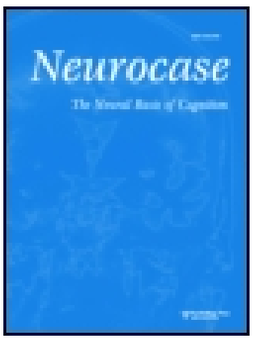

Routledge
Taylor & Francis Group

Neurocase
The Neural Basis of Cognition

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/nncs20

Visual feedback of finger writing in a patient with sensory aphasia: a case report and theoretical considerations

Yoshihiro Itaguchi , Yuho Suzuki , Chiharu Yamada & Kazuyoshi Fukuzawa

To cite this article: Yoshihiro Itaguchi , Yuho Suzuki , Chiharu Yamada & Kazuyoshi Fukuzawa (2020): Visual feedback of finger writing in a patient with sensory aphasia: a case report and theoretical considerations, Neurocase

To link to this article: https://doi.org/10.1080/13554794.2020.1858111

Published online: 07 Dec 2020.

NEUROCASE
https://doi.org/10.1080/13554794.2020.1858111

Routledge
Taylor & Francis Group

Visual feedback of finger writing in a patient with sensory aphasia: a case report and theoretical considerations

Yoshihiro Itaguchi[a], Yuho Suzuki[b], Chiharu Yamada[c] and Kazuyoshi Fukuzawa[c]

[a]Department of Computer Science, Shizuoka University, Hamamatsu, Japan;; [b]Department of Rehabilitation, Tokyo Metropolitan Rehabilitation Hospital, Tokyo, Japan; [c]Department of Psychology, Waseda University, Tokyo, Japan

ABSTRACT

Through cognitive task performance, we examined the functional role of finger writing (kūsho) in a Japanese patient with moderate sensory aphasia and reading difficulties. We hypothesized that the visual feedback of kūsho would improve visual language processing, which we tested with a "kanji construction task" using character subparts. Results showed a higher number of correct responses 1) when the patient used kūsho and 2) when visual feedback of finger movements was available. The results suggest that kūsho may not improve the retrieval of phonological information but does aid the visual processing necessary to assemble character subparts.

ARTICLE HISTORY
Received 11 October 2020
Accepted 26 November 2020

KEYWORDS
word; aphasia; reading; language disorders; visual perception; finger movements; embodied cognition

Introduction

This study investigated the effect of finger movements called *kūsho* ("air writing" in Japanese) on language task performance in a patient with aphasia and reading difficulty. In kūsho, one moves an index finger as a substitute for a pen to recall the shape of written language or the spelling of a word (Endo, 1988; Kess & Miyamoto, 1994; Sasaki, 1987). In a recent study of young (Itaguchi et al., 2015, 2017) and older (Itaguchi et al., 2019) Japanese adults, Itaguchi and colleagues showed that the visual feedback, not the kinesthetic feedback, of kūsho writing contributes to its facilitative effect on recalling the shape of characters. The mechanism underlying this effect on language tasks is, however, not yet clear, and the present study addressed this question by investigating a stroke patient with aphasic symptoms.

The "kanji construction task" is frequently used to investigate the mechanism underlying facilitative effects of finger movements. In such a task, participants try to assemble three kanji sub-parts to form an actual kanji character (Sasaki, 1987). Because visual feedback is important in inducing the facilitation of finger movements during a cognitive task, two studies showed that the number of correct responses was larger when participants engaged in kūsho than when they did not move their fingers or when they made an irrelevant motion such as circle-drawing (Itaguchi et al., 2015, 2017). Importantly, even if participants used kūsho writing, there were no facilitative effects when they did not watch their own movements, that is, when no visual feedback of the finger movements was available. A brain imaging study found involvement of the border area between the inferior parietal lobule and the occipital lobe during a kanji construction task (Matsuo et al., 2001). Another study using a different task reported that neural activity in the dorsal occipitoparietal area and the primary visual area decreased when participants moved their index finger while counting the strokes of a kanji character (Matsuo et al., 2003). These behavioral and brain imaging findings indicate that finger writing movements can help visualize characters (Sasaki, 1987) and decrease neural processing load, which may result in better task performance. However, critical evidence supporting this notion has not yet been provided.

