Original Article

The Effects of Inaccessible Visual Feedback Used Concurrently or Terminally

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Abstract. [Purpose] Concurrent feedback is more detrimental for long-term retention of motor skills because learners depend on accessible visual information provided in parallel with movements. However, visual information is not always accessible. Furthermore, the effects of concurrent feedback vary with aspects of the task being performed. We investigated the effects of inaccessible visual feedback used concurrently or terminally, focusing on aspects of movement. [Subjects and Methods] Fourteen subjects were quasi-randomly assigned to either a concurrent feedback group or a terminal feedback group. They practiced a task that involved right shoulder flexion with a specific acceleration. Learning achievements were assessed by measurement of errors in movement duration, peak timing, and strength. [Results] Regarding errors in movement duration, the concurrent feedback group was superior to the terminal feedback group during the midterm and final sessions. Regarding errors in peak timing, learning occurred in the concurrent feedback group, but not in the terminal feedback group because the improvement in performance during practice was inadequate. Regarding errors in peak strength, learning occurred in both groups. [Conclusion] Concurrent visual feedback that is used inaccessibly has learning effects that either equal or surpass those of terminal feedback that is used with inaccessible visual information for all parameters.
Key words: Motor learning, Feedback timing, Inaccessible visual feedback

INTRODUCTION

Patients who undergo physical therapy may have difficulty in walking and performing movements such as roll over because of some type of disorder. In many cases, patients cannot perform a target movement in a manner similar to that before onset of the disorder. In such cases, physical therapists determine the optimal movement for the patient and instruct them regarding the movement. Physical therapists then train the patients until they are capable of performing the movement. Extrinsic feedback is a technique that physical therapists use to teach patients motor skills. Physical therapists improve the movement of patients by giving visual, verbal, or haptic information about the results of a movement and by guiding the patients to appropriate movement.

Physical therapists provide feedback to patients either during (concurrent feedback) or after task execution (terminal feedback). In concurrent feedback, information is provided in parallel with movement, and the movement is regulated by extrinsic information. Therefore, almost all responses are repeated accurately during a practice session. In the clinical setting, there are practices with concurrent feedback such as practice of partial weight bearing using a weight scale, adjusting the power of muscles using electromyography, balancing with a stabilometer, and walking using a mirror image. In contrast, a number of errant responses occur during a practice session guided by terminal feedback because learners cannot gain information in parallel with their movement[2]. In previous studies, concurrent feedback has been more beneficial for immediate performance, but more detrimental for the long-term retention of motor skills compared with terminal feedback[1, 3–5]. However, Fox[6] examined the effects of feedback timing, feedback frequency, and methods of decreasing frequency using a 100% concurrent feedback group, 100% terminal feedback group, 50% concurrent feedback group that participated in every single trial and 50% feedback group that participated in the second half of each block. The 100% concurrent feedback group showed decreased performance compared with the 100% terminal feedback group, and both 50% concurrent feedback groups showed performances equivalent to that shown by the 100% terminal feedback group in the retention phase. Similarly, Park[7] reported that motor learning occurs effectively by gradually decreasing the frequency of concurrent feedback.

These results showed that the level of performance during practice can be maintained by adequate adjustment of the frequency of visual information provided in parallel with movement but that the learning achievement degrades

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when excessive visual information is provided in parallel with movement. Such a phenomenon was attributed to the fact that comparatively accessible visual information supersedes other kinesthetic information. In practice, utilizing concurrent feedback with electromyography, a stabilometer, or a mirror image enables learners to evaluate how they should move easily. Therefore, they tend to depend on visual information, which means there is no effective motor learning, as observed previously. In such cases, therapists should decrease the frequency of feedback, but they may be unable to decrease the frequency in the practice of a continuous skill such as walking. In this situation, dependency on visual information can be decreased by making visual feedback inaccessible. However, the learning effect of feedback used as inaccessible information is still incompletely understood. Furthermore, some previous studies showed similar results; however, the effects vary within parameters, as exemplified by force adjustment, movement timing, and position adjustment[1, 8, 9]. The purpose of this study was to test the learning effects of inaccessible visual feedback used concurrently or terminally, focusing on aspects of movement.

