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Original Article

Extrinsic feedback from a feedback device promotes the learning of range of motion measurements

Kazunori Akizuki, RPT, PhD[1)*], Kaho Mitamura, RPT[2)], Ryohei Yamamoto, RPT, PhD[3)], Kazuto Yamaguchi, RPT, MS[4)], Yukari Ohashi, RPT, PhD[5)]

[1)] *Department of Physical Therapy, Faculty of Rehabilitation, Kobe International University: 9-1-6 Koyouchou, Higasinada, Kobe, Hyogo 658-0032, Japan*
[2)] *Department of Rehabilitation, Saitama Iwatsuki Hospital, Japan*
[3)] *Department of Rehabilitation, Kyushu University of Nursing and Social Welfare, Japan*
[4)] *Department of Rehabilitation, Misato Central General Hospital, Japan*
[5)] *Department of Physical Therapy, Ibaraki Prefectural University of Health Sciences, Japan*

Abstract. [Purpose] Although it is widely recognized that feedback is important for skill acquisition or improvement, feedback is not completely utilized in physical therapy education. Therefore, we aimed to verify the effect of extrinsic feedback from a feedback device on proficiency in range of motion measurements by a universal goniometer. [Participants and Methods] The participants included 22 physical therapy students who were randomly assigned to feedback (n=11) and non-feedback groups (n=11). The passive right knee flexion range of motion was set as the measurement task. The experiment consisted of a pretest phase, practice trials, and a posttest phase. In the pretest phase, all participants conducted three measurements without extrinsic feedback. Extrinsic feedback related to measurement error from a device was given only to the feedback group. The posttest was conducted 24 hours after the practice trials with the same content as that in the pretest. [Results] The improvement rate from pretest to posttest was greater in the feedback group than in the non-feedback group. The results indicated that the measurement error decreases with extrinsic measurement error-related feedback during practice. [Conclusion] The utilization of extrinsic feedback from a feedback device is effective for enhancing range of motion measurement skills.

Key words: Range of motion, Extrinsic feedback, Motor learning

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INTRODUCTION

If the joint range of motion (ROM) is restricted by the influence of orthopedic disease, neurosurgical disease, or aging, restrictions are imposed on many activities of daily living, such as standing up, walking, and climbing stairs[1–3]. Therefore, in domains such as orthopedic surgery and physical therapy, the ROM is used as information for clinical reasoning, an index of surgical outcomes, and an index of the intervention effect[4, 5]. Many methods for the measurement of joint ROM have been proposed, such as visual estimation[6] and the use of a universal goniometer[7], electrogoniometer[8], digital image[9], or a three-dimensional motion analyzing apparatus[10]. Additionally, a method using a smartphone has been recently developed[11, 12]. However, in the clinical setting, a universal goniometer has been generally used to measure the ROM for a long time. Therefore, the validity and reliability of the measurement of the ROM by the universal goniometer are research topics of high interest to clinicians and has been clarified in previous research[7, 11, 13].

Lenssen et al. examined the degree of measurement error for the knee joint ROM by a universal goniometer using the

*Corresponding author. Kazunori Akizuki (E-mail: akizuki@kobe-kiu.ac.jp)

Bland-Altman method; the degree of agreement among the therapists was observed to be fair, as the difference was within 8° and was indistinguishable from errors[14)]. In addition, Akizuki et al. investigated the measurement errors for the knee joint ROM in students from the department of physical therapy, as well as in experienced physical therapists[15)]. The results revealed that the measurement error decreases as experience is gained. These previous studies indicate that a certain measurement technique is necessary to measure the ROM with some accuracy, and that the measurement technique has room for improvement through experience and practice.

The learning process for the ROM measuring technique comprises motor learning, and the role of feedback (FB) in motor learning is great[16–18)]. FB can be classified as intrinsic or extrinsic[19, 20)]. Intrinsic FB is generated by one's own visual, auditory, and tactile sense, without special equipment. The intrinsic FB arising in the ROM measurement comprises visual information regarding the alignment between the universal goniometer and measurement axis. Extrinsic FB is given to learners by some artificial means, for example as a FB device. As extrinsic FB contains error information, the learner recognizes the error when extrinsic FB is provided and modifies the motor program to reduce the error. Therefore, extrinsic FB is essential for motor learning, but it is hardly consciously used in physical therapy education. In addition, a study investigating the impact of FB device use on ROM measurement learning has not yet been conducted, and it has not been clarified whether the acquisition of ROM measurement skills requires extrinsic FB. Although the conventional practice for improving ROM measurement skills does not utilize a FB device, we hypothesized that the use of a FB device during ROM measurement practice would promote efficient improvement in measurement skills.

