



Original Article

## Differences in skill level influence the effects of visual feedback on motor learning

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**Abstract.** [Purpose] No previous studies have confirmed whether the effects of visual feedback on motor learning vary according to learner skill level for a learning task. The purpose of this study was to clarify whether differences in skill influence the effects of visual feedback on motor learning. [Participants and Methods] Sixty-four participants were assigned to one of four different feedback groups (concurrent-100%, concurrent-50%, terminal-100%, or terminal-50%). The learning task was to adjust the load amount continuously to the left lower limb in accordance with sound stimulation at intervals of 1 Hz. The four groups performed a pretest, practice sessions, and a retention test 24 hours after practice. After completing these measurements, the participants were classified as either high- or low-skilled based on the results of the pretest. [Results] Only the groups of low-skilled participants who used concurrent feedback showed lower root mean square errors in the retention test compared to in the pretest. [Conclusion] Differences in skill level for the same task influenced the effects of visual feedback on motor learning. Furthermore, concurrent visual feedback can help improve motor learning in low-skilled learners for the same task.

**Key words:** Motor learning, Skill level, Visual feedback

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### INTRODUCTION

Visual feedback (VF) is a manner to provide augmented feedback in various practice settings, such as rehabilitation and sports. In the field of rehabilitation, the effects of VF were reported on neurological disorders, such as stroke and cerebral palsy<sup>1-3)</sup>, knee osteoarthritis<sup>4)</sup> and the older adults with impaired physical function<sup>5)</sup>. Furthermore, VF has been verified to not only be therapeutic but also suitable for acquiring rehabilitation skills<sup>6)</sup>. Classic and conventional research on feedback and motor learning suggest that motor learning cannot take place without providing feedback including VF<sup>7)</sup>. Timing and frequency are important factors of VF. Two kinds of timing were defined: concurrent and terminal<sup>8)</sup>. Concurrent VF (CVF) is presented concurrently with the movement, and the learner is influenced by such information during the performance of the movement. In contrast, with terminal VF (TVF), the learner receives information after the performance of the movement. The feedback frequency is defined by the ratio of the number of trials for which feedback is given to the number of practice trials. For example, at 100% feedback, the learner is given feedback for all trials, and at 50% feedback only once per two trials. The effects of feedback frequency and timing on motor learning have been verified in simple and complex tasks, respectively.

Wulf and Shea<sup>9)</sup> reported that it is difficult to clearly define the complexity of a given task; however, they stipulated that

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complex tasks are those that are learnt across multiple sessions, whose movements have several degrees of freedom, and are probably prone to being ecologically valid. In other words, complex tasks are often practical tasks such as a sports action. On the other hand, simple tasks are those that have a single degree of freedom, can be learnt in a single session, and appear to be artificial. In short, simple tasks are tasks such as the tapping task used in classical research.

Regarding the difference of feedback timing on motor learning, in previous studies, CVF was found to be more beneficial for immediate performance, yet more detrimental to the long-term retention of motor skills when compared with TVF<sup>10-12</sup>. On the other hand, some studies using complex tasks support the effectiveness of CVF, but there are few reports claiming that CVF is more effective in motor learning than TVF<sup>13, 14</sup>. Regarding the influence of feedback frequency on motor learning, it has been reported that on simple tasks, low frequency TVF was not as effective as high frequency TVF in improving performance during practice, yet was effective in terms of motor learning<sup>15-17</sup>. Additionally, in reports on CVF of different frequencies, it is generally considered ineffective for motor learning; however, it has also been reported to be effective for motor learning, but only when used at a low frequency<sup>9, 18-20</sup>. By contrast, for complex tasks, there are reports that both low frequency CVF and TVF were effective for motor learning and reports that frequent CVF might work effectively for motor learning<sup>21, 22</sup>.

Previous studies have reported that high frequency feedback or CVF in simple tasks improved performance during practice, but it was likely to degrade motor learning. Therefore, it was believed that motor learning was effectively enhanced by lowering the frequency of both CVF and TVF. On the other hand, in complex tasks, CVF is thought to improve performance during practice, but it is not clear whether it is CVF or TVF that is more effective in motor learning. Many studies on task complexity and VF have defined task complexity according to the type of task.

