Effects of visual terminal feedback on hand dexterity in relation to visuospatial ability in patients with subacute stroke: A preliminary study

Jun Yabuki

j.yabuki@mejiro.ac.jp

Mejiro University

Tatsuya Kaneno
Tokyo Metropolitan University

Ryohei Yamamoto
Kumamoto Health Science University

Kazuto Yamaguchi
Nihon Institute of Medical Science

Wataru Nakano
Tokoha Gakuen University

Kazunori Akizuki
Mejiro University

Research Article

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Abstract

Background

Hand dexterity impairments in patients with stroke reduce activities of daily living (ADL) and quality of life. Task-specific training with feedback (FB) for stroke rehabilitation have yielded inconsistent results on enhancing motor learning among stroke survivors. Furthermore, visuospatial ability is associated with motor learning, but this has not previously been reported in patients with subacute stroke. Therefore, we aimed to investigate whether visual terminal FB affects motor learning of hand dexterity, as well as the relationship among motor function, visuospatial ability, and motor learning, in patients with subacute stroke.

Methods

Seventeen patients (age: 66.1 ± 13.8 years) with subacute stroke who had mild upper limb motor impairment were included in this study. The experimental task was to adjust the force control task. The visuospatial task was the Rey–Osterrieth Complex Figure Test (ROCFT). The experimental protocol was conducted on 2 consecutive days, with day 1 consisting of a pre-test (PRE), practice, and short-term retention test (SRT), and day 2 consisting of a long-term retention test (LRT) and the ROCFT. The difference between the target grasping force and the measurement results (grasping error) was assessed as the dependent variable, as a measure of motor learning, using the Friedman test and post hoc test. Spearman's rank correlation analysis was used to evaluate correlations of the grasping error in each test, motor function (by Fugl–Meyer assessment of the upper extremity and action research arm test), and copy, organization, and recall ROCFT scores.

Results

Grasping error significantly decreased in the SRT and LRT compared with the PRE values. Furthermore, no significant correlation was found between motor function and performance on each test, whereas significant moderate negative correlations were found between copy and recall scores and performance on LRT (ρ = -0.51 and -0.53, respectively).

Conclusion

Our findings indicate that visual terminal FB improved hand dexterity in patients with subacute stroke who had mild upper-limb motor impairment. Visual ability was an important factor associated with motor learning. Future studies should use visual terminal FB and consider the establishment of training programs for visuospatial ability in stroke rehabilitation.
Background

The incidence of stroke is increasing worldwide and adversely affects many patients [1]. Approximately 85% of stroke survivors experience motor paralysis of the upper extremities, and 50% still have residual motor deficits more than 6 months after onset [2]. In particular, they have difficulty improving movements that require hand dexterity, such as manipulating objects and grasping. Such reduced hand activity in daily life results in reduced activities of daily living (ADLs) and quality of life [3]. Pennati et al. [4] investigated changes in the sensorimotor function and precision grasping ability of the upper extremities and hands over a 6-month period after stroke and found that even patients with stroke with improved sensorimotor function remained impaired in precision grasping. Patients with stroke have impaired hand coordination of the paralyzed upper extremity, when performing actions such as grasping objects and using tools, which can lead them to avoid using the paralyzed upper extremity and to compensate for this by using the non-paralyzed upper extremity, causing learned non-use of the paralyzed upper extremity [5]. Therefore, establishing training using coordinated movements of the paralyzed hand is important for improving hand dexterity in patients with stroke.