To further clarify the functional role of kūsho behavior, we tested a patient with sensory aphasia, E.E., who showed reading difficulty with the aphasic symptoms after a stroke. In daily situations, she often showed kūsho writing when trying to say the name of an object or to read written Japanese, either the phonetic writing system (kana) or the logographic writing system (kanji). Her brain lesion included the left posterior part of the middle and superior temporal area, the angular gyrus, and the supramarginal gyrus. The posterior part of the superior temporal area seems to be important for retrieval of Japanese phonetic representations (Sakurai et al., 2000), and it is therefore not surprising that E.E. showed reading difficulty. If the functional role of kūsho writing is related to visual processing, as previous studies argued, its benefits would be expected to occur exclusively in visual aspects of language processing. Accordingly, we hypothesized that the visual feedback of kūsho would improve the patient's visual processing, as it does in neurologically intact individuals, but that it would not influence her phonological retrieval processing. We had two alternative possibilities; first, if kūsho writing improves general language processing, reading performance should also improve; and second, if kinesthetic factors of the kūsho movements are the main contributor to facilitation, performance should not vary with the availability of visual feedback. To examine these different possibilities, we carried out a kanji construction task with two visual feedback conditions and three hand conditions, following the paradigms used in previous studies (Itaguchi, Yamada, et al., 2015, 2017, 2019).

CONTACT Yoshihiro Itaguchi itaguchi-y@inf.shizuoka.ac.jp Department of Computer Science, Shizuoka University, Hamamatsu 432-8011, Japan

The present study also has significant relevance to neuropsychological phenomena. Patients with pure alexia use finger tracing actions as an aid in reading letters, characters, or words that they are otherwise unable to read (Bender et al., 1982; Dejerine, 1891; Goldstein, 1948; Kashiwagi & Kashiwagi, 1989; Kim et al., 2011; Landis et al., 1982; Maher et al., 1998). In Japanese patients with pure alexia, the beneficial effects of finger tracing, especially for kana, have been confirmed regardless of whether the lesion area included the splenium (Seki et al., 1995) or not (Sakurai et al., 2006). It has also been reported that a patient with a splenium lesion and alexia could read a character (kana or kanji) only by observing another person's writing action, but not when normally reading the same character (Tanaka et al., 2002). Although the present study did not assess the apparent connections between kūsho and other neuropsychological phenomena, our investigation illustrates the relationship between bodily movement and cognition in terms of brain function.

Methods

Participants

Our primary participant was E.E., a 62-year-old right-handed woman with sensory aphasia. On March XX, 2017, E.E. started having nonsensical conversations with her sister. The next day at noon, she was unable to communicate her own name and was transported to a hospital by ambulance. She was conscious during the transport, but medical staff observed severe sensory aphasia and right hemispatial neglect. A CT scan found an infarct in the left middle cerebral artery territory and damage in the left temporal-parietal area, and she was treated with an anticoagulant. The stroke lesion included the left posterior part of the middle and superior temporal area, the angular gyrus, and the supramarginal gyrus. In April, E.E. was moved to another hospital for language rehabilitation. She did not receive any special therapies for reading and writing. In June, after providing written informed consent, she took part in our experiments 1 and 2. The study and consent procedures were approved by the Ethics Committee on Human Research of Waseda University (No. 2018–051).

Neurological and neuropsychological observations

At stroke onset, the patient's sensory aphasia was so severe that conversation was not possible. However, her general cognitive abilities and activities of daily living (ADL) were well preserved, without any memory problems. She showed good comprehension of situations and others' intentions, and communication was therefore possible and generally smooth through nonverbal cues. The patient did not show sensorimotor dysfunctions, and she walked independently in and out of the hospital. Two and a half months after stroke onset, when she participated in this study, the patient's sensory aphasia had recovered to a moderate level, and there were no signs of apraxia, agnosia, or hemispatial neglect. Her speech was fluent, but she showed impaired comprehension and poor word retrieval. She frequently demonstrated spontaneous use of kūsho during conversations, when trying to name objects, and in reading and writing characters and words on clinical tests. She sometimes, but not always, watched her finger movements.

Neuropsychological tests

The patient's Raven's Colored Progressive Matrices score was 31/36, above the average for healthy older adults (the average score for 60–69-year-old adults is 29.2, SD = 5.4), indicating preserved general intelligence and reasoning abilities. No problems were found on the line cancellation (40/40) or bisection task, or in line drawing or copying, although her figures looked slightly deformed. On the Standard Language Test of Aphasia (SLTA), a Japanese comprehensive aphasia test, she failed "following a verbal order," "sentence repetition," "scene description in writing," and "writing a short sentence" at the time of the experiment. Writing and copying characters was fluent, and her writing difficulty seemed to be explained by her aphasic symptom. Although she scored 100% for reading characters and hiragana and kanji words on the SLTA, she consistently complained about not being able to read or producing words. She did not show no specific error pattern both in reading and writing of characters or words in clinical tests.