However, in reviewing the relationship between feedback and motor learning, it was reported that the influence of feedback on motor learning changes depending on how complex the task is for learners<sup>23</sup>. In other words, the feedback group effective for motor learning changes depending on the skill level of the learner with respect to the task. However, studies on VF groups and motor learning considering learners' skill levels were not conducted.

If it is possible to select a VF group based on a learner's skill level at the start of practice, it can effectively lead to motor learning. Therefore, the purpose of this study was to clarify whether differences in skill level influence the effects of visual feedback on motor learning. Furthermore, we also attempted to examine the effects of VF timing and frequency on learners with different skill levels.

## PARTICIPANTS AND METHODS

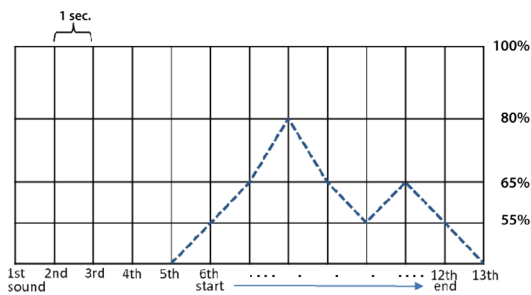
Sixty-four healthy young adults (32 males, 32 females) participated in this study. Their mean age was  $22.2 \pm 1.9$  years. All participants had no history of neurological or musculoskeletal pathology, and had never performed a learning task. Ethical approval for this study was obtained from the Ibaraki Prefectural University of Health Sciences Ethics Committee (Approval No. 684). We explained the procedures to the participants and obtained their written informed consent to participate in this study before testing began.

The learning task was to adjust the load amount continuously to the left lower limb in accordance with sound stimulation at intervals of 1 Hz. Participants took a standing posture with the left lower limb on the force plate (Kistler Instruments AG, Winterthur, Switzerland). Participants were instructed to hold off on starting the task until the fifth tone of the sound stimulus and were asked to adjust the load amount on the left lower limb from the sixth tone in the order of 55%, 65%, 80%, 65%, 55%, 65%, and 55% of the weight of each participant. The order of load adjustment is shown in Fig. 1. This study employed a method developed by the authors.

The load on the left lower limb was measured with the force plate at a sampling frequency of 100 Hz. The VF was created by using three lamps arranged in the order of green, blue, and red, from right to left. The green, blue, and red lamps were set so that they light up when the amount of load on the left lower limb fell within  $\pm 2\%$  of 55%, 65%, and 80% of the weight of each participant. The three lamps were controlled using an analog multipoint comparator MuWiC (Unimation System Inc., Kanagawa, Japan). MuWiC is a controller that manipulates the switching on/off of eight channels according to the input voltage. The signal in the Z axis of the force plate was input to the MuWiC and the result was outputted to the three lamps according to the input value to the MuWiC. All lamps were set not to light up when the load on the left lower limb was outside the range specified to light the lamp. The measurement environment is shown in Fig. 2. The three lamps were displayed on a 21-inch monitor placed 1.5 m away from the participants. The speaker for reproducing the sound stimulus for timing the movement was placed on the left side of the monitor.

In advance of the measurement, the weight of each participant was measured using the force plate, and 55%, 65%, and 80% of the weight of each participant was calculated. We then explained the learning task and the VF groups to the participants. Procedures are shown in Fig. 3. The participants completed a pretest, practice trials, and a retention test. In the pretest, the participants performed six trials without feedback. The practice session consisted of three blocks of six trials each, with a 1-min break between each block. Participants were given a 20-sec interval between each trial. During the practice trials, participants received VF in the assigned condition. The retention test was conducted 24 hours after completion of the practice and was similar to that of the pretest.

VF of varying timing and frequency was used in this study. Two VF timings of CVF and TVF were used. CVF was given

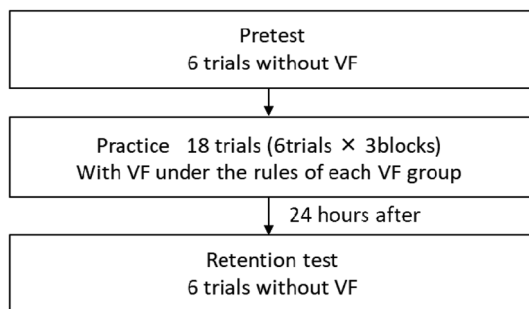


**Fig. 1.** Schematic diagram of the task.

Vertical axis: The relative value of the load amount applied to the left lower limb to the weight of each participant (%).