Task-specific training is a common strategy for improving hand coordination in patients with stroke [6]. Task-specific training is used to improve motor skills in tasks based on real-life environmental conditions. In a systematic review of task-oriented training components for upper extremity and hand motor skills in patients with stroke, Timmermans et al. [6] reported that feedback (FB) on performance has a strong therapeutic effect. FB facilitates motor learning and can be classified into two main categories: intrinsic and extrinsic. Intrinsic FB represents sensory information that individuals obtain from their own movement, whereas extrinsic FB represents information provided externally as instructions about movement results, such as knowledge of results (KR) and knowledge of performance (KP) [7]. Extrinsic FB includes various FB strategies, such as the timing and frequency of FB provision. Previous randomized controlled trials have focused on upper-limb and hand motor function in patients with subacute stroke and have compared the improvement of motor function in conditions with and without task-oriented training. However, the details of FB strategies, such as frequency and timing of FB, are unknown [8–10]. In a previous study focusing on the effects of FB on upper-limb motor learning and hand coordination, 37 patients with chronic stroke were classified into three different FB conditions (KR, KR + KP, and No-KR) and their performance on a finger-reaching task using the paralyzed upper limb was compared. The KR and KR + KP groups showed greater improvement than the No-KR group in terms of movement accuracy and movement time reduction at post-test (after 2 weeks) and retention test (after 1 month) [11]. Furthermore, a previous study comparing the performance of 28 patients with chronic stroke in two different FB conditions (KR and KR + KP groups) on a finger-reaching task showed that only the KR + KP condition improved motor patterns [12]. However, negative effects of extrinsic FB on patients with chronic stroke have also been reported. A study of the effects of FB and no-FB conditions on motor learning in an upper-limb tracking task in patients with chronic stroke showed that motor learning was inhibited in the FB condition [13, 14]. In summary, there is no consistent consensus on FB strategies to enhance motor learning of the upper extremities and hand coordination in patients with subacute and chronic stroke.
In addition, visuospatial ability has also recently attracted attention as a factor that enhances motor learning [15–18]. Visuospatial ability is an important component that includes a variety of cognitive functions that aid the encoding of visual images [19] and are involved in integrating the location of oneself with objects and tools. In particular, the superior and inferior parietal lobes have been shown to be responsible for this function in brain regions [20].

Neuropsychological assessments, such as the Montreal Cognitive Assessment (MoCA), Mental Rotation (MR), and the Rey–Osterrieth Complex Figure Test (ROCFT) have been used to assess visuospatial ability [21]. In particular, the ROCFT has been found to be an important predictor of motor learning capacity in older individuals [15, 18]. Furthermore, VanGilder et al. [16] validated a predictive model of motor learning in patients with chronic stroke and showed that the ROCFT scores were a factor in constructing a well-fitting model. However, the relationship between visuospatial ability and motor learning in patients with subacute stroke (< 6 months) remains unclear because the patients in the study by VanGilder et al. were in the chronic phase (mean time since onset: 3.8 years), were younger (mean age: 58.4 years) than the cohort in the present study, and the number of cases was small (n = 7). Investigation of this relationship could indicate that visuospatial ability is an important component of hand coordination rehabilitation in patients with stroke during the recovery phase.

We hypothesized that the use of visual terminal FB in patients with stroke would improve the ability to adjust the grasping force, even in patients with motor impairments. We also hypothesized that the relationship between visuospatial ability and motor learning in patients with stroke would be positive, with higher visuospatial ability correlating with higher motor learning ability. Thus, as a preliminary study, we aimed to clarify FB strategies that enhance the motor learning of hand coordination and to determine the relationship between visuospatial ability and motor learning in patients with subacute stroke.

**Methods**

**Participants**

This study was conducted at Ibaraki Prefectural University Hospital, which has a convalescent rehabilitation ward [22]. All patients were diagnosed with stroke by their previous physician and transferred to Ibaraki Prefectural University Hospital for rehabilitation, where physical therapy, occupational therapy, and speech therapy were initiated. Patients admitted to the hospital between July 2021 and August 2022 were consecutively screened, and one of the authors obtained informed consent from each patient to participate in the study. The sample size was based on Riga et al. [23], who set up an experimental design similar to this study, as there are no previous studies using the same experimental design. The inclusion and exclusion criteria for this study were set according to those described by Tabu et al. [24]. The inclusion criteria were as follows: 1) ability to understand verbal instructions; 2) absence of any disease that interfered with task performance, such as hand pain; 3) mild motor paralysis in the paralyzed upper limb and fingers (Brunnstrom recovery stage 4 or higher); 4) ability to extend the wrist joint on the paralyzed side by 20° or more voluntarily; 5) ability to extend the proximal interphalangeal
joints and metacarpophalangeal joints of the first to third fingers voluntarily by at least 10° on the paralyzed side; and 6) ability to sit independently. The exclusion criteria were as follows: 1) previous experience with a similar task, 2) orthopedic or neurological disease of the hand that interfered with daily life on the non-paralyzed side, 3) cognitive impairment (Mini Mental State Examination score < 21), 4) visual impairment (hemianopsia, diplopia, and reduced visual acuity) that prevented them from seeing the monitor, and 5) those deemed unsuitable by the attending investigator.

