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Original Article

Feedback protocol of 'fading knowledge of results' is effective for prolonging motor learning retention

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Abstract. [Purpose] "Knowledge of results" (KR) is information about the success of an action relative to a goal. A reduced frequency of "knowledge of results" reportedly promotes motor learning more than a high frequency. However, the effect of gradually diminishing or increasing "knowledge of results" pattern has been rarely studied and is controversial. We investigated the effectiveness of diminishing "knowledge of results" pattern in motor learning. [Participants and Methods] Forty-six healthy adults were randomly assigned to either the 100% KR, 50% KR, or faded KR group. Participants were tasked with exerting 60% of their maximum voluntary contraction of their left shoulder flexion muscle in an isometric exercise. Participants practiced the task 20 times a day for 4 days. A pretest and posttest were conducted before and immediately after the acquisition, respectively. Retention tests were conducted 1 day, 1 week, and 2 weeks after the acquisition. [Results] The absolute error was significantly reduced in the posttest in the faded KR and 50% KR cohorts. However, there was no significant difference in the 100% KR group. In the faded KR subjects, the improvement effect was observed up to 1 week following acquisition. [Conclusion] Faded "knowledge of results" productively prolongs the effect of motor learning.
Key words: Faded knowledge of results, Motor learning, Feedback

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INTRODUCTION

Motor learning is a series of processes associated with practice or experience leading to relatively permanent changes in the ability of skilled performance. Feedback is information about the difference between a target value and actual performance, which promotes learning. Currently, feedback is considered to have both intrinsic and extrinsic components. The intrinsic feedback is directly perceptible by the learner as a result of an action. The extrinsic effect comes from information returned to learners by artificial means. One example of an extrinsic feedback is "knowledge of results (KR)," which is information about the success of action to the goal, provided by a third party through language.

In previous studies, the effectiveness of high-frequency KR (100% KR) and relatively low-frequency KR (10–67% KR)

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protocols have been compared in various tasks and participants. It has been generally recognized that a reduced relative frequency of KR promoted motor learning more effectively than a high relative frequency in healthy participants[1–4]. Recently, some papers targeting persons with cerebral palsy and Parkinson’s disease who may have impaired motor cortex activity demonstrated that reducing KR frequency can enhance motor learning, similar to what has previously been found for unimpaired participants[5, 6]. It has been suggested that learners in high-frequency KR experiences depend on external feedback information too much[2, 7–9], whereas those in reduced relative frequency KR environments perform greater active information processing without overly depending on external KR feedback.

Apart from the frequency of KR, the concepts of faded KR and bandwidth KR have also been discussed with regard to effective motor learning. Faded KR is a way to give KR at a relatively high frequency in the initial practice phase and then gradually decreasing it as practice progresses. In the report of Nicholson & Schmidt[3], a faded KR group and also a reverse-faded KR group were compared in a spatial-temporal patterning task. There was no significant difference just after the acquisition phase; however, the faded KR group showed fewer errors in the retention test after 24 h. This result suggests that a training program involving gradually decreasing pattern of KR may be useful for motor learning. Unfortunately, at this point, there have been few studies comparing the effectiveness of programs that provide a low frequency of KR at a constant rate versus those that use a faded KR schedule. Also, most previous studies have performed retention tests only after 24 h, and the longer-term learning effect after this point has not been established.

We speculated that a faded KR protocol may have a relatively high learning effect, and the purpose of this study was to rigorously investigate this hypothesis. We proceeded by comparing the effectiveness of 100% KR, 50% KR, and the faded KR approaches as applied to an isometric contraction adjustment task of shoulder joint flexion muscles. We investigated the effect of each of these three methods for up to 2 weeks after the acquisition phase.

PARTICIPANTS AND METHODS

Forty-six healthy adults (19 males and 27 females; mean age=21.8 ± 2.7 years) took part in this study. All were right handed and had no prior experience with the experimental task. This study was approved by the Ethics Committee of Fujita Health University (Approval No. HM14-103), and informed consent was obtained from all participants.

The task was to adjust the isometric strength of the left shoulder joint flexion muscles to a particular level. Participants were positioned supine on a stable treatment table, and a manual dynamometer (μTas F-1, Anima Corp., Tokyo, Japan) was used to measure the isometric strength they generated. Participants were asked to place elbows extended at 0° on both sides and to place the forearms on both sides in a slightly pronation position. They were then instructed to perform isometric contraction of the shoulder flexion muscles at the shoulder joint with a flexion 0 degrees. As a base measurement, the maximum isometric voluntary contraction of the shoulder flexion muscle was measured three times by the manual dynamometer. The average of the three maximum efforts value was defined as the maximum voluntary contraction (100% MVC).