SUBJECTS AND METHODS

Subjects

Fourteen healthy young adults (8 men, 6 women) participated in this study. Their mean age was 21.4 ± 0.6 years. All subjects were right-hand dominant, had no history of neurological or musculoskeletal pathology, and had never performed the task. We explained the procedures to the subjects and obtained their written informed consent to participate in this study before testing began.

Methods

The subjects were quasi-randomly assigned to one of two feedback groups such that the male to female ratio was 4:3 for each group. They practiced the same task under different feedback conditions. The learning task involved shoulder flexion to move the right wrist with a specified acceleration and timing. The concurrent and terminal feedback groups were seated in front of an oscilloscope and a monitor, with an acceleration meter attached to their right wrists. The starting position had the subjects seated on a chair with their right arm pulled down by the side of their bodies. The examiner instructed the subjects to confirm the start time, the timing and strength of the acceleration peak, and the time at which movement was stopped with the target acceleration waveform. They started performing the task on hearing a specific set of sounds, which comprised a percussive tone and a starting tone played with a specific timing. The percussive tone was played before starting the task, while the starting tone was played 1 s after the percussive tone.

In this study, visual feedback was made inaccessible, compared with feedback relevant to muscular strength and position of limbs commonly used in previous studies, by visualizing acceleration of the right wrist. The concurrent feedback group was provided feedback in parallel with their movement by looking at the screen of an oscilloscope that was fitted with the target acceleration waveform. Furthermore, the subjects were tasked with reading aloud between each block so that they could not practice mentally. The terminal feedback group was provided with feedback after each block of attempts. Their feedback was an image of the oscilloscope recorded during task execution. We set up a partition made of cloth to prevent subjects from watching their right arms during task execution.

The experimental protocol included a pretest, an acquisition session, and a retention test. During the pretest, participants performed 5 trials without feedback. The acquisition session consisted of 10 blocks of 6 trials each, with a 1-min break between each block. Participants in the concurrent feedback group practiced the task while receiving concurrent feedback, whereas the terminal feedback group practiced the task and received feedback after every 6 trials. The retention test took place 24 h after the acquisition session. During the retention test, participants executed the task under the same conditions used during pretest. Acceleration data and a signal synchronized with the percussive tone from the electrical stimulator were printed on thermal paper with a thermal array recorder. In this study, learning achievement was determined by errors of movement duration, peak timing, and peak strength. Movement duration was defined as the time between the point at which the acceleration waveform began rising and the point at which it returned to baseline (Fig. 1). The target movement duration was 0.8 s. The error in peak timing was derived from the difference on the horizontal axis between the peak of the target acceleration waveform and the peak of the measured waveform (Fig. 2). The error in peak strength was the difference in length on the vertical axis between the peak of the target acceleration waveform and the peak of the measured waveform (Fig. 2).

In this research, the motion of the task was fast, and it was comparatively difficult to understand the feedback; therefore, modification of movement during each trial may have been too difficult in the concurrent feedback group. In this group, no discontinuous waveforms were modified in any trial; therefore, modification of movement on the basis of feedback information may have practically occurred after the 2nd trial of each block. Therefore, the second, third, fourth, fifth, and sixth trials of each block were analyzed. In addition, the results from block 1 were excluded from the analysis because the terminal feedback group only received the effect of feedback beginning with block 2. Blocks 2 to 10 were divided into 3 sessions. Statistical analyses were conducted using the SPSS ver. 20 software (SPSS Statistics, IBM Corp., Armonk, NY, USA) for Windows. The design for the analysis of the test and acquisition data was a 2×5 (feedback $\times$ test and session) ANOVA with repeated measures on the last factor. Post-ANOVA comparisons were performed using the Tukey procedure for the factors of test and session and an independent samples t-test for the factor of feedback.
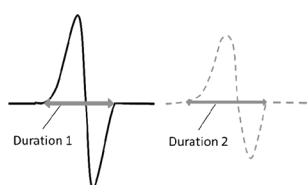
Fig. 1. Movement duration
Solid line: the target waveform, Dotted line: the waveform of executed movement
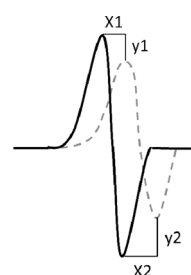(Duration1− Duration2)= the error of movement duration