Horizontal axis: Progress of sound stimulation that sounds at intervals of 1 Hz.

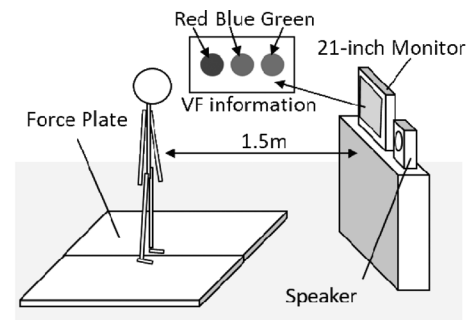
Dotted line: The order of the target load amount to the left lower limb.



**Fig. 3.** Schedule of measurement.

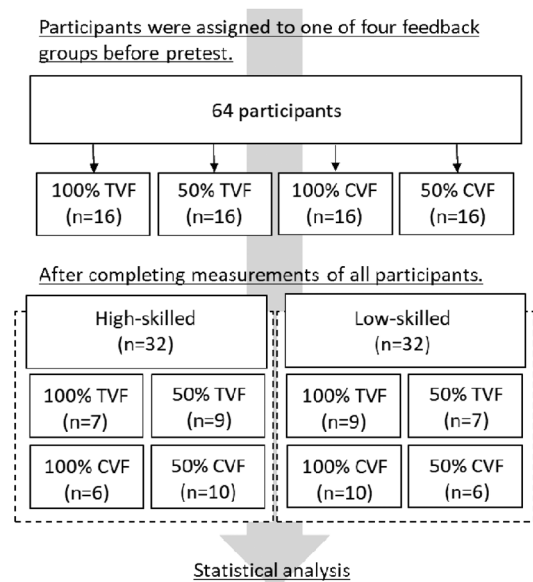
VF: Visual feedback.

In the practice session, there was a 1-min break between each block and a 20-sec interval between each trial.



**Fig. 2.** Measurement environment.

VF: Visual feedback.



**Fig. 4.** Schedule of analysis and assignment to visual feedback (VF) and skill level groups.

TVF: Terminal visual feedback; CVF: Concurrent visual feedback.

Participants were assigned to one of four feedback groups before the pretest. After measurements of all participants were completed, they were classified into either high-skilled or low-skilled groups based on the results of the pretests of all participants. The number of people in both groups was the same. Statistical analysis was done after classifying skill levels.

by displaying the state of the three lamps on the monitor during task execution. The TVF was given after completion of the task by reproducing images of three lamps and sound stimuli recorded during task execution. Next, two VF frequencies of 100% and 50% were used. At 100% group, VF was given for all trials. At 50% group, VF was given at a rate of once per 2 trials. Therefore, in this study, four VF groups (of 100% CVF, 50% CVF, 100% TVF, and 50% TVF) were used. The participants were quasi-randomly assigned to one of four feedback groups such that the male to female ratio was 1:1 for each group. Furthermore, we classified the participants into a high-skilled and a low-skilled group based on the initial skill level (Fig. 4). Of the 64 participants, 32 with higher pretest results were classified as high-skilled group, and the remaining 32 were classified as low-skilled group. Therefore, the breakdown of the participants included in the high-skilled group was 7 for 100% TVF, 9 for 50% TVF, 6 for 100% CVF, and 10 for 50% CVF. Further, the breakdown of the participants included in the low-skilled group was 9 in 100% TVF, 7 in 50% TVF, 10 in 100% CVF and 6 in 50% CVF. Since the classification of the skill level was done after sorting participants to each VF group, the number of participants included in each group varied.

In this study, Root Mean Square Error (RMSE) was used as a parameter to evaluate performances during practice and motor learning. In addition, because participants were instructed to turn on the lamps of VF according to the 6th, 7th, 8th, 9th, 10th, 11th, and 12th notes of stimulus sound, data of the load amount of 598 to 602 ms, 698 to 702 ms, 798 to 802 ms,

898 to 902 ms, 998 to 1,002 ms, 1,098 to 1,102 ms, and 1,198 to 1,202 ms were used to calculate RMSE. RMSE was the value obtained by dividing the average value of the absolute error from the target value for each sampling time by the body weight of each participant.

