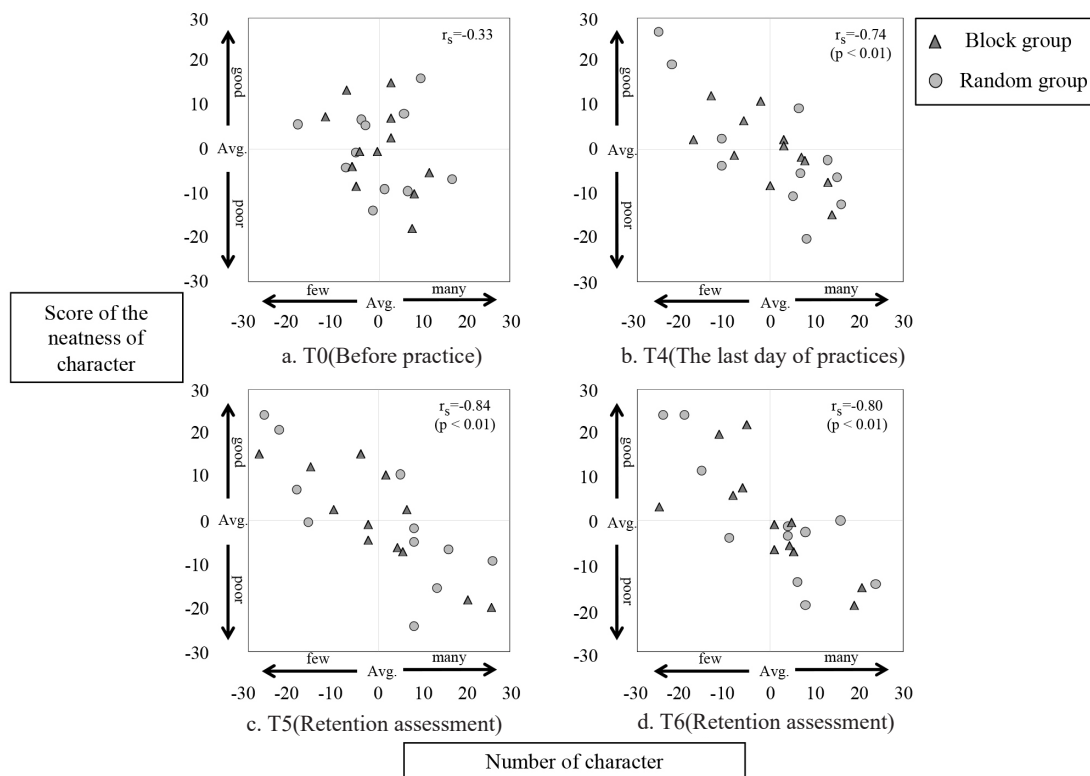
Figure 2. The correlation between the numbers of characters and the neat of characters.

Spearman rank correlation coefficients: baseline, −0.33; week 1, −0.57 ($p < 0.01$); week 2, −0.70 ($p < 0.01$); week 3, −0.73 ($p < 0.01$); week 4, −0.74 ($p < 0.01$); retention assessment 1, −0.84 ($p < 0.01$); and retention assessment 2, −0.80 ($p < 0.01$) (Figure 2).

Discussion

For performing activities of daily living, it is important to be able to write at a standard speed and with a certain neatness so as to make the writing legible to others.[7–9] Many studies have assessed the mastery of handwriting by assessing the speed at which the individual writes, the pressure applied, and the accuracy (neatness) of the writing. Reportedly, computers have been used to assess accuracy by measuring one representative character.[10,11] Moreover, studies have reported the use of computers with character-reading softwares, using which the participants' writing samples were scanned and entered into the computer and the percentage of characters that the program could recognize were assessed.[12,13] Many studies have assessed writing speed using methods that are easy to implement in clinical settings. In contrast, although there many methods for assessing the accuracy (neatness) of characters, methods that utilize computers may not be easy to use in clinical settings.