We also assessed the patient's kanji reading abilities and vocabulary size using "100 RAKAN" (Amano & Kondo, 1998), comprising 100 items related to kanji two-character word reading. E.E.'s score was 34, lower than the minimum score for the reference group (88.0 years old on average; Itaguchi et al., 2019); their average score was 67.6 (SD = 20.4, range = 37–91). The average score for Japanese university students was 55.1 (SD = 14.8, n = 1407) in Amano and Kondo (1998) and 68.5 (SD = 9.5, n = 96) in Itaguchi et al. (2017). Note that this test was conducted when E.E. came to the hospital as an outpatient in October (199 days after stroke onset and 120 days after experiment 1). At this time, although she showed improved language abilities compared to when she left the hospital, she still showed sematic and phonetic paraphasia.

Kanji construction task

The procedures of the kanji construction task (Figure 1A, B) followed those of previous studies (Itaguchi et al., 2015, 2017; Itaguchi, Yamada, et al., 2019; Sasaki, 1987), but the task was slightly modified to take into account E.E.'s neuropsychological disabilities. Usually participants are asked to verbally report the kanji character that they mentally construct. However, E.E. sometimes could not answer verbally because of her symptoms, even when she came up with the correct figure in her mind. Accordingly, we allowed her to answer by writing the character down only when she was unable to remember how to read it out but was confident about her answer (Figure 1c); we did not encourage her to answer in writing, and only one and immediate writing answer was accepted for a trial. Therefore, we obtained two types of correct responses: responses that were auditorily matched to the pronunciation of the original kanji, and responses that were visually matched to the shape of the original kanji. Since the second type of correct response was allowed only after E.E. gave up on a verbal response, we separately counted the correct responses for the two types

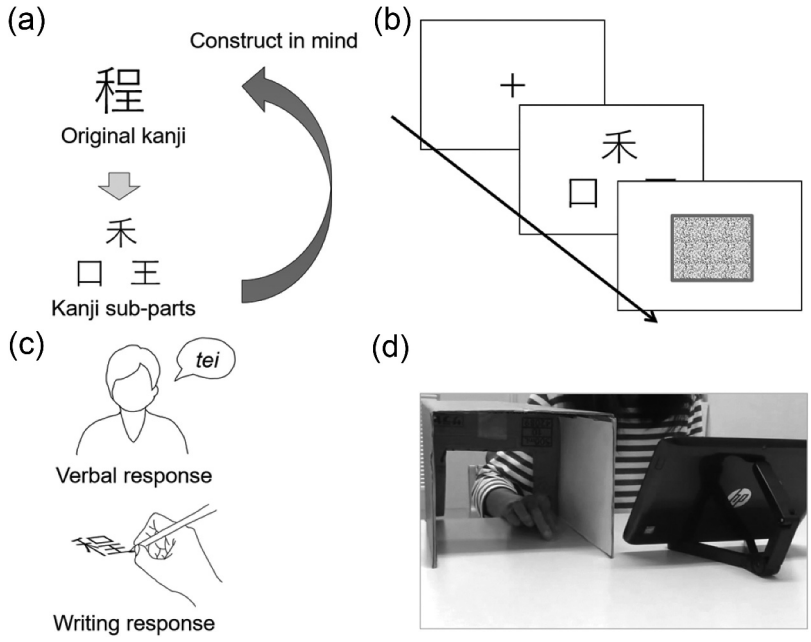

Figure 1. **Experimental stimuli, sequence, response methods, and scene**. An example of an original kanji character and its sub-parts (a). The participant tried to assemble one original character from three decomposed sub-parts presented in a triangle arrangement (b). E.E. was asked to verbally communicate the original kanji (c, top), and she was also allowed to answer by writing the character, but only when she was unable to read out the character in her mind (c, bottom). An example of an experimental scene of E.E. trying to accomplish the task in the kūsho and eye-on-display condition (d).

of responses. There were no ambiguous responses that were difficult to judge whether the response was correct or not. Furthermore, the answer time was changed to 30 s to accommodate E.E.'s disabilities. The experiment was conducted by a speech therapist, one of the coauthors (Y.S.). We used a computer display to present visual stimuli and videorecorded E.E.'s responses throughout the experiment. She was able to understand all instructions.