**Equipment**

In this study, a device (iWakka, Nagoya Institute of Technology, Japan) was used to measure the grasping force quantitatively. This device consists of a monitor, grasping device, control box and Windows PC (Microsoft, Redmond, WA) with the iWakka Viewer application installed. The grasping device had a height of 80 mm, a diameter of 65 mm, and a weight of 0.112 kg. The force of grasping could be visualized by measuring the strain of the plate spring produced when the grasping device was opened and closed with a strain gauge, and a maximum grasping force of 0.5 kg could be measured (Fig. 1a). In previous studies, this device was used to evaluate and practice the ability to adjust the grasping force in healthy young and older adults and patients with stroke [25–28]. The sampling frequency was 10 Hz, and the spring constant of the plate spring was $4.82 \times 10^2$ N/m. Participants could check the difference between the target grasping force and the measured grasping force (grasping error) reflected on the monitor as visual FB and were expected to improve their task performance by adjusting their movement for the next trial (Fig. 1b).

[Figure 1 near here]

**Experimental design**

This study was conducted over 2 consecutive days. Participants completed the Edinburgh Handedness Test (EHI), pre-test, practice, and short-term retention test on day 1, and a long-term retention test and visuospatial ability assessment on day 2. The EHI was used to assess participants’ handedness. After EHI, participants performed a familiarization task in which they grasped the grasping device for 10 s at a force of 0.1 kg, without viewing the monitor, for five trials. The experimental task, including familiarization, was performed using the paralyzed upper limb. The results were not provided to the participants. The experimental task started after the completion of five trials of the familiarization task.

**Experimental task**

Figure 2 shows the experimental tasks performed in this study. The task trial consisted of adjusting the grasping force for 30 s, 10 s for each waveform, in the order of 0.1 kg, 0.4 kg, and 0.25 kg target grasping force. The participants performed the task without viewing the monitor during the task trials. The trial results were provided to the participants after trial completion. FB was provided by presenting the trial results on the monitor for 10 s. A metronome (6 bpm) was used to signal the change in the target grasping force. This allowed the participants to change their adjusted grasping force in accordance with the timing of the change in the target grasping force. Therefore, the purpose of this task was to learn
coordinated hand movements by trying to bring the measured grasping force as close to the target grasping force as possible, based on the tactile and motor sensations that occur when grasping devices.

[Figure 2 near here]

The test phase (pre-test, short-term retention test, and long-term retention test) consisted of 3 trials, each without FB, and the practice phase consisted of 15 trials (5 practice blocks × 3 trials per block) with FB. The interval between trials for the test trials was 10 s. For the practice trials, the next trial started 15 s after the end of the feedback period, and the interval between practice blocks was 1 min. The pre-test was conducted to assess the pre-practice conditions. Short- and long-term retention tests were conducted to assess the immediate and long-term effects of practice, respectively. The short-term retention test was conducted 5 min after the completion of the last trial (15th trial) of the fifth practice block, and the long-term retention test was conducted 24 h after the short-term retention test was completed (Fig. 3).

The ROCFT is a neuropsychological assessment of visuospatial ability (visuospatial construction and memory) that consists of copy and recall trials [29]. In this study, a copy trial and a 3-min delayed-recall trial were implemented. Previous studies have shown that information is forgotten by 2–3 min after the end of the copy trial [30] and that performance does not differ between a 3-min and a 30-min delayed-recall trial in various age groups (18–74 years) [31]. Therefore, a recall trial was performed 3 min after the end of the copy trial. The order of descriptions was recorded using a video camera when the copy task was performed. To prevent participants from noticing the replay task, a 10-item personality test [32] was conducted between the copy and recall trials after completion of the copy trial. This prevented participants from noticing the presence of a recall trial.