Therefore, we aimed to verify the effect of extrinsic FB from a FB device on proficiency in the measurement of the joint ROM using a universal goniometer by comparing practice with a FB device versus a conventional practice method. The results support the use of extrinsic feedback from a feedback device to enhance ROM measurement skills.

PARTICIPANTS AND METHODS

The participants were 22 fourth-year undergraduate students (mean age, 21.2 ± 0.4 years; 11 female and 11 male students) from the department of physical therapy, who had already taken lectures on ROM measurement. Prior to the start of the study, the contents of the experiment were explained to all potential participants, as well as the person to be measured; those who provided consent participated in the study. This study received approval from the Mejiro University Ethics Review Committee (approval number: 15-013).

Passive right knee flexion ROM measurement was set as the measurement task. An electrogoniometer (SG150, Biometrics Ltd., UK) and universal goniometer were used to measure the ROM. The electrogoniometer measurement value was taken as the reference value, and the absolute value of the difference between the reference value and the participant's measured value by the universal goniometer was defined as the measurement error.

The electrogoniometer was attached to the right leg using double-sided tape, with the knee flexed to 60° (Fig. 1). The proximal attachment point was localized to 1 cm from the lateral epicondyle of the femur, along a line connecting the greater trochanter and the lateral epicondyle of the femur. The distal attachment point was localized to 1 cm from the head of the fibula, along a line connecting the head of the fibula and the lateral malleolus. The bony landmarks used as references were identified by palpation and marked. Using tape, a thin string was attached between both pairs of landmarks (i.e., the greater trochanter and lateral epicondyle of the femur; and the head of the fibula and lateral malleolus), and used as a guide to attach the electrogoniometer. Once the electrogoniometer was placed and secured, an elastic wrap was used to prevent its slippage during measurements, as well as to hide its position from the participants (Fig. 2). The electrogoniometer was connected to a data logger (PH-7010, DKH, Japan), which provided a real-time display of the measurements to the experimenter, with signals saved at a sampling frequency of 100 Hz. ROM assessed by an electrogoniometer in this manner shows a high degree of coincidence with the ROM as assessed by a three-dimensional motion analyzing apparatus in the range of 50°–100° of knee flexion[15)].

The universal goniometer had a handle 30 cm in length and angle marks in 1° increments. The measurement landmarks were the greater trochanter, lateral epicondyle of the femur, head of the fibula, and lateral malleolus. The angle formed by the line connecting the greater trochanter and the lateral epicondyle of the femur, and the line connecting the head of the fibula and the lateral malleolus were measured by the participants in 1° increments. The participants performed the measurements using their usual technique; no instructions were provided regarding the confirmation of the localization of landmarks by palpation, the technique for passively flexing the knee, and the method used to position the goniometer on the leg. As soon as the participants completed their measurement, they were instructed to announce "done" and report the measurement to the experimenter. The experimenter marked the end of the trial into the data logger using an external event trigger (IS3, DKH, Japan). This event marker was used to synchronize the signal from the electrogoniometer with the end-position as measured using the universal goniometer.

During the trials, the right knee joint flexion was set to angles of 60° ± 10°, 75° ± 10°, and 90° ± 10°. The person to be measured watched the display of the feedback logger, and when the set angle was reached, announced that "the knee will not bend any further" and resisted the force being applied to flex the knee by the participant. The measurement time was set as the interval between external inputs from the event marker (i.e. the time from the start of the trial), including the palpation of bony landmarks, to the time at which the participant announced "done".

Motor learning is defined as “a set of internal processes associated with practice or experience, leading to a relatively permanent change in the capability for movement”[21]. Therefore, among the performance changes caused by practice, only a relatively permanent change can be regarded as a result of motor learning[22, 23]. Based on the concept that temporary effects disappear with time, the transfer design has been devised as a research design to confirm the results of motor learning[24]. In the present study, we used experimental procedures based on the transfer design.

We randomly assigned the participants to FB (n=11) and non-FB groups (n=11). The experiment consisted of a pretest, practice trials, and a posttest (Fig. 3). In the pretest, all participants performed three measurements without FB, at the set angles of 60° ± 10°, 75° ± 10°, and 90° ± 10° (in random order), to confirm their level of skill before practice. The practice trials started 3 minutes after the pretest and comprised three trials per block, with one trial for each of the three set angles (60° ± 10°, 75° ± 10°, and 90° ± 10°; in random order). Participants completed a total of 5 practice blocks (a total of 15 trials). During the practice trials, the FB group was given the value measured by the electrogoniometer as extrinsic FB, after the participant had reported their measured value. In contrast, the non-FB group did not receive extrinsic FB. The posttest was performed 24 hours after the practice trials to determine the change in the measurement skill itself, by eliminating the temporary effects of practice. The content of posttest was the same as that in the pretest; no FB was provided to either group.