We used three hand conditions to examine the facilitative effect of kūsho on kanji construction task performance (Itaguchi, Yamada, et al., 2015, 2017, 2019). In the "kūsho condition," E.E. moved her right index finger freely on a table as if writing and was encouraged to use kūsho to solve the task. In the "static condition," she kept her right hand clenched on the table and was not allowed to move any fingers. In the "circle-drawing condition," she made continuous circular motions with her right index finger. The static condition was a control condition, as it did not involve motor planning or visually or kinematically meaningful feedback. The circle-drawing condition was introduced to eliminate the possibility that simply moving a finger while thinking improves task performance.

There were two visual conditions. In the "eye-on-hand condition," to elicit the facilitative effect of kūsho E.E. was instructed to watch her right index finger during a trial as much as possible. In the "eye-on-display condition," she was asked to watch the display, and her right hand was covered with a box to prevent her from seeing it (Figure 1D).

We conducted two separate experiments with unbalanced experimental conditions (see Table 1). In experiment 1, only the eye-on-hand condition was presented, combined with three hand conditions (10 trials in each block), to test the facilitative effect of kūsho. In experiment 2, we tested the role of visual feedback of finger movements, using only the kūsho condition combined with two types of visual conditions (12 trials in each block). Before starting the main experiment, E.E. performed several practice trials without any instructions, to observe whether she spontaneously used kūsho during the task. We then explained the experimental conditions to her, and she again had several practice trials.

Stimulus

We used 54 stimuli adopted from the controlled sets of previous studies (for details, see Itaguchi et al., 2017). All kanji characters used in the study are learned in Japanese primary school and can be broken down into three sub-parts. For the blocked conditions in each experiment, we controlled the percentage of correct responses using the performance of older adults without neurological and neuropsychological dysfunctions (n = 12, average age = 88.0, (SD = 6.2), average MMSE score = 26.1 (SD = 2.9)). The sets of stimuli were randomly

Table 1. Differences between experiments 1 and 2.

	Experiment 1	Experiment 2
Visual conditions	Eye-on-hand	Eye-on-hand and Eye-on-display
Hand conditions	Kūsho, Static, and Circle-drawing	Kūsho
Number of stimuli	10 in each block	12 in each clock
Average correct responses for healthy older adults*	24.2% (9.8), 25.0% (9.9), and 22.5% (11.5)	6.6% (9.8) and 6.3% (4.7)

* The value in parenthesis is a standard deviation.

assigned to each blocked condition (Table 1). We did not use kana in the experiment because almost all of kana does not have sufficient parts to break down, and the task difficulty cannot be controlled.

Results

E.E. always showed spontaneous kūsho writing during each of five practice trials before receiving instructions regarding the experimental conditions. In experiment 1, all trials were eye-on-hand conditions. The total number of correct responses was 6, 4, and 5 for the kūsho, static, and circle-drawing conditions, respectively (Figure 2A), and the number of correct written responses was 3, 1, and 1. The maximum score (i.e., the number of trials) in each condition was 10. In experiment 2, all trials were kūsho conditions. The total number of correct responses was 8 and 5 in the eye-on-hand and eye-on-display conditions, respectively (Figure 2B), and the number of correct written responses was 5 and 2. The maximum score in each condition was 12. While the numbers of correct responses were higher than the standard for healthy older adults (about 20% and 6% in experiments 1 and 2, respectively), E.E.'s time limit was 30 s, compared to 10 s for healthy individuals. In both experiments, there were no paraphasic errors in verbal and written responses. Her writing responses were fast and smooth without hesitation and errors. The detailed results of the experiments were provided as supplementary information.

Discussion

The present study offers three novel findings. First, we confirmed that even a patient with aphasic symptoms used kūsho spontaneously to solve a language task, which has been observed in daily clinical settings in Japan but never formally tested. Second, we observed, for the first time, a facilitative effect of the visual feedback of kūsho writing on language task performance in a patient with aphasia. Third and most importantly, in our patient, the visual feedback of her kūsho behavior seemingly had an impact on her written rather than her verbal responses. This finding agrees with our hypothesis that kūsho aids the visual processing necessary to accomplish a kanji construction task but does not interact with the retrieval of phonetic representations of characters. These results are generally consistent with previous reports that found facilitative effects in kūsho visual feedback on the kanji construction task (Itaguchi et al., 2015, 2017; Sasaki, 1987), suggesting that substituting finger action for a pen provides limited but reliable benefits for language processing, even in individuals with language difficulties.