Figure 1 shows the flow of the experiment. A pretest was conducted before data acquisition with no KR. A target value

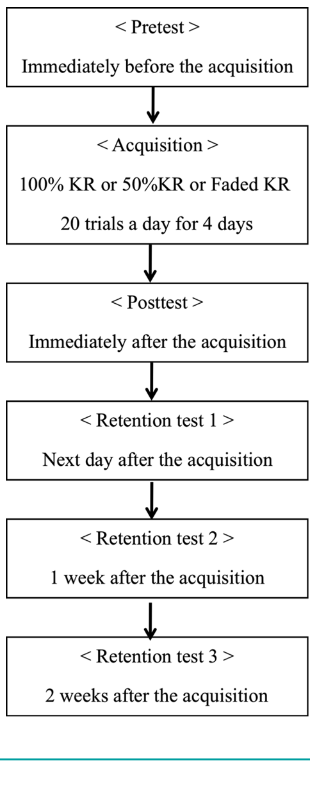

Fig. 1. The flow of the experiment.

was then set at 60% of the maximum value (60% MVC), and explained to the participants, who were instructed to produce this target level of isometric strength for 5 s.

The participants were randomly assigned to one of the three acquisition groups: 15 participants in a 100% KR group (6 males and 9 females), 15 in a 50% KR group (6 males and 9 females), and 16 in a faded KR group (7 males and 9 females). Participants then practiced the isometric contraction of the left shoulder flexion muscles, attempting to achieve the 60% MVC target value, 20 times at intervals of 10 s. This practice was continued over for four days. The 100% KR group received KR on every trial. The 50% KR group received KR 10 times alternately over 20 sessions. The faded KR group received 100% KR at the first day, 75%KR at the second day, 50% KR at the third day, and 25% KR in the fourth day (Table 1).

The posttest was held immediately after the data acquisition session on the fourth day. In this event, participants were instructed to perform the 60% MVC of the isometric shoulder joint flexion with no KR.

Retention test 1 was taken on the next day. Retention tests 2 and 3 were conducted at 1 and 2 weeks after the acquisition, respectively. In retention tests 1, 2, and 3, participants were instructed to perform the 60% MVC of the isometric shoulder joint flexion with no KR.

We calculated the difference of the absolute value between the actual value produced by each participant and the 60% target value, which we defined as the "absolute error." The mean absolute error of each test was used in our statistical analyses. Differences between the pretest and the other tests of each group were analyzed using a paired t-test. Differences between the 100% KR, 50% KR, and faded KR groups of each test were analyzed using the Kruskal-Wallis H-test. For all statistical analyses, we utilized SPSS Statistics, version 24 (SPSS Inc., Chicago, IL, USA).

RESULTS

The average value of the maximum voluntary contraction (100% MVC) of the isometric shoulder flexion was 180.3 ± 79.5 N, 165.3 ± 79.0 N, and 151.4 ± 53.8 N for the 100% KR, 50% KR, and faded KR groups, respectively. Therefore, the average target values, which represent 60% MVC, were 108.2 ± 47.7 N, 99.2 ± 47.4 N, and 90.8 ± 32.3 N. Table 2 shows the mean and standard error of the target values and the actual values in the pretest, posttest, and retention tests. Mean absolute errors

Table 1. Knowledge of results (KR) schedule ○ : KR - : no KR

Trial	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
100% KR																				
1st–4th days	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
50% KR																				
1st–4th days	○	-	○	-	○	-	○	-	○	-	○	-	○	-	○	-	○	-	○	-
Faded KR																				
1st day	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
2nd day	○	○	○	-	○	○	○	-	○	○	○	-	○	○	○	-	○	○	○	-
3rd day	○	-	○	-	○	-	○	-	○	-	○	-	○	-	○	-	○	-	○	-
4th day	○	-	-	-	○	-	-	-	○	-	-	-	○	-	-	-	○	-	-	-

All participants practiced 20 trials a day for 4 days. The 100% KR group received KR on every trial. The 50% KR group received KR 10 times in each day. The faded KR group received KR in a frequency that gradually decreased from 100% on the first day to 25% on the fourth day.

Table 2. The mean and standard error (SE) of the actual values in the pretest, posttest, and retention test

	Target value	Actual value				
		Pretest	Posttest	Retention test 1	Retention test 2	Retention test 3
100% KR						
Mean (N)	108	96.0	115	120	122	119
SE	12.3	13.7	14.2	14.7	15.2	14.5
50% KR						
Mean (N)	99.2	106	104	101	108	113
SE	12.1	12.9	10.9	12.7	13.4	15.2
Faded KR						
Mean (N)	90.8	82.8	93.1	94.0	98.3	103
SE	8.1	7.7	7.8	7.2	7.6	8.9

Target value was set at 60% of the maximum voluntary contraction (100% MVC). Refer to Figure 1 for the schedule of the experiment.

