

Visuo-haptic multisensory learning enhances encoding and recall of Rey-Osterrieth complex figure shapes

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The objective of this study is to measure the impact of multisensory learning incorporating an original haptic modality on human visual memory via a behavioural experiment using the Rey-Osterrieth Complex Figure Test (ROCFT) . Recent studies have reported that children with difficulties in letter or figure perception have weaker visual perception processes. The scientific evidence on the effect of the learning support using haptics is required. Adult participants (n=52) drew a ROCFT image through copy and recall, and then re-learned the image using a three-dimensional ROCF plate. Two groups were formed : the V-H group relearned the image using two modalities (haptics and vision) , whereas the V group was only visually explored. The second task was administered 24 hours after the first session. The data was analysed by two-way ANOVA with the scores on ROCFT as a dependent variable and the different modalities and scores before and after the learning as independent variables. In addition to the total scores on ROCFT, scores in each subunit divided into three were also analysed in the same way. The result suggested the validity of visuo-haptic multisensory cognitive integration on visual memory.

Introduction

In a study by Goto et al [1]., visual perception abilities were examined in children with developmental dyslexia. The study found that these children showed weaknesses in visual processing, as reflected in their performance on visual memory tasks involving geometric figures. For children with such difficulties in visual recognition of letters and shapes, haptic-based learning approaches—such as forming letters out of clay—have been implemented as a form of educational support [2].

One possible mechanism by which haptic learning improves performance on visual perception tasks is the transfer of information across sensory modalities. For example, Reales et al [3]. reported that learning through touch enhanced performance on visual perception tasks with an effect size comparable to that of

visual learning. Furthermore, Helbig et al [4]. demonstrated that using two cues—vision and touch—enabled more accurate estimation of shapes and sizes than using vision alone. These findings suggest that the integration of visual and haptic information may be beneficial for learning visual patterns through haptic experiences.

The transmission and integration of information between touch and vision have also been demonstrated from a neuroscientific perspective. In an fMRI study, James et al [5]. reported that when participants touched and recognized artificially made clay-like objects, activation was observed in the lateral occipital complex (LOC) and middle occipital areas of the brain. Moreover, the same brain regions were activated even when the participants later viewed the same objects without touching them. Based on these findings, James et al. concluded that a shared object representation system in the lateral occipital complex facilitates the influence of haptic learning on activity in visual brain areas.

Nishino et al [6]. proposed a neural model in which the lateral occipital complex (LOC) serves as the central region for the integration of three-dimensional information between vision and touch. According to this model, haptic and visual images are first formed independently through bottom-up processing via distinct sensory pathways, and are then integrated through top-down processing centered in the LOC. Similarly, Simon et al [7]. also proposed a model that explains how imagery is generated from haptic input. In the model proposed by Simon et al., when a person touches a familiar object, information flows from the prefrontal cortex to the lateral occipital complex (LOC), which facilitates the recall of object imagery including shape and semantic content. Conversely, when touching an unfamiliar object, the somatosensory cortex provides support for spatial imagery processing via the intraparietal sulcus, allowing new imagery to be constructed within the LOC. Both Simon's and Nishino's models share the view that top-down processing centered in the lateral occipital complex plays a key role in integrating inputs from different sensory modalities to support cognition. Based on the models proposed by Nishino and Simon [6,7], it can be assumed that not only seeing an object but also touching it enables the formation of more precise mental imagery, which can then be recalled and expressed more vividly through visual means. In other words, for individuals with difficulties in visual processing, utilizing touch as an alternative input pathway may facilitate the construction of object imagery and contribute to the enhancement of visual cognitive functions.

As a study on the formation of object imagery using haptics, Solène et al [8]. conducted an experiment with preschool children, in which participants learned about three-dimensional geometric shapes through simultaneous visual and haptic exploration. The study compared learning outcomes on the morphological features of squares, rectangles, and triangles between a group that learned through vision alone and a group that engaged in combined visual-haptic exploration. The results showed that the group using both vision and touch performed better on classification tasks based on shape features. The authors suggested that this active exploration—“looking while touching”—may have led to dual coding through both visual and haptic