The role of visual feedback in the kūsho effect

We attribute the kūsho effect observed in E.E. to her moving her finger as if writing, as task performance in the circle-drawing condition was slightly lower than that in the kūsho condition in experiment 1. This observation is not evidence, given that only one patient participated in this experiment, we did not apply any statistical tests, and the difference in the numbers of correct responses was small. However, we also observed that, as expected, the patient's task performance in the kūsho condition was better with visual feedback than without. These results are consistent with our hypothesis that the visual feedback of kūsho, not kinesthetic feedback or mere finger movement, improves task performance, (Itaguchi et al., 2015, 2017).

Our most interesting finding was that the patient's use of kūsho apparently influenced only her written responses. Considering her number of verbal responses, the increase in her written responses was large. It is likely that visual feedback increased the number of correct written responses, which were only provided when E.E. could not read the original kanji character after she successfully came up with its configuration. This suggests that kūsho may aid in retrieving the visual image but not the auditory information of the original character, supporting previous findings from neurologically healthy individuals (Itaguchi et al., 2015, 2017). The success of writing correct characters whose reading could not be retrieved can be explained by considering her aphasic symptom and by assuming that the retrieval process of phonological information is independent of the process required for visual construction of a character. It is also important that smooth writing and copying was achieved based on the visual image of a character in her daily situation, which implies that the association between kinesthetic (or motoric) and visual representations of characters was preserved.

The present experiments, however, cannot exclude other interpretations of the results. First, the number of correct responses was higher in the circle-drawing condition than in the static condition, suggesting that circular finger movements also facilitated task performance. Furthermore, since we had no condition that tested the effects of visual feedback of circular motion, we cannot judge a possible effect of the visual feedback of irrelevant motion on language processing in patients with aphasia. Second, the possibility that kūsho plays a role in

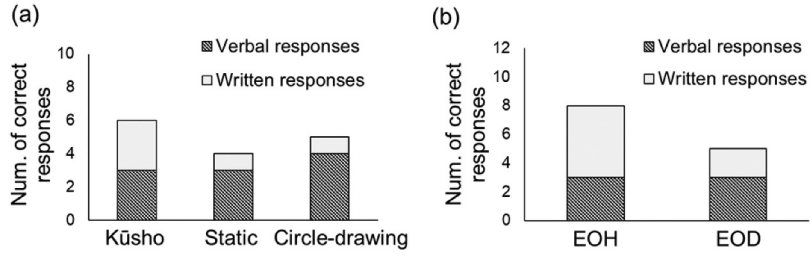

Figure 2. **E.E.'s results on the kanji construction task**. Experiment 1 consisted only of the eye-on-hand visual condition (a), and experiment 2 consisted only of the kūsho hand condition (b). The maximum score was 10 and 12 in experiments 1 and 2, respectively. EOH: eye-on-hand condition. EOD: eye-on-display condition.

memory retention during visual processing, which was not true in a previous study, was not investigated in this patient (Itaguchi et al., 2015). Although these possibilities have been considered when studying large numbers of healthy young volunteers, we have results from only the one patient participating in this study. A higher number of participants with aphasia is thus needed to confirm these findings.