[Figure 3 near here]

**Measurement outcome**

The Fugl–Meyer Assessment for the Upper Extremity (FMUE) and Action Research Arm Test (ARAT) were used to evaluate motor function. In a systematic review of the outcome measures of upper extremity function in patients with stroke, the FMUE was the most commonly used upper extremity function assessment tool, while the ARAT was a measure commonly used in combination with FMUE [33]. Motor function assessment was performed within 1 week prior to the start of the study.

Root mean square error (RMSE) was calculated from the absolute values of the target grasping force and the measured grasping force per unit time. A smaller RMSE thus indicated a greater ability to adjust the grasping force. We used the central 5-s interval of each target grasping force (e.g., for a 0–10-s interval, the interval from 2.5–7.5 s was used) as the analysis interval, to exclude any deviation in grasping timing that occurred when the target grasping force switched. Measurements of visuospatial ability included copy, organization, and 3-min delayed-recall scores on the ROCFT. The copy score indicated whether the participants were able to understand the form and relative position of each unit of the figure and copy it accurately, while the 3-min delayed-recall score indicated whether encoding of the copied figure, retention of the encoding memory, and recall of the retained memory were performed accurately. The scoring
method for the copy and 3-min delayed-recall scores was based on the method of Loring et al. [34] and used a 36-point scale. The organization score indicates the organizational strategy for how the figure was segmented and described when it was depicted. The scoring method for the organization score was based on the method of Chervinsky et al. [35] and used a 36-point scale. Higher scores for each item indicated higher visuospatial ability.

**Statistical analysis**

First, the Shapiro–Wilk test was conducted to examine the normality of the RMSE. Then, based on the results of the Shapiro–Wilk test, Friedman tests were conducted with the RMSE as the dependent variable and test (pre-test, short-term retention test, and long-term retention test) and practice block (blocks 1–5) as factors, to clarify the effects of practice and motor learning on the ability to adjust the grasping force. When significant differences were found in the Friedman test, the Wilcoxon signed-rank sum test with Holm’s correction was implemented. Next, Spearman's rank correlation coefficients were calculated for performance on each test and motor function (FMUE, ARAT) and visuospatial ability (ROCFT) to clarify the relationship of performance on each test with motor function, and visuospatial ability (copy score, organization score, and 3-min delayed-recall score). All tests were performed using R software (version 4.3.1; R Core Team, Vienna, Austria). The significance level was p < 0.05.

**Results**

**Characteristics of participants in this study**

Figure 4 shows the process of participant recruitment. From July 2021 and August 2022, nineteen patients with subacute stroke participated in this study. However, one patient was discharged before evaluating the motor function, and one patient withdrew during the experiment. Consequently, seventeen patients (male/female: 8/9; mean age: 66.1 ± 13.8 years) completed the trial. Table 1 presents the participants’ information. Participants in this study had mild motor deficits in the upper extremities of the paralyzed side. Six participants had right hemiplegia and 11 had left hemiplegia on the paralyzed side.

![Figure 4 near here]

**Table 1. Characteristics of participants**
<table>
<thead>
<tr>
<th></th>
<th>Sex</th>
<th>Age (years)</th>
<th>Days</th>
<th>EHI</th>
<th>Stroke type</th>
<th>Affected hemisphere</th>
<th>FMUE (0–66)</th>
<th>ARAT (0–57)</th>
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**Change in ability to adjust grasping force**

Figure 5 shows the RMSE values for the test and practice blocks. According to the Shapiro–Wilk test, the pre-test (p = 0.022), short-term retention test (p = 0.002), long-term retention test (p = 0.045), Block 3 (p = 0.021), Block 4 (p = 0.033), and Block 5 (p = 0.013) data were not normally distributed, while data from Blocks 1 (p = 0.271) and 2 (p = 0.338) were normally distributed. The results of the Friedman test showed a significant main effect (F = 23.65, df = 2, p < 0.001). In addition, the post hoc test revealed significant differences between the pre-test and short-term retention test (p < 0.001) and between the pre-test and long-term retention test (p < 0.001) (Figure 5a). No significant differences were found between the short- and long-term retention tests (p = 0.330). The practice block also showed a significant main effect (F = 26.682, df = 4, p < 0.001) (Figure 5b). Post hoc tests showed significant differences between Block 1 and
each other block (Block 1 vs. Block 2: p = 0.003, Block 1 vs. Block 3: p = 0.002, Block 1 vs. Block 4: p = 0.005, Block 1 vs. Block 5: p = 0.003).