The primary outcome of this study was the improvement rate from pretest to posttest, which represents the degree of motor learning. For improvement rates, data normality was evaluated using the Shapiro-Wilk test, and differences between the groups were evaluated using the Welch’s t-test or the Mann-Whitney U test, as appropriate. The secondary outcomes were the average measurement error and average measurement time within the pretest, blocks 1–5, and posttest. The measurement

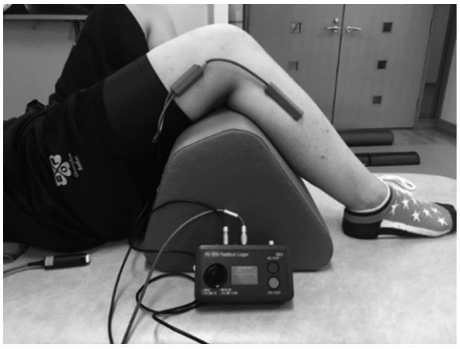

Fig. 1. Position of the electrogoniometer. The proximal attachment point was localized to 1 cm from the lateral epicondyle of the femur, along a line connecting the greater trochanter and the lateral epicondyle of the femur. The distal attachment point was localized to 1 cm from the head of the fibula, along a line connecting the head of the fibula and the lateral malleolus.

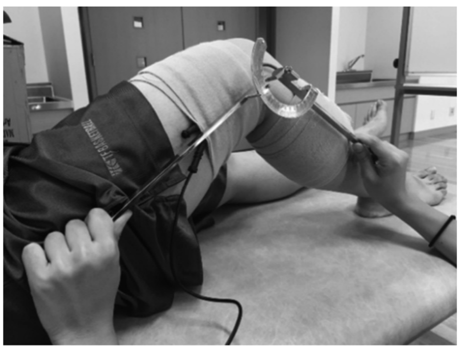

Fig. 2. Measurement of the knee range of motion using a universal goniometer. An elastic wrap was used to prevent its slippage during measurements, as well as to hide its position from the participants. The participants performed the measurements using their usual technique.

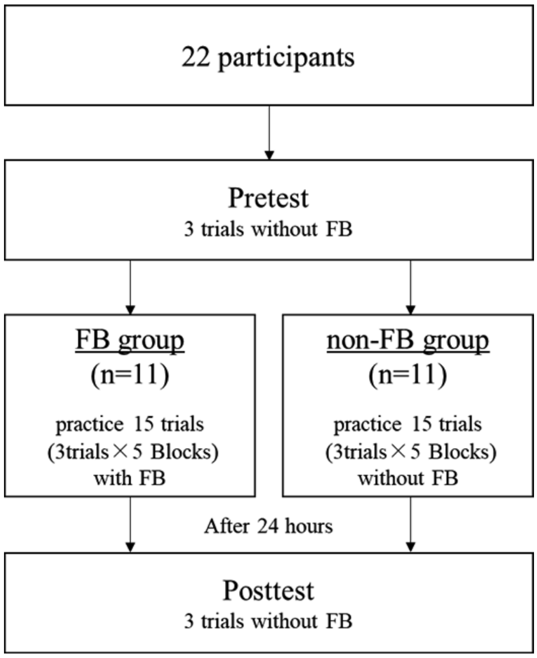

Fig. 3. Experimental design. During the practice trials, the FB group was given the value measured by the electrogoniometer as extrinsic FB, after the participant had reported their measured value. In contrast, the non-FB group did not receive extrinsic FB. In the pretest and posttest, all participants performed three measurements without FB.

error and measurement time were analyzed using two-way ANOVA (group [FB, non-FB] ×measurement sequence [pretest, blocks 1–5, posttest]), with the measurement sequence as a repeated measure. For significant interactions, simple main effect tests were performed. All statistical analyses were performed using an Excel statistical software package (BellCurve for Excel, Social Survey Research Information Co., Ltd., Tokyo, Japan), and the significance level was set at 5%.

RESULTS

The improvement rate of the measurement error was 34.4 ± 26.4% in the FB group and −9.6 ± 57.9% in the non-FB group. Since normality was confirmed, Welch's t-test was used to compare the groups. The FB group had a significantly greater measurement error improvement rate than that of the non-FB group (p=0.038, Cohen's d=1.03).