Language dysfunctions and finger movements

This is the first study reporting that the visual feedback of kūsho aids language task performance in a patient with aphasia. Similar psychological phenomena (called "kinesthetic reading" of "Schreibendes Lesen," i.e., writing reading), where finger tracing of letters or characters contributed to the retrieval of a phonetic representation of written language, have been reported in patients with pure alexia without agraphia (Dejerine, 1891; Goldstein, 1948; Ihori et al., 2000; Kashiwagi & Kashiwagi, 1989; Maher et al., 1998). In usual kinesthetic reading, a patient watches their finger while tracing a letter or character and obtains some benefits from the action, which does not contradict previous and current findings that visual feedback of finger movements is important for the facilitative effect of finger writing (Itaguchi et al., 2015, 2017). While the literature has focused on kinesthetic information related to language as an underlying mechanism of finger action helping patients with pure alexia while reading (Kashiwagi & Kashiwagi, 1989; Kim et al., 2011; Lott et al., 1994; Potagas et al., 2017; Seki et al., 1995), the present results suggest that the visual feedback of the movements might play a certain role in kinesthetic reading. Many studies have suggested that the impact of current visual feedback is so strong that it could invoke automatic motor action (e.g., Brass et al., 2001; Fadiga et al., 1995; Itaguchi & Kaneko, 2018) and alter the sensorimotor coordination established throughout one's life (e.g., Itaguchi & Fukuzawa, 2019; Krakauer, 2009). E.E.'s primary symptoms were impaired sematic comprehension, poor word retrieval, and reading difficulties; she did not, however, show impairments of general intelligence, reasoning ability, sensorimotor function, or visual processing, which might be important for her benefiting from kūsho. Although the present study cannot address the relation between the facilitative effect of kūsho and the possible decrease in neural load in the visual area proposed by previous studies (Itaguchi et al., 2015; Matsuo et al., 2003), this notion is not contradicted by the current findings. In future studies, finger writing in clinical settings should also be examined by appropriately dissociating its kinesthetic and visual factors, both to clarify the mechanism underlying the relation between bodily movement and cognitive processing and to improve the efficiency of clinical rehabilitation.

While the effects of finger movements on task performance may stem from a tight coupling between visual and kinetic representations in written languages (Bartolomeo et al., 2002; Longcamp et al., 2003; Tanaka et al., 2002; Yim-Ng et al., 2000), there is a critical difference between the current and previous studies, as E.E.'s finger movements did not improve her reading performance. This can probably be explained by differences in lesions and symptoms. E.E. did not have pure alexia but aphasia with reading difficulties. While her brain lesion included the posterior part of the superior temporal area, important for the retrieval of phonetic representations in the Japanese language system (Sakurai et al., 2000), the lesions responsible for pure alexia are reported to be the medial occipital area and the splenium (Geschwind, 1965; Ohno et al., 2002; Potagas et al., 2017; Seki et al., 1995), the fusiform gyrus (BA 37), or the posterior part of the inferior occipital area (BA18/19) (Rosazza et al., 2007; Sakurai et al., 2006). Furthermore, benefits from trace reading are usually more evident for kana than for kanji (Sakurai et al., 2006; Seki et al., 1995), but we only used kanji. Our patient, whose main symptom was sensory aphasia and whose brain lesions included other areas than those responsible for pure alexia, benefited only when searching for a visual image of a kanji character but not when retrieving the character's phonetic representation from finger movements.

Researching the underlying mechanism of finger movements executed intentionally or unintentionally in daily life may have many applications. Trace reading is effective in rehabilitation of patients with alexia (Kashiwagi & Kashiwagi, 1989; Kim et al., 2011; Seki et al., 1995). Seki et al. (1995) showed that after a long and intensive practice of kinesthetic reading, a patient with alexia improved his reading and showed generalization to unpracticed characters, even when they were presented very briefly using a tachistoscope (200 ms) that did not allow the patient to trace them, indicating that tracing movements can be internalized. Thomas (2015) reported that kūsho improved kanji learning in second-language learners of Japanese. In addition to language processing, finger movements are known to assist arithmetic problem solving (e.g., Michaux et al., 2013) and counting (Itaguchi et al., 2015). However, in this study, although E.E. often used kūsho when she tried to say the name of an object or to read characters, finger movements did not help her to retrieve the auditory information of the characters in the kanji construction experiment. This may be consistent with the notion that the origin of kūsho behavior should be separated from its functional roles (Itaguchi et al., 2015); kūsho behavior is employed as a "habit" more than an action that is always expected to improve task performance. Considering her reading difficulty and the previous finding that kūsho behavior is common in Japanese, especially for older adults (Itaguchi et al., 2015, p. 2019), it is reasonable and natural to move her finger in a daily situation. To establish a way of improving clinical and educational applications for individuals with reading difficulties, we must carefully assess the effects of finger movements on cognitive tasks by isolating entangled variables. Progress of the understanding of these effects may allow us to improve the efficiency of reading rehabilitation, not only in patients with stroke but also in second-language learners and children with dyslexia.

Disclosure statement

There are no relevant financial or non-financial competing interests to report.

Funding

This work was supported by JSPS KAKENHI [grant numbers 18K03188, 18K13372, 20K21831].

ORCID

Yoshihiro Itaguchi http://orcid.org/0000-0002-2033-2171

References

Amano, S., & Kondo, T. (1998). *Estimation of mental lexicon size with word familiarity database*. (Ed.),^(Eds.).. ICSLP.