modalities, thereby enabling more accurate mental imagery of geometric features. However, the experiment conducted by Solène et al. examined the effects of haptic learning only within the limited scope of simple shape recognition. This approach does not fully correspond to the demands of more complex visual memory tasks such as learning Japanese characters, including kanji. To evaluate the impact of haptic learning using a more practical visual cognitive task, we designed a study based on the Rey-Osterrieth Complex Figure Test (ROCFT), which is also commonly used in the assessment of reading and writing disorders [9]. The ROCFT allows for the evaluation of visual memory through a drawing-based recall score. In this study, we developed a three-dimensional version of the ROCFT using a 3D printer and employed it as a haptic learning task. Among the various memory tests available, we selected the Rey-Osterrieth Complex Figure Test (ROCFT) because the Japanese writing system contains a large number of characters, placing a greater demand on visual information processing compared to alphabetic languages. For this reason, the ROCFT is considered to be a valid tool for comprehensively assessing the visual processing abilities involved in Japanese reading and writing. Previous studies have reported that children with reading and writing disorders in Japanese perform significantly worse on the ROCFT recall task compared to typically developing children. Accurate copying and recall in the ROCFT require multiple aspects of visual information processing, such as attention to both parts and the whole of the figure, pattern recognition, visuospatial cognition, and planning—skills also essential for reading and writing.

In this study, we investigated how haptic learning using a three-dimensional version of the ROCFT affects recall drawing performance in healthy adults. The aim was to examine the impact of haptic-based learning on visual memory.

I. Method

1. Participants

This study included 52 healthy adults (16 men and 36 women; mean age = 35.7 years, SD = 9.1). The experiment began with a reproduction task, followed by a relearning phase. During the relearning phase, participants were randomly assigned to one of two groups: a Vision-Haptic (V-H) group that used both visual and haptic modalities ($n = 26$; 8 men and 18 women; mean age = 36.0 years, SD = 8.46), and a Vision (V) group that used only the visual modality ($n = 26$; 8 men and 18 women; mean age = 35.0 years, SD = 9.73). Furthermore, an independent t-test was conducted to compare the drawing performance between the V-H and V groups prior to the recognition task. The results confirmed that there was no significant difference between the two groups ($t(50) = -1.29$, $p = 0.20$, not significant). A previous study by Yamashita et al. [10] assessed 144 healthy Japanese adults across different age groups using the ROCFT, following the standard procedure and scoring method proposed by Osterrieth [11]. The study found no significant differences in performance by gender, and no age-related differences within the age range of 18 to 55. Based on these findings, the present study recruited healthy male and female adults aged 18 to 50 years.

Participants were included only if they had no history or current diagnosis of major neurological or psychiatric disorders. In addition, handedness was assessed using the Japanese version of the FLANDERS Handedness Test [12], and normal haptic sensation of the fingers was confirmed using the SW tester [13]. This study was conducted with the approval of the Ethics Committee for Medical Research Involving Human Subjects at Kyoto University.

2. Experimental Stimuli

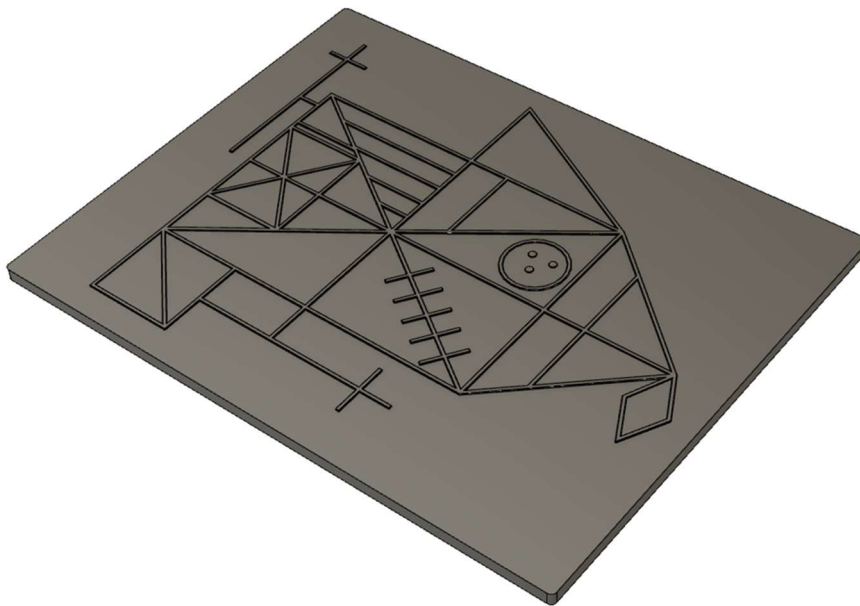


Figure 1. Three-dimensional ROCFT stimuli were created based on the three-dimensional data of ROCFT with a three-dimensional printer.