In the present study, we utilized assessment methods that do not require any kind of device and thus are easy to implement in clinical settings. Using these methods, we counted the number of characters that could be copied within a pre-determined time period (150 s) to assess writing speed. Because there is no existing method for objectively assessing character neatness, we developed a quantitative method to assess the same. An investigation of the reproducibility of our method indicated good concordance in the scores that were independently determined by the two evaluators with intraclass correlation coefficients between 0.67 and 0.82, indicating generally good reliability. To further improve reliability, we utilized the mean values of the scores determined by the two evaluators in the analyses. In addition, writing is a quiet activity, hence statue and muscle strength do not impact significantly. In this research the majority of our subjects were women, therefore we did not compare male versus female.

Differences in the practice methods used to learn a skill can have a major effect on the level of mastery of that skill.[4,5] In the present study, we compared the efficacy for learning handwriting using block and random practice methods with a particular focus on the speed and neatness with which the participants were able to write characters. We did not observe any clear differences between the two groups in terms of learning efficacy. However, the components that express handwriting performance are not limited to speed and neatness alone. They also include the way the pencil is held, a fine control of pencil, the shape of the hand, the pressure with which the pencil is held and used, and various other elements.[8–13] The writer's attitude and objectives also have an effect on learning efficacy.[2] For example, a writer may have in mind a goal of writing quickly or neatly. The elements that are required to learn handwriting may not indicate the same degree of mastery. In addition, it has been reported that at least 60 min of practice per day is required to master handwriting and that the acquisition of a serviceable speed requires 3 months whereas acquiring the ability to write neatly requires 6 months of practice.[2] Thus, mastering handwriting with a high degree of motor skill takes more than the 4-week practice period utilized in the present study, which presumably is too short to acquire this mastery. This may be one reason why we did not observe a difference between the two groups in terms of learning efficacy.

On the contrary, by contrasting the number of characters and neatness, it was noted that participants who had poor rates of improvement in the number of characters written in the time limit tended to show improved character neatness scores. The number of characters and speed was negatively correlated, with increasing significance as the practice process continued on. This suggested a trade-off between writing speed and character neatness. No difference was found by the different practice methods used. The same relationship was maintained at the retention assessments conducted after the end of the practice period. This suggests that it was difficult for the subjects to learn writing speed and neatness simultaneously.

The number of characters written indicates 'motor speed', while the neatness score indicates 'motor precision'. According to Paul M. Fitts, "when required motor precision is increased, it results in longer time for motor action (he Fitts's law,[4,15])". Similarly, this research result of trade-off relationship between the number of characters and writing speed suggests that the handwriting speed and neatness undergo a learning process consistent with the Fitts's law, regardless of the learning method used.

No objectives or other instructions regarding learning handwriting were provided to the participants. The results of this study suggest that this may have had an effect on whether they emphasized speed or neatness as they learned. We intend to further study the characteristics of mastering handwriting with the non-dominant hand over longer practice periods and by instructing the participants to emphasize either speed or neatness as an

objective of learning.

Conclusion

To investigate the characteristics of mastering handwriting, we compared learning effects in the terms of the number of characters that could be written within a time limit and character neatness over a 4-week practice period between the two groups: block practice group, in which practice began with simple symbols and then gradually progressed to more difficult tasks, and random practice group, in which entire sentences were copied from the beginning. The reason for focusing on speed and neatness was that mastering handwriting includes various components such as handwriting speed, neatness, pencil pressure, and hand shape and that simultaneously learning all of these may not provide results that represent the learning process. However, focusing these two characteristics may be one reason why we did not observe any major differences between the groups in terms of learning efficacy. It is also possible that the 4-week practice period utilized in this study was insufficient for revealing any differences in the learning efficacy between the two methods. Nevertheless, we observed a trade-off between handwriting speed and neatness, which was consistent with the Fitts's law.

Declaration of conflicting interests

The authors of this study have no conflicts of interest to declare.

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