Bartolomeo, P., Bachoud-Lévi, A.-C., Chokron, S., & Degos, J.-D. (2002). Visually-and motor-based knowledge of letters: Evidence from a pure alexic patient. *Neuropsychologia*, *40*(8), 1363–1371. https://doi.org/10.1016/S0028-3932(01)00209-3

Bender, M. B., Stacy, C., & Cohen, J. (1982). Agraphesthesia: A disorder of directional cutaneous kinesthesia or a disorientation in cutaneous space. *Journal of the Neurological Sciences*, *53*(3), 531–555. https://doi.org/10.1016/0022-510X(82)90249-0

Brass, M., Bekkering, H., & Prinz, W. (2001). Movement observation affects movement execution in a simple response task. *Acta psychologica*, *106*(1), 3–22. https://doi.org/10.1016/S0001-6918(00)00024-X

Dejerine, J. (1891). Sur un cas de cécité verbale avec agraphie suivi d'autopsie. *Mémoires de la Société de Biologie*, *3*, 197–201.

Endo, Y. (1988). The role of a motoric aspect of representation: Spontaneous writing-like behavior in Japanese. *Practical Aspects of Memory: Current Research and Issues*, *2*, 459–463.

Fadiga, L., Fogassi, L., Pavesi, G., & Rizzolatti, G. (1995). Motor facilitation during action observation: A magnetic stimulation study. *Journal of Neurophysiology*, *73*(6), 2608–2611. https://doi.org/10.1152/jn.1995.73.6.2608

Geschwind, N. (1965). Disconnexion syndromes in animals and man. *Brain*, *88*(3), 585. https://doi.org/10.1093/brain/88.3.585

Goldstein, K. (1948). *Language and language disturbances; aphasic symptom complexes and their significance for medicine and theory of language*. Grune & Stratton.

Ihori, N., Kawamura, M., Fukuzawa, K., & Kamaki, M. (2000). Somesthetic disconnection syndromes in patients with callosal lesions. *European Neurology*, *44*(2), 65–71. https://doi.org/10.1159/000008199

Itaguchi, Y., & Fukuzawa, K. (2019). Adaptive changes in automatic motor responses based on acquired visuomotor correspondence. *Experimental Brain Research*, *237*(1), 147–159. https://doi.org/10.1007/s00221-018-5409-x

Itaguchi, Y., & Kaneko, F. (2018). Motor priming by movement observation with contralateral concurrent action execution. *Human Movement Science*, *57*, 94–102. https://doi.org/10.1016/j.humov.2017.11.007

Itaguchi, Y., Yamada, C., & Fukuzawa, K. (2019). Writing in the air: Facilitative effects of finger writing in older adults. *PloS One*, *14*(12), e0226832. https://doi.org/10.1371/journal.pone.0226832

Itaguchi, Y., Yamada, C., & Fukuzawa, K. (2015). Writing in the air: Contributions of finger movement to cognitive processing. *PloS One*, *10*(6), e0128419. https://doi.org/10.1371/journal.pone.0128419

Itaguchi, Y., Yamada, C., Yoshihara, M., & Fukuzawa, K. (2017). Writing in the air: A visualization tool for written languages. *PloS One*, *12*(6), e0178735. https://doi.org/10.1371/journal.pone.0178735

Kashiwagi, T., & Kashiwagi, A. (1989). Recovery process of a Japanese alexic without agraphia. *Aphasiology*, *3*(1), 75–91. https://doi.org/10.1080/02687038908248977

Kess, J. F., & Miyamoto, T. (1994). *Japanese psycholinguistics: A classified and annotated research bibliography* (Vol. 24). John Benjamins Publishing.

Kim, E. S., Rapcsak, S. Z., Andersen, S., & Beeson, P. M. (2011). Multimodal alexia: Neuropsychological mechanisms and implications for treatment. *Neuropsychologia*, *49*(13), 3551–3562. https://doi.org/10.1016/j.neuropsychologia.2011.09.007

Krakauer, J. W. (2009). *Motor learning and consolidation: The case of visuomotor rotation (Progress in motor control* (pp. 405–421). Springer.