In this study, a three-dimensional model of the ROCFT was created using 3D design software (Fusion 360, Autodesk Inc.), and a B5-sized haptic version was produced using a 3D printer (see Figure 1). The Rey-Osterrieth Complex Figure Test (ROCFT) is a visual memory test originally developed by the Swiss psychologist Rey in 1941 and later standardized by Osterrieth in 1944 (see Table 1). Participants are first asked to copy the figure while viewing it (copy phase), and then, after a three-minute delay, to reproduce the figure from memory (recall drawing). Visual perception and memory are assessed based on the accuracy of both the shape and the placement in the recall drawing. Higher scores indicate greater accuracy, with a maximum score of 36 points. Because the ROCFT also reflects fine motor skills, executive functioning, and visuospatial abilities, it is often used for screening individuals with learning disabilities [15]. In this study as well, both task administration and scoring were conducted according to the method described by Osterrieth [11].

In addition to the total score on the ROCFT, this study independently classified the figure into three distinct

unit groups based on structural characteristics, and analyzed the scores for each group. The first group, "external units," includes features such as protruding triangles and crosses located along the outer edge of the figure, contributing to the overall shape image. The second group, "internal units," consists of intersecting lines and patterns that form the structural core of the figure. The third group, "detail units," includes small, distinctive components resembling facial features or diamond shapes. Separate scores were calculated for each unit group to examine performance in more detail. This classification was based on the Organization Scoring System (OSS) developed by Chervinsky [16]. The OSS method analyzes construction strategies by cognitively dividing Rey's figure into six sections and evaluating whether each section was drawn as an organized whole. Although construction strategies were not assessed in this study, the OSS-based segmentation was used to reorganize the figure into three unit groups according to their position and features.

According to a study by Hayashi et al. [17] on the readability of Braille for visually impaired individuals, the highest accuracy rate was achieved when the raised dots were 0.5 mm in height. Based on this finding, the raised elements of the three-dimensional ROCFT used in this study were set to a height of 0.5 mm. The lines formed by the raised elements were 1 mm wide and colored black to ensure visibility. Thus, participants were able to perceive the complex figure using either haptic or visual input.

3. Experimental Protocol

1) First ROCFT Recall Drawing

Participants first completed a copy task, in which they drew the figure while viewing the three-dimensional ROCFT model. This was followed by a 3-minute rest period. After the rest, participants were given a blank sheet of paper and asked to reproduce the figure from memory—this was the first recall drawing.

2) Relearning Phase

After the first ROCFT recall drawing, the 52 participants were divided into two groups for the relearning phase. In the V-H group, participants performed the relearning task by observing and simultaneously touching the three-dimensional ROCFT model for three minutes, using the index, middle, and ring fingers together. The use of three fingers was intended to enable haptic perception not only through the fingertips but also through a broader area of the palm. In contrast, the V group engaged in the relearning task by visually observing the 3D ROCFT model for three minutes without haptic input.

3) Second Recall Drawing After Relearning (24 Hours Later)

The second recall drawing was conducted 24 hours after the first, following a period that included sleep.

This interval was chosen based on previous findings that sleep contributes to the consolidation of visual memory (18), with the aim of evaluating the stability of memory after the relearning phase.

4. Analysis Method

1) Performance Changes Between the Two Groups After Relearning

To examine differences in the effects of relearning between the two groups, a two-way repeated measures ANOVA was conducted with "group" (V vs. V-H) and "time of assessment" (pre- vs. post-relearning) as factors. The "time of assessment" was treated as a within-subjects factor. Analyses were performed not only on the total ROCFT score but also on the three subscales: external units, internal units, and detail units. Additionally, to evaluate the effect of relearning within each group, paired t-tests were conducted comparing scores before and after the relearning phase. All statistical analyses were performed using IBM SPSS Statistics version 27.