[Figure 5 near here]

**Relationship between performance on each test and motor function and visuospatial ability**

Figure 6 shows the correlations among test performance, motor function (FMUE and ARAT), and visuospatial ability (copy score, organization score, and 3-min delayed-recall score). Spearman’s rank correlation coefficients revealed a moderately negative correlation of performance on the long-term retention test with the copy score (p = 0.038, $\rho = -0.51$) and the 3-min delayed-recall score (p = 0.028, $\rho = -0.53$). No significant correlations were found between test performance and motor function parameters.

[Figure 6 near here]

**Discussion**

In this study, we investigated whether task-oriented training using visual terminal FB could enhance motor learning in patients with subacute stroke with motor impairment in the upper limb. We also investigated the relationship between the visuospatial ability and motor learning in patients with subacute stroke. The results of this study showed that visual terminal FB enhanced motor learning of the ability to adjust grasping force in patients with subacute stroke. Furthermore, while motor function was not associated with motor learning ability of adjusting the grasping force, visuospatial ability was associated with this ability. The results of this study indicated an improvement in the ability to adjust the grasping force in the short- and long-term retention tests as compared to the pre-test. These results suggested that using a FB strategy is appropriate.

FB timing can be classified into concurrent FB (FB given during the trial) and terminal FB (FB given after the trial is completed) [36]. In visual FB, concurrent FB improved performance during practice as compared to terminal FB. However, visual terminal FB has been shown to make learners depend on extrinsic FB, thus overlooking intrinsic FB (i.e., proprioception) and inhibiting motor learning [36]. Our result was similar to those of previous studies on older individuals and patients with stroke [37, 38]. In contrast, visual terminal FB has been shown to enhance motor learning in movement tasks with simple task complexity by facilitating visuomotor transformations, thus improving the preplanning of movements in the next trial [39]. Furthermore, in terms of FB frequency, previous research has shown that granting FB in all practice trials (i.e., 100% FB) inhibits motor learning [40]. However, in a meta-analysis, no differences in motor learning were noted according to FB frequency [41]. The participants in this study were older and had mild upper-extremity motor impairments, based on age and FMUE results [42]. Rehabilitation in older patients with stroke has been shown to provide functional improvement; however, this improvement decreases with increasing age [43]. This study, which included older patients with subacute stroke and mild motor impairments, suggested that FB strategies are effective in enhancing motor learning.
The results of this study also showed a moderate positive correlation between visuospatial ability and performance in adjusting grasping force but found no correlation between motor function and performance in adjusting grasping force. Therefore, the results of this study suggested that visuospatial ability is a more important factor in motor learning in patients with subacute stroke than is motor function or pre-test task performance. In addition to the ROCFT, other methods have been used to assess visuospatial ability, such as the MoCA and MR. In particular, the ROCFT can evaluate visuospatial construction and memory in visuospatial ability [21]. Visuospatial construction is used to understand the presented visual FB rapidly. Participants need to recognize the grasping error within the short presentation time (10-s) of the FB after the trial ends. This suggests that visuospatial construction contributes to rapid visual FB screen recognition. Furthermore, visuospatial memory might have contributed to the correct encoding of the presented visual FB, and the retention and recall of important information for motor planning for the next trial. Both visuospatial construction and memory have been shown to involve the superior and inferior parietal lobe regions, which translate visual information into limb movements [44, 45]. Few studies have focused on the relationship between visuospatial ability and motor learning in patients with stroke, with only one study reporting a small number of patients with chronic stroke (n = 7) [16]. Compared with previous studies on motor learning in patients with stroke, this study included a larger number of patients in the recovery phase (n = 17), increasing the reliability of the results.