Landis, T., Graves, R., Benson, F., & Hebben, N. (1982). Visual recognition through kinaesthetic mediation. *Psychological Medicine*, *12*(3), 515–531. https://doi.org/10.1017/S0033291700055616

Longcamp, M., Anton, J.-L., Roth, M., & Velay, J.-L. (2003). Visual presentation of single letters activates a premotor area involved in writing. *Neuroimage*, *19*(4), 1492–1500. https://doi.org/10.1016/S1053-8119(03)00088-0

Lott, S. N., Friedman, R. B., & Linebaugh, C. W. (1994). Rationale and efficacy of a tactile—kinaesthetic treatment for alexia. *Aphasiology*, *8*(2), 181–195. https://doi.org/10.1080/02687039408248650

Maher, L. M., Clayton, M. C., Barrett, A. M., Schober-Peterson, D., & Rothi, L. J. G. (1998). Rehabilitation of a case of pure alexia: Exploiting residual abilities. *Journal of the International Neuropsychological Society*, *4*(6), 636–647. https://doi.org/10.1017/S1355617798466128

Matsuo, K., Kato, C., Okada, T., Moriya, T., Glover, G. H., & Nakai, T. (2003). Finger movements lighten neural loads in the recognition of ideographic characters. *Cognitive Brain Research*, *17*, 263–272. https://doi.org/10.1016/S0926-6410(03)00114-9

Matsuo, K., Kato, C., Tanaka, S., Sugio, T., Matsuzawa, M., Inui, T., Moriya, T., Glover, G. H., & Nakai, T. (2001). Visual language and handwriting movement: Functional magnetic resonance imaging at 3 tesla during generation of ideographic characters. *Brain Research Bulletin*, *55*(4), 549–554. https://doi.org/10.1016/S0361-9230(01)00564-0

Michaux, N., Masson, N., Pesenti, M., & Andres, M. (2013). Selective interference of finger movements on basic addition and subtraction problem solving. *Experimental Psychology*, *60*(3), 197–205. https://doi.org/10.1027/1618-3169/a000188

Ohno, T., Takeda, K., Kato, S., & Hirai, S. (2002). Pure alexia in a Japanese-English bilingual: Dissociation between the two languages. *Journal of Neurology*, *249*(1), 105–107. https://doi.org/10.1007/PL00007837

Potagas, C., Kasselimis, D., Peppas, C., Alexandri, N.-M., & Dellatolas, G. (2017). Pure alexia in a patient with multiple sclerosis. *Neurological Sciences*, *38*(3), 511–513. https://doi.org/10.1007/s10072-016-2739-y

Rosazza, C., Appollonio, I., Isella, V., & Shallice, T. (2007). Qualitatively different forms of pure alexia. *Cognitive Neuropsychology*, *24*(4), 393–418. https://doi.org/10.1080/02643290701377877

Sakurai, Y., Momose, T., Iwata, M., Sudo, Y., Ohtomo, K., & Kanazawa, I. (2000). Different cortical activity in reading of Kanji words, Kana words and Kana nonwords. *Cognitive Brain Research*, *9*(1), 111–115. https://doi.org/10.1016/S0926-6410(99)00052-X

Sakurai, Y., Yagishita, A., Goto, Y., Ohtsu, H., & Mannen, T. (2006). Fusiform type alexia: Pure alexia for words in contrast to posterior occipital type pure alexia for letters. *Journal of the Neurological Sciences*, *247*(1), 81–92. https://doi.org/10.1016/j.jns.2006.03.019

Sasaki, M. (1987). Why do Japanese write characters in space? *International Journal of Behavioral Development*, *10*(1), 135–149. https://doi.org/10.1177/016502548701000201

Seki, K., Yajima, M., & Sugishita, M. (1995). The efficacy of kinesthetic reading treatment for pure alexia. *Neuropsychologia*, *33*(5), 595–609. https://doi.org/10.1016/0028-3932(94)00138-F

Tanaka, S., Katayama, M., Ozawa, T., & Inui, T. (2002). A case of pure alexia who can read letters by observing others' writing action. *Japanese Journal of Neuropsychology*, *18*(2), 68–75.

Thomas, M. (2015). Air writing as a technique for the acquisition of Sino-Japanese characters by second language learners. *Language Learning*, *65*(3), 631–659. https://doi.org/10.1111/lang.12128

Yim-Ng, R. V., Andrade, J., & Jackie Andrade, Y. Y. (2000). Contribution of finger tracing to the recognition of Chinese characters. *International Journal of Language and Communication Disorders*, *35*(4), 561–571. https://doi.org/10.1080/136828200750001296