Table 3. The mean and standard error (SE) of each absolute error in the pretest, posttest, and retention tests

	Pretest	Posttest	Retention test 1	Retention test 2	Retention test 3
100% KR					
Mean (N)	17.0	9.2	16.4	20.9	23.7
SE	3.9	2.7	4.4	5.5	5.1
50% KR					
Mean (N)	21.0	10.6	11.4	16.3	20.9
SE	4.0	2.2	1.9	4.6	3.7
Faded KR					
Mean (N)	20.7	5.7	11.2	12.1	14.6
SE	3.4	1.4	2.5	2.3	3.2

of individual groups are shown in Table 3. Absolute errors in the 100% KR, 50% KR, and faded KR groups did not show any statistical differences in pretest, posttest, and retention tests using Kruskal-Wallis H-test.

In the faded KR and 50% KR groups, the absolute error was significantly smaller in the posttest than in the pretest ($p=0.001$ and $p=0.016$, respectively). On the other hand, in the 100% KR group, there was remarkably no significant difference between pretest and posttest. The errors in the faded KR group of retention tests 1 and 2 were significantly smaller than that in the pretest ($p=0.045$ and $p=0.039$, respectively). On the other hand, in the 100% KR and 50% KR groups, there was no significant difference between the pretest and the retention tests.

DISCUSSION

In this study, we examined the effect on motor learning using an isometric contraction adjustment task of the shoulder joint flexion muscles in the 100% KR, 50% KR, and faded KR groups. We found that the 50% KR and faded KR groups obtained significantly better performance after practicing 20 trials for 4 days. However, only the faded KR group showed a retention effect up to 1 week after the acquisition. Therefore, our current study showed that faded KR and 50% KR have a more immediate positive effect compared with a 100% KR protocol and that of the three alternatives examined here, the faded KR program has the most retention effect on motor learning in an adjustment task of flexion strength of the shoulder joint.

Previous studies have usually focused only on the different outcomes between high (100%) and relatively low-frequency KR protocols. For example, Butki & Hoffman compared 100% KR and 50% KR protocols using a golf putting task. In the acquisition phase, participants performed 96 trials and those receiving 100% KR performed significantly better than the 50% KR group. However, in the retention test after 24 h, the 50% KR participants had better performance than those in the 100% KR group[10)]. In another study, Ishikura compared 100% KR and 33% KR protocols also using a golf putting task. In acquisition, participants performed 60 trials, and the error was significantly lower in the posttest than in the pretest for both the 100% KR and 33% KR protocols. However, in the retention test after 24 h, the 33% KR participants were more accurate than those who received 100% KR[4)]. Thus, 100% KR appears to enhance acquisition performance compared with low-frequency KR, whereas the 100% KR system is inferior to low-frequency KR in retention tests[11–14)]. The reason for this difference is currently unknown. However, the results of several previous studies suggest that learners perform more active information processing without depending on KR when reduced relative frequency KR is provided. Moreover, in such environments, performance is not over-corrected[3, 11)].

In our current study, there was no significant improvement of performance when using 100% KR at acquisition. The number of trials was 30 to 108 per day in the acquisition phase[1, 5, 15)], whereas the number of trials per day was as small as 20 in the practice phase in this study. This may be a reason why the improvement in performance after practice was not obtained for the 100% KR group in this study. As in previous investigations, our current study found no significant improvement in the performance of retention tests when using the 100% KR protocol, meaning that there seems to be a less permanent learning effect resulting from a 100% KR training. This is perhaps because participants depended on KR too much and processed less intrinsic feedback.

In faded KR trainings, participants are initially given KR at a relatively high frequency, which then gradually decreases as practice progresses. To our knowledge, there have been only a very few previous reports comparing a faded KR method with any other approach[1, 3, 16)]. Earlier studies on faded KR have performed retention tests only up to 24 h, and therefore, a long-term learning effect has not been established. In addition, previous studies, except for one paper, only compared faded KR to 100% KR. The outlier was a study by Nicholson and Schmidt, which compared faded KR, reverse-faded KR, and 50% KR in a spatial-temporal patterning task. They found no significant differences in results regarding initial acquisition, but faded KR showed the best performance in the retention test after 24 h, and at that point, the reverse-faded KR approach was significantly inferior to all the other groups[3)].