II. Results

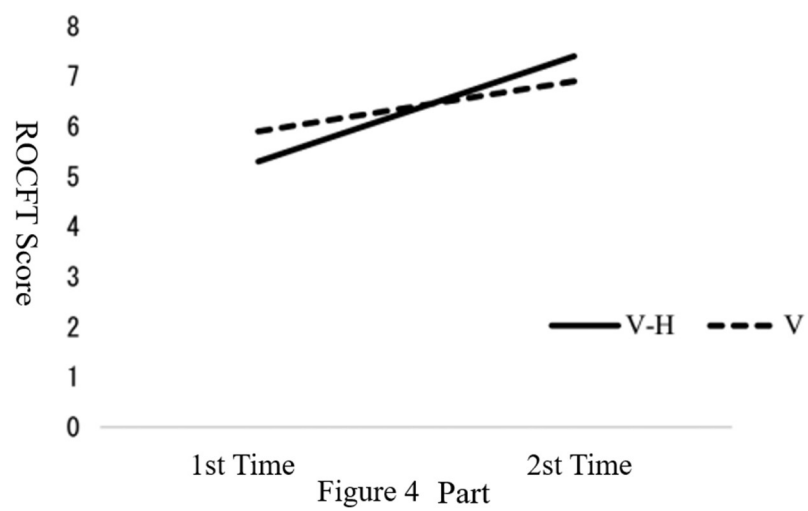
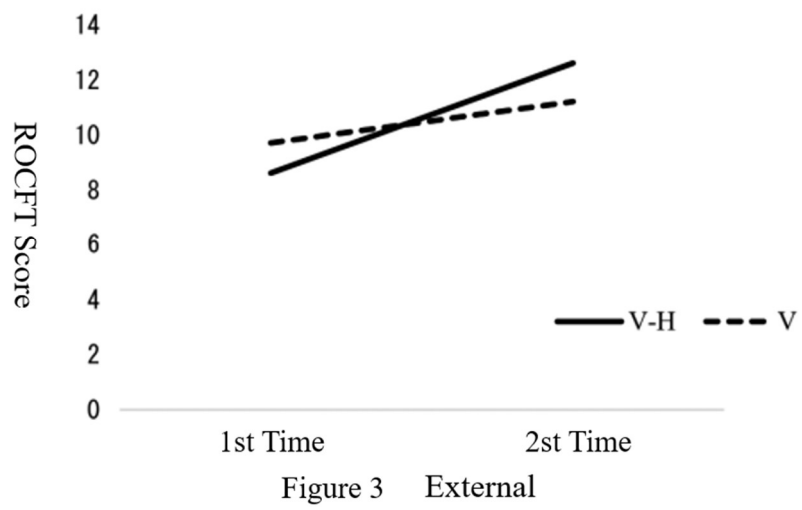
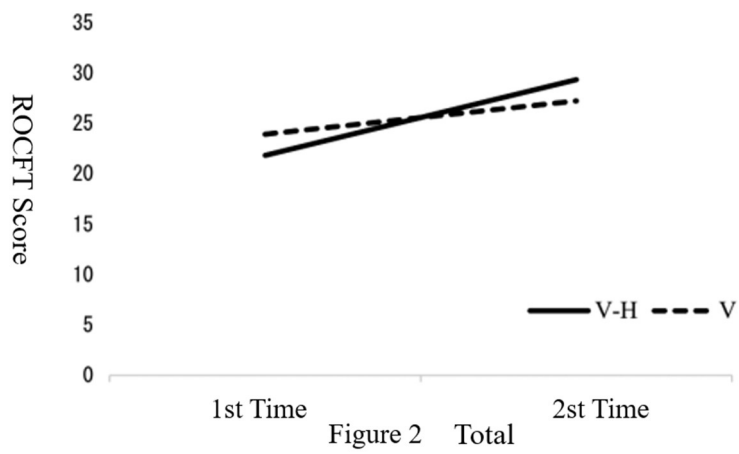
1) Performance Changes Between the Two Groups After Relearning

The results of the two-way repeated measures ANOVA showed a significant interaction for the total score ($F = 13.78$, $p = 0.00$, $p < 0.01$). A significant interaction was also observed for the external units ($F = 10.92$, $p = 0.00$, $p < 0.01$) and the detail units ($F = 5.32$, $p = 0.03$, $p < 0.05$). These findings indicate that the V-H group showed a greater improvement in drawing performance after relearning compared to the V group. However, no significant difference was found for the internal units ($F = 0.95$, $p = 0.34$, $p > 0.05$). Furthermore, paired t-tests comparing performance before and after the relearning phase within each group revealed significant differences in both groups. V-H group: $t(25) = -8.85$, $p = 0.00$ ($p < 0.01$). V group: $t(25) = -4.46$, $p = 0.00$ ($p < 0.01$). These results indicate that both groups showed significant improvement in performance following the relearning task.