Statistical analyses were conducted using IBM SPSS Statistics 24 (IBM Corp., NY, USA) for Windows. The design for the analysis of the test and acquisition data was a  $2 \times 2 \times 2 \times 5$  (timing  $\times$  frequency  $\times$  skill level  $\times$  test and practice) ANOVA with repeated measures on the last factor. Post hoc tests were conducted when significant main effects or interactions were observed. Statistical significance was set at  $p < 0.05$ .

## RESULTS

Table 1 shows the transition of RMSE of each group in the pretest, practice trial, and retention test. For repeated measures analyses, Greenhouse-Geisser correction was applied to adjust for sphericity in this study. A significant test and practice main effect was observed,  $F(3.520, 197.130) = 18.383, p < 0.001, \eta^2 = 0.247$ . A significant timing  $\times$  skill level  $\times$  test and practice interaction was also found,  $F(3.520, 197.130) = 3.680, p < 0.001, \eta^2 = 0.062$ . Based on this result, two two-way analyses of variance were performed (Table 2).

First, because significant interaction was observed in timing  $\times$  skill level  $\times$  test and practice,  $2 \times 5$  (timing  $\times$  test and practice) ANOVA with repeated measures on the last factor and post hoc tests were performed for each skill group. In the high-skilled group, no significant main or interaction effects were found. In the low-skilled group, a significant main effect was found at test and practice,  $F(2.934, 88.014) = 19.907, p < 0.001, \eta^2 = 0.399$  and significant interaction was found between test and practice  $\times$  timing,  $F(2.934, 88.014) = 4.864, p = 0.004, \eta^2 = 0.140$ . As a significant interaction was observed in test and practice  $\times$  timing, the one-way ANOVA with repeated measures on the test and practice were performed for the low-skilled CVF and TVF groups. In the low-skilled CVF group, the significant main effect was found and the Tukey procedure indicated that Block 1, Block 2, Block 3 and the retention test were significantly smaller than the pretest (Table 2a\*\*). In the low-skilled TVF group, a significant main effect was not found. As a result of independent t-tests for the CVF and TVF groups at each test and practice, the low-skilled CVF group showed a significantly smaller value compared to the TVF group in Blocks 1, 2, and 3 (Table 2b\*\*).

Next,  $2 \times 5$  (skill level  $\times$  test and practice) ANOVA with repeated measures on the last factor and post hoc tests were performed for each timing group. In the TVF group, a significant main effect was found at skill level,  $F(1, 30) = 11.391, p = 0.002, \eta^2 = 0.275$ , with the high-skilled group showing a significantly smaller value than the low-skilled group (Table 2c\*\*). In the CVF group, a significant main effect was found at test and practice,  $F(3.021, 90.620) = 15.807, p < 0.001, \eta^2 = 0.345$  and

**Table 1.** Changes in root mean square error (RMSE) for each skill level and visual feedback (VF) condition

Skill Level	VF	Pretest	Block 1	Block 2	Block 3	Retention Test
High	100%TVF	13.1 $\pm$ 3.7	12.9 $\pm$ 3.5	11.6 $\pm$ 4.4	9.8 $\pm$ 4.4	11.4 $\pm$ 4.4
	50%TVF	14.2 $\pm$ 2.8	13.1 $\pm$ 4.8	13.0 $\pm$ 5.3	12.3 $\pm$ 5.6	14.0 $\pm$ 7.5
	100%CVF	14.7 $\pm$ 2.1	12.7 $\pm$ 2.3	11.8 $\pm$ 4.3	10.3 $\pm$ 3.3	13.1 $\pm$ 3.1
	50%CVF	13.2 $\pm$ 2.3	12.8 $\pm$ 2.2	13.8 $\pm$ 4.4	14.5 $\pm$ 6.0	14.5 $\pm$ 6.7
Low	100%TVF	21.4 $\pm$ 2.1	16.8 $\pm$ 5.2	15.8 $\pm$ 5.5	14.9 $\pm$ 4.7	14.3 $\pm$ 7.9
	50%TVF	22.4 $\pm$ 2.8	23.0 $\pm$ 7.5	22.1 $\pm$ 10.0	19.2 $\pm$ 9.5	19.5 $\pm$ 8.9
	100%CVF	22.9 $\pm$ 4.4	14.1 $\pm$ 4.3	11.6 $\pm$ 4.3	10.3 $\pm$ 3.6	13.3 $\pm$ 4.6
	50%CVF	21.5 $\pm$ 3.4	11.9 $\pm$ 4.1	11.6 $\pm$ 2.4	12.0 $\pm$ 3.1	15.6 $\pm$ 6.2

Values are presented as the mean  $\pm$  standard deviation (SD).