In our current study, the error of the faded KR group was significantly reduced, compared with the other two protocols, for up to 2 weeks after acquisition. Therefore, it appears that the error for the faded KR group tends to be smaller than those for the other groups in the retention tests because the learning effect is maintained longer. Together with the study by Nicholson and Schmidt, the evidence suggests that learning progress may become effective without depending on KR toward the end of the learning process.

In conclusion, the present study has demonstrated that the accuracy of performance is improved in 50% KR and faded KR protocols and that the improvement of skill is likely to last longer in the faded KR program of training. That is, a faded KR strategy appears to be best for motor learning.

The acquisition schedule of most previous studies only encompassed 1 day, the retention effect was followed up for only 24 h, and the participants were often healthy adults. However, from the perspective of improving rehabilitation therapy, tests of effectiveness with longer retention periods should be undertaken with patients who actually need rehabilitation intervention. In our current effort, the participants practiced acquisition for four consecutive days and the practice effect was investigated for up to 2 weeks. In the future, it would likely be productive to investigate the effects of various types of KR over even longer periods, in not only healthy individuals but also utilizing patients receiving a variety of rehabilitation interventions.

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The authors indicated no conflicts of interest.

REFERENCES

1) Wulf G, Schmidt RA: The learning of generalized motor programs: Reducing the relative frequency of knowledge of results enhances memory. J Exp Psychol Learn Mem Cogn, 1989, 15: 748–757. [CrossRef]
2) Winstein CJ, Schmidt RA: Reduced frequency of knowledge of results enhances motor skill learning. J Exp Psychol Learn Mem Cogn, 1990, 16: 677–691. [CrossRef]
3) Nicholson DE, Schmidt RA: Scheduling information feedback to enhance training effectiveness. Proceedings of the Human Factors Society 35th Annual Meeting, 1991: 1400–1403.
4) Ishikura T: Reduced relative frequency of knowledge of results without visual feedback in learning a golf-putting task. Percept Mot Skills, 2008, 106: 225–233. [Medline] [CrossRef]
5) Hemayattalab R, Rostami LR: Effects of frequency of feedback on the learning of motor skill in individuals with cerebral palsy. Res Dev Disabil, 2010, 31: 212–217. [Medline] [CrossRef]
6) Chiviacowsky S, Campos T, Domingues MR: Reduced frequency of knowledge of results enhances learning in persons with Parkinson’s disease. Front Psychol, 2010, 1: 226. [Medline] [CrossRef]
7) Salmoni AW, Schmidt RA, Walter CB: Knowledge of results and motor learning: a review and critical reappraisal. Psychol Bull, 1984, 95: 355–386. [Medline] [CrossRef]
8) Lee TD, White MA, Carnahan H: On the role of knowledge of results in motor learning: exploring the guidance hypothesis. J Mot Behav, 1990, 22: 191–208. [Medline] [CrossRef]
9) Sparrow WA, Summers JJ: Performance on trials without knowledge results (KR) in reduced relative frequency presentations of KR. J Mot Behav, 1992, 24: 197–209. [Medline] [CrossRef]
10) Butki BD, Hoffman SJ: Effects of reducing frequency of intrinsic knowledge of results on the learning of a motor skill. Percept Mot Skills, 2003, 97: 569–580. [Medline] [CrossRef]
11) Vander Linden DW, Cauraugh JH, Greene TA: The effect of frequency of kinetic feedback on learning an isometric force production task in nondisabled subjects. Phys Ther, 1993, 73: 79–87. [Medline] [CrossRef]
12) Bilodeau EA, Bilodeau IM: Variable frequency of knowledge of results and the learning of a simple skill. J Exp Psychol, 1958, 55: 379–383. [Medline] [CrossRef]
13) Annett J: Learning a pressure under conditions of immideate and delayed knowledge of results. Q J Exp Psychol, 1959, 11: 3–15. [CrossRef]
14) Ho L, Shea JB: Effects of relative frequency of knowledge of results on retention of a motor skill. Percept Mot Skills, 1978, 46: 859–866. [Medline] [CrossRef]
15) de Oliveira DL, Corrêa UC, Gimenez R, et al.: Relative frequency of knowledge of results and task complexity in the motor skill acquisition. Percept Mot Skills, 2009, 109: 831–840. [Medline] [CrossRef]
16) Wulf G, Schmidt RA, Deubel H: Reduced feedback frequency enhances generalized motor program learning but not parameterization learning. J Exp Psychol Learn Mem Cogn, 1993, 19: 1134–1150. [Medline] [CrossRef]