This study had some limitations. First, no control conditions, such as a control group or concurrent FB group, were included. Setting FB conditions other than visual terminal FB would make this study more meaningful. Second, patients with stroke or severe motor impairments and non-subacute stroke were excluded. Based on the inclusion and exclusion criteria, only participants with subacute stroke who could manipulate the grasping device were included. Patients with stroke accompanied by severe motor impairments had difficulty using the grasping device independently. Therefore, our findings should be cautiously considered for different attributes, such as motor function (severe or moderate) and stage (acute or chronic).

**Conclusions**

This study investigated the effects of task-specific training with visual terminal FB on motor learning of hand dexterity in patients with subacute stroke who have mild motor impairment, as well as the relationship between visuospatial ability and motor learning. The results suggested that task-specific training using visual FB is effective for patients and indicate that visuospatial ability, rather than motor function, is related to motor learning. Future studies should examine FB strategies that enhance motor learning in patients with stroke in different movement tasks, with assessment of visuospatial ability, and visuospatial ability training methods that enhance motor learning.

**Abbreviations**

ARAT
Action Research Arm Test
EHI
Edinburgh Handedness Inventory
FB
feedback
FMUE
Fugl–Meyer assessment for the upper extremity
KP
knowledge of performance
KR
knowledge of results
MR
mental rotation
MoCA
Montreal Cognitive Assessment
RMSE
root mean square error
ROCFT
Rey–Osterrieth Complex Figure Test.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of the Ibaraki Prefectural University of Health Sciences (approval number: 995) and was registered in the UMIN clinical trial (UMIN000049991). The experimental design was conducted in accordance with the principles of the Declaration of Helsinki. All participants provided written informed consent after the conditions of participation in the study were explained to them.

Consent for publication

Not applicable.

Data availability

The dataset included in the manuscript is available from the corresponding author, Jun Yabuki, upon request (j.yabuki@mejiro.ac.jp).

Competing interests

The authors declare no competing interests.
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Author contributions

Study Design: JY, TK, RY, KY, WN, and KA. Data collection: JY. Data analysis: JY. Data interpretation: JY, TK, RY, KY, WN, and KA. Manuscript writing: JY. Manuscript review: JY, TK, RY, KY, WN, and KA. All authors have read and approved the final version of the manuscript.

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Not applicable.

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Figures

**Figure 1**

**Experimental equipment and experimental environments.** (a) Grasping device (right) and control box (left). We can quantitatively assess the participant’s grasping force in the range of 0–0.5 kg. (b) Feedback during the experiment task. Participants receive feedback on how accurately they adjusted the measured grasping force (red line) relative to the target grasping force (blue line).
Figure 2

Experiment task. The target grasping force is shown in blue solid line.

Figure 3

Experimental schedule. The participants performed the pre-test (PRE), practice test, and short-term retention test (SRT) on day 1, and the long-term retention test (LRT) and Rey–Osterrieth Complex Figure Test (ROCFT) on day 2. One block consisted of three trials, with one block for each of the three tests (PRE,
Patients screened for inclusion between July 2021 and August 2022 (n = 19)

- Evaluated motor function (n = 18)
- Discharge (n = 1)

- Completed experiment (n = 17)
- Withdraw consent (n = 1)

- Analyzed (n = 17)

Figure 4

Progress of the patients through the experiment.
Figure 5

Change in ability to adjust grasping force. (a) Results of grasping errors. Outlier points are shown in black points. Abbreviations: PRE, pre-test; SRT, short-term retention test; LRT, long-term retention test. (b) Results of grasping errors in each practice block. Abbreviations: B1–B5, Block 1–5.
Figure 6

**Correlation of performance on each test with motor functions and visuospatial functions.** Values in tiles indicate Spearman rank correlation coefficients. Combinations showing significant correlations are color-coded, with Spearman's rank correlation coefficients close to 1 shown in red and those close to -1 shown in blue. Combinations that do not show significant correlations are shown in white. Abbreviations: PRE, pre-test; SRT, short-term retention test; LRT, long-term retention test; FMUE, Fugl–Meyer assessment for upper extremity; ARAT, Action research arm test; Copy, copy score; ORG, organization score; Recall, 3-min delayed-recall score.