TVF: Terminal visual feedback; CVF: Concurrent visual feedback.

**Table 2.** Changes in RMSE for each skill level and VF timing

Skill level	VF timing	Pretest	Block 1	Block 2	Block 3	Retention test
High	TVF	13.7 $\pm$ 3.1	13.0 $\pm$ 4.2	12.4 $\pm$ 4.9	11.2 $\pm$ 5.1	12.9 $\pm$ 6.3
	CVF	13.8 $\pm$ 2.3	12.8 $\pm$ 2.2	13.0 $\pm$ 4.3	13.0 $\pm$ 5.4	14.0 $\pm$ 5.5
Low	TVF	21.8 $\pm$ 2.4	19.5 $\pm$ 6.8	18.6 $\pm$ 8.2	16.8 $\pm$ 7.3	16.6 $\pm$ 8.5
	CVFa**	22.3 $\pm$ 4.0	13.3 $\pm$ 4.2	11.6 $\pm$ 3.6	11.0 $\pm$ 3.4	14.2 $\pm$ 5.2

Values are presented as mean standard deviation.

RMSE: Root Mean Square Error; VF: Visual feedback; TVF: Terminal visual feedback; CVF: Concurrent visual feedback.

a\*\*: In the low-skilled CVF group, the Tukey procedure indicated that Block 1, Block 2, Block 3 and the retention test were significantly smaller than the pretest (respectively,  $p < 0.001$ ).

b\*\*: The low-skilled CVF group showed a significantly smaller value compared to the TVF group in Blocks 1, 2, and 3 ( $p = 0.004, p = 0.004, \text{ and } p = 0.007$ , respectively).

c\*\*: In the TVF group, the high-skilled group showing a significantly smaller value than the low-skilled group ( $p = 0.002$ ).

d\*\*: In the CVF group, the high-skilled group showed a significantly smaller value than the low-skilled group in the pretest ( $p < 0.001$ ).

significant interaction was found for test and practice  $\times$  skill level,  $F(3.021, 90.620)=11.938$ ,  $p<0.001$ ,  $\eta^2=0.285$ . As a result of independent t-tests for the high-skilled and low-skilled groups at each test and practice, the high-skilled group showed a significantly smaller value than the low-skilled group in the pretest (Table 2d\*\*).

## DISCUSSION

The purpose of this study was to clarify whether differences in skill level influence the effects of visual feedback on motor learning. The results of this study showed that improvement of performance during practice and motor learning did not occur in the low-skilled TVF group. By contrast, the performance of the low-skilled CVF group during practice improved to the same level as the high-skilled groups. Furthermore, the low-skilled CVF group did not differ from the other groups in the retention test, but it was the only motor learning caused in the low-skilled CVF group. In the high-skilled group, there was no improvement of performance during practice and motor learning for any VF groups. In addition, the VF frequency did not show any significant main effect or interaction with other factors.

In this research, the task of continuously adjusting the load amount was used. Winstein et al.<sup>24)</sup> investigated the learning effects of CVF and TVF by using the task of statically adjusting the load amount on the lower limbs. It was shown by Winstein et al. that CVF effectively improved performance during practice yet degraded motor learning. Their study yielded results similar to many previous studies using simple learning tasks.

Both our study and the study by Winstein et al. used learning tasks to adjust the load amount, but different results were obtained. The reason for this difference is that the learning task in this study involves the temporal factor of performing the load adjustment at the designated times, which is a complex task compared to the static load adjustment task used by Winstein et al. Because the learning task in our study was complex, it was presumed that the low-skilled TVF group failed to improve performance during practice and, therefore, did not cause motor learning. Due to the difference between the two studies, it is thought that the effective VF group for motor learning is not determined by the type of learning task. Even with similar tasks, the difficulty for learners varies depending on the complexity of the task, so it is believed that the effective VF groups may change accordingly.