Fig. 2. Peak timing and strength
Solid line: the target waveform, Dotted line: the waveform of executed movement
x1+x2= the error of peak strength
y1+y2= the error of peak timing

Table 1. Errors in movement duration

	Pretest	First session	Midterm session*	Last session*	Retention test
Concurrent feedback	1.0 ± 0.3	0.5 ± 0.2	0.3 ± 0.1	0.3 ± 0.1	0.5 ± 0.1
Terminal feedback	1.0 ± 0.3	0.7 ± 0.3	0.6 ± 0.2	0.6 ± 0.2	0.5 ± 0.2

Unit: Seconds. Mean ± SD. *Significant difference between concurrent feedback and terminal feedback ($p < 0.05$)

Table 2. Errors in peak timing

	Pretest	First session	Midterm session*	Last session	Retention test
Concurrent feedback	0.8 ± 0.2	0.3 ± 0.1	0.2 ± 0.1	0.2 ± 0.0	0.4 ± 0.2
Terminal feedback	0.7 ± 0.4	0.6 ± 0.3	0.4 ± 0.2	0.3 ± 0.2	0.4 ± 0.2

Unit: seconds. Mean ± SD. *Significant difference between concurrent feedback and terminal feedback ($p < 0.05$)

Table 3. Errors in peak strength

	Pretest	First session	Midterm session	Last session	Retention test
Concurrent feedback	28.3 ± 6.3	17.7 ± 2.3	12.8 ± 8	9.3 ± 4.1	13.1 ± 6.9
Terminal feedback	26.7 ± 7.3	20.8 ± 8.4	18.8 ± 9.0	14.5 ± 6.6	14.4 ± 9.3

Unit: mm. Mean ± SD.

RESULTS

With regard to errors in movement duration, a significant main effect was found for test and session and for feedback. A significant feedback × test and session interaction was also found (Table 1). In the terminal feedback group, the Tukey procedure indicated that the errors in movement duration committed during the midterm session, final session, and retention test were significantly smaller than those committed during the pretest. In the concurrent feedback group, the Tukey procedure indicated that the errors in movement duration committed during the first session, midterm session, final session, and retention test were significantly smaller than those committed during the pretest. Furthermore, an independent samples t-test indicated that the errors in movement duration committed by the concurrent feedback group were smaller than those committed by the terminal feedback group during the midterm session and final session.

In terms of errors in peak timing, a significant main effect was found for test and session and for feedback (Table 2). In the concurrent feedback group, the Tukey procedure indicated that errors in peak timing committed during the first session, midterm session, final session, and retention test were significantly smaller than those committed during the pretest. In the terminal feedback group, these differences were not significant. Furthermore, an independent samples t-test indicated that the errors in peak timing committed by the concurrent feedback group were smaller than those committed by the terminal feedback group during the midterm session.

In terms of errors in peak strength, a significant main effect for test and session was found (Table 3). The Tukey procedure indicated that errors in peak strength committed during the first session, midterm session, final session, and retention test were significantly smaller than those committed during the pretest.