Table 1. Two-way analysis of variants between V-group and V-H-group

	V-H ($n=26$)		V ($n=26$)		Interaction (Group $\times$ Evaluation Time)	
	1st Time	2st Time	1st Time	2st Time	F 值	p 值
Total	21.8 (4.2)	29.3 (3.7)	23.9 (6.7)	27.2 (6.5)	13.78	0.00**
External	8.6 (2.1)	12.6 (2.4)	9.7 (3.7)	11.2 (3.4)	10.92	0.00**
Internal	8.4 (1.8)	9.6 (1.5)	8.1 (1.7)	8.9 (1.6)	0.95	0.34
Part	5.3 (1.8)	7.4 (1.5)	5.9 (2.3)	6.9 (2.6)	5.32	0.03*

$p < 0.05^*$ $P < 0.01^{**}$



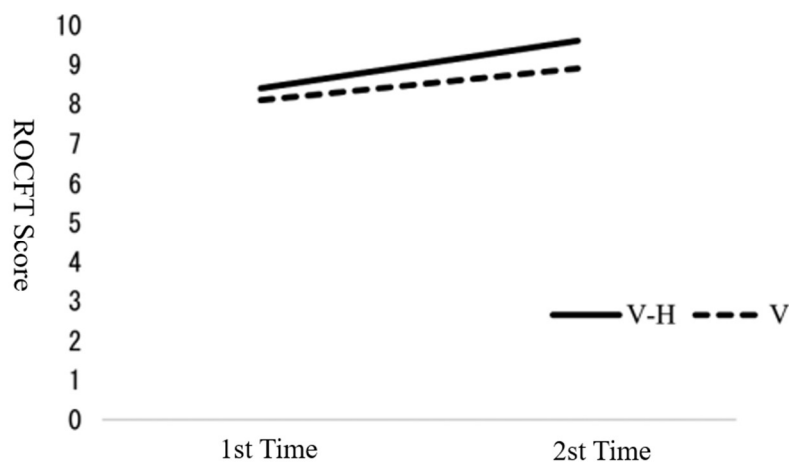


Figure 5 Internal

III. Discussion

The analysis using the custom-developed three-dimensional version of the ROCFT revealed that the learning of complex visual forms was enhanced by concurrent haptic exploration. It is presumed that in the "see-and-touch" learning condition, active haptic perception supported the visual cognitive process. Helbig et al. (4) have reported that the use of both visual and haptic cues enhances the recognition of three-dimensional shapes through cross-modal integration of sensory information. Our findings suggest that multisensory learning—in this case, the combination of visual and haptic input—may promote better memory retention than visual input alone. It is also possible that the inclusion of an active learning component, such as haptic exploration, helped organize complex figure information more effectively during the encoding phase.

Furthermore, the analysis that divided the complex figure into external units, internal units, and detail units revealed that the enhancing effect of haptic exploration on visual memory was observed in the external and detail units. However, no such effect was found for the internal units. The external units constitute the overall outline of the ROCFT figure. Cognitive processing of such outer features of a complex figure requires the ability to direct attention to the entire figure, as well as visuospatial functions for understanding the positional relationships among individual elements within the figure. Such global shape recognition is likely facilitated by tracing the contours of the three-dimensional figure with the hand, making haptic exploration particularly useful. The detail units consist of small, independent forms, and their distinct features and positions can be easily identified through individual haptic contact. In contrast, no significant difference was found between the two groups for the internal units. This may be because internal units are composed of intersecting lines and embedded structural elements that do not naturally attract attention like the outer contours. Recognizing such internal features requires intentional allocation of attention while

suppressing the tendency to focus on more prominent, easily noticeable aspects of the figure. Furthermore, the way in which participants touched the figure may have influenced the results. In this study, the method of touching the three-dimensional ROCFT model with the index, middle, and ring fingers together resulted in a relatively large contact area, likely allowing haptic information such as outer contours and distinctive parts of the figure to be more easily perceived. However, the intricate line structures of the internal units may not have been effectively conveyed through haptic input alone. It is likely that participants needed to rely more on visual information and engage in higher-order processing to comprehend the structural characteristics of these internal elements. Given the tendency of haptic learning to draw less attention to internal structures when relying solely on touch, it is suggested that, in clinical settings, especially when teaching characters with complex internal structures such as kanji, incorporating air-writing (tracing characters in the air with a finger) prior to full haptic learning of the entire character may help direct learners' attention to the internal line components more effectively.

One of the clinical implications of this study is the potential effectiveness of haptic learning for children who have difficulty in visually recognizing and recalling character shapes. Previous research by Ogino et al. [9] also suggests a relationship between reading and writing disabilities and visual memory as assessed by the ROCFT. Moreover, clinical studies involving children with difficulties in written expression—particularly with kanji—have reported reduced performance in recall drawing tasks on the ROCFT when scored using the same Osterrieth method employed in this study [19, 20]. If haptic learning can improve ROCFT drawing performance as demonstrated here, it may also help compensate for weaknesses in visual cognitive processing in children with reading and writing difficulties. Exploratory learning that involves both viewing and touching three-dimensional characters may promote the encoding of character shapes and contribute to improved written expression, especially for complex characters like kanji.

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