Some studies that use complicated learning tasks, such as athletic movements, reported that the CVF may contribute to motor learning, but no research has reported that the effect exceeds the learning effect with TVF<sup>13, 22, 25-27)</sup>. These previous studies did not consider differences in the learners' skill levels. Wishart et al. examined the effective VF timing in motor learning in the young and older adults<sup>28)</sup>. In the study, a bimanual coordination task, assumed to be complex, was used. As a result, young adults demonstrated motor learning with both CVF and TVF, but older adults demonstrated motor learning only with CVF. The older adults in that study and the low-skilled groups in our study showed similar results in the motor learning of complex tasks with CVF.

However, there were differences between the results of our study and those of Wishart et al. In Wishart et al.'s study, motor learning occurred with both CVF and TVF groups in young adults, but improvement in performance during practice and motor learning did not occur with all VF groups in the high-skilled groups in our study. There are two possible reasons for this. First, the high-skilled participants in this study may have had high skills at the start of practice and, hence, little scope for performance improvement. In other words, since the learning task used in this study was an original task, participants in the high-skilled group may show a ceiling effect. Even under the low-skilled CVF group, the performance during practice improved to the same level as the high-skilled groups, but no further improvement in the performance was noted. Secondly, it is possible that the visual information used as VF might not have been the kind of information that could change the performance of the high-skilled participants in this study. Chiou and Chang<sup>29)</sup> examined the effects of continuous and discrete CVF and discrete concurrent auditory feedback on motor learning for the bimanual coordination task. The results of their study showed that continuous CVF caused better performance than other feedback groups during practice yet was unable to maintain such performance in the retention test. On the other hand, in discrete visual and auditory feedback, improved performance during practice and motor learning occurred. The three lamps used as VF in our study was discrete information, and the participants did not know the load amount to the left lower limb when the load amount was outside the range of 55%, 65%, and 80%  $\pm$  2%. In addition, the bandwidth of  $\pm$  2% set on the lamps allowed for some error, so that high-skilled participants already demonstrated the maximum performance possible with VF at the beginning of practice. In order to cause motor learning, it is believed that the VF should be the kind of information that can improve performance during practice.

Previous studies using simple tasks reported that CVF was effective for motor learning only when used at a low frequency<sup>9, 19, 20-22)</sup>. Wulf et al.<sup>22)</sup> used a complicated ski-slalom task to investigate the learning effects of high and low frequency CVF. As a result, high frequency CVF caused better performance during practice than low frequency CVF, but no difference in motor learning was reported. In the present study, the participants with the high-skilled group showed better performance at the beginning of practice, which was unchanged with VF. Therefore, regardless of whether VF frequency was high or low, the effect of VF was not observed.

In the low-skilled TVF group, improvement of performance during practice did not occur even with 100% TVF, which is generally effective for practicing complex tasks. Even with 50% TVF, the improvement in performance and motor learning did not occur. On the other hand, under the low-skilled CVF groups, the 100% and 50% groups caused the same improvements in performance during practice and motor learning. The results of the study by Wulf et al. showed differences between



groups during practice, but in our study no difference was found between the groups. The reason for this is believed to be the degree of influence that visual information has on performance during practice. Both the 50% and 100% groups improved performance up to the maximum level of performance that could be demonstrated by using the VF information of this study at Block 1. Therefore, there was no improvement in performance due to practice beyond that.

Based on the results of this study, it is recommended that learners with a low skill level practice complex motor tasks to improve performance and motor learning by practicing the CVF. A possible limitation of this study is that the skill level of participants in the study had to be judged, and the criteria for judging skill level may differ depending on learning tasks. In order to apply the results of this research to other tasks, it will be necessary to develop a method for judging a learner's skill level in any learning task. In addition, the quality of information presented, such as the continuity of VF, may also be a factor influencing performance during practice and motor learning. Since the learning task used in this study was an original task, the possibility that the high-skilled group had a ceiling effect cannot be denied. Future studies should analyze the highest performance level of the learning task used in this study. In addition, we will examine the effects of the quality of visual information on performance during practice and motor learning vis-à-vis the learner's skill level on the task.

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