DISCUSSION

The purpose of this study was to test the learning effects of inaccessible visual feedback used either concurrently or terminally, focusing on aspects of movement. We focused attention on aspects of the acceleration waveform. Furthermore, we made visual feedback inaccessible, compared with muscular strength and position of the limbs commonly used in previous studies, by visualizing acceleration of the right wrist. It is commonly believed that no proprioceptive organ for the acceleration of limb motion exists. McCloskey[10] reported that intramuscular mechanoreceptors receive sensation of positions, spindles of muscles, passive and voluntary motion. Acceleration is most likely derived from these sensations, complemented by sensations from the joints and skin. Therefore, the concurrent feedback used in this study may be more inaccessible than that used in a number of previous studies.

The results of our study on the error in movement duration showed that changes in the performance of the terminal feedback group during the acquisition sessions occurred later than changes in the performance of the concurrent feedback group. This is similar to results reported in a number of previous studies. However, in terms of motor learning, the concurrent feedback group showed a learning achievement equivalent to that shown by the terminal feedback group, a result different from that in a number of previous studies. With regard to the results of our study on the errors in peak timing, there was no change in performance; therefore, motor learning did not occur. Finally, the results of our study on the error in peak strength showed that the change in performance during the acquisition sessions and motor learning occurred equally in both groups. However, contrary to previous studies, the performance of the concurrent feedback group did not change immediately during the acquisition sessions.

These results indicate that the change in performance of the concurrent feedback group during the acquisition sessions either equaled or surpassed the change in performance of the terminal feedback group and that the motor learning of the concurrent feedback group equaled that of the terminal feedback group. Furthermore, the concurrent feedback group improved its performance at a stage in which the performance of the terminal feedback group was not adequately improved. In addition, contrary to previous studies, motor learning occurred in the concurrent feedback group.

The differences in outcome between this study and previous studies are thought to be due to the fact that the feedback used in this study was information about acceleration of movement. Hirata[11] performed an experiment relevant to concurrent feedback using a computer program having the function of a prism. A prism is a lens modifying visual information with a regularity that reverses front–back or horizontal direction. The results suggested that the effects of the prism remained during the retention test, even if feedback was not provided. In terms of this study, it is thought that the acceleration of limb movement is information that is more inaccessible than other sensations of movement, such as muscular strength and position of the limbs. Therefore, probing the relationships between target acceleration and movement may well achieve the same effect as a prism. Additionally, for the procedure, the concurrent feedback group and the terminal feedback group have effects of 100% and summary feedback respectively. One hundred percent feedback is what was provided to a learner after each trial. On the other hand, summary feedback is what was provided to a learner in the block after each set of practice. In the previous study comparing 100% to terminal feedback, summary feedback was more detrimental for immediate performance, but more beneficial for the long-term retention of motor skills compared with 100% terminal feedback[12]. A factor other than feedback timing may have effects on the results of this research, but the concurrent feedback having effects of 100% feedback showed learning achievement equivalent to that of the terminal feedback group having effects of summary feedback. Thus, the learning achievement of the concurrent feedback group might be an improvement.

The present study tested the effects of inaccessible feedback on motor learning. Each parameter reflected a different aspect of movement. The effect of concurrent feedback that immediately improves performance during practice is strong and remains relatively intact. Furthermore, concurrent feedback works effectively for motor learning. The results suggest that concurrent feedback comprised of inaccessible visual information works effectively for motor learning as well as performance during practice. In the clinical setting, during the practice of continuous skills such as walking, where it is difficult to decrease the frequency of feedback, therapists can occasionally ask the patient to probe the relationship between feedback and motion using visual concurrent feedback and systematic modification of the visual information. In doing so, dependency on patient feedback may decrease and effective motor learning may take place. In this way, it is necessary to adjust accessibility according to the skill level of patients when concurrent feedback is used. The advantages of guidance that improves performance immediately during practice are obtained, the negative effects of dependency on visual information are suppressed, and motor learning occurs effectively in a short period of time.

However, the limitation of this research is that the optimal degree of accessibility remains uncertain. Visual information in this research was supposedly more inaccessible than that in previous studies; however, there is no method of determining the degree of accessibility of the visual feedback used in this research. Therefore, further experiments are necessary to quantify the degree of accessibility of visual feedback.

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