Table 1 shows the measurement errors in the pretest, practice trials (blocks 1–5), and posttest for both groups. The results of ANOVA indicated that although the main effects of group ($F_{1,20}$=0.89, p=0.36) and measurement sequence ($F_{6,120}$=1.11, p=0.36) were not significant, there was a significant interaction between group and measurement sequence ($F_{6,120}$=2.96, p=0.010). The simple main effect test revealed that the measurement error was significantly smaller in the FB group than in the non-FB group in block 5 (p=0.029). Furthermore, in the FB group, blocks 4, 5 and posttest had significantly less measurement error compared to that in pretest (p=0.002, p<0.001 and p=0.002, respectively) and block 1 (p=0.009, p<0.001 and p=0.010, respectively). In contrast, there were no significant simple main effects in the non-FB group.

The improvement rate of the measurement time was 7.0 ± 31.7% in the FB group and 30.6 ± 11.8% in the non-FB group. Since normality was confirmed, Welch's t-test was used to compare between groups. The FB group had a significantly lower measurement time improvement rate than that in the non-FB group (p=0.038, Cohen's d=1.04).

Table 2 shows the measurement times in the pretest, practice trials (blocks 1–5), and posttest for both groups. The results of ANOVA indicated that although the main effect of group ($F_{1,20}$=1.58, p=0.22) and the interaction between group and measurement sequence ($F_{6,120}$=1.37, p=0.23) were not significant, there was a significant main effect for measurement sequence ($F_{6,120}$=10.61, p<0.001). Post-hoc tests using the Bonferroni method revealed that the measurement time was significantly longer in the pretest than in blocks 1–5 and the posttest (all p<0.001).

DISCUSSION

Although it is widely recognized that feedback is important for motor learning, feedback is not completely utilized in physical therapy education. The process by which a novice physiotherapist or physical therapy student learns the skill required in clinical practice is motor learning, and we believe that the effective use of feedback can lead to a more efficient improvement in skills. Therefore, in the present study, we aimed to verify an effect of extrinsic FB from a FB device on proficiency in the measurement of the ROM, which is an essential skill in physical therapy. Our results revealed that the FB group was significantly superior to the non-FB group in terms of the improvement rate of the measurement error, which reflects the results of motor learning. Additionally, extrinsic measurement error-related FB from a device during practice significantly decreased the measurement error, with an effect that persisted after 24 hours. On the other hand, the measurement error did not significantly decrease in non-FB group. Furthermore, although significance was not reached, the measurement time during the practice trials was longer in the FB group than in the non-FB group.

These results confirmed our hypothesis. Namely, it is revealed that utilizing the FB device is effective for motor learning in ROM measurement skills. We believe that it became possible for participants to use the available accurate extrinsic feedback by using a feedback device in the FB group, thereby promoting motor learning impacting their measurement skills. The participants in the FB group were able to recognize the deviation between their own measured value and the reference value, and correct their actions, resulting in a more accurate measure in the next trial. In contrast, the participants in the non-FB

Table 1. Changes in the measurement error for the FB and non-FB groups (°)

	Pretest	Block 1	Block 2	Block 3	Block 4	Block 5	Posttest
FB group	5.8 ± 1.4	5.5 ± 2.9	4.2 ± 1.8	4.1 ± 2.3	3.6 ± 1.9	3.0 ± 1.5	3.6 ± 1.3
Non-FB group	5.1 ± 2.3	4.7 ± 2.5	4.9 ± 4.6	5.1 ± 2.8	5.4 ± 3.1	5.6 ± 4.4	5.3 ± 3.2

Mean ± Standard deviation. FB: feedback.

Table 2. Changes in the measurement time for the FB and non-FB groups (sec)

	Pretest	Block 1	Block 2	Block 3	Block 4	Block 5	Posttest
FB group	34.3 ± 12.4	29.1 ± 12.2	28.1 ± 9.9	28.4 ± 9.6	24.9 ± 6.8	24.3 ± 5.1	31.1 ± 15.1
Non-FB group	31.8 ± 8.8	24.4 ± 9.6	22.3 ± 7.6	22.3 ± 7.8	22.3 ± 9.6	21.7 ± 11.0	22.3 ± 8.7

Mean ± Standard deviation. FB: feedback.

group were only able to use intrinsic FB. They were not provided information regarding whether it was necessary to modify their actions or to what extent their actions needed to be modified. It is thought that motor learning will not occur in such situations[25, 26]. Furthermore, in general educational situations, there is feedback from the instructor that is an extrinsic FB that can be used by the learner. However, the accuracy of the instructor's feedback is uncertain, as it is based on the instructor's visual estimation. Watkins et al. examined the intertester reliability for measurements of the knee ROM by visual estimation among physical therapists who had a mean of 7.2 ± 4.0 years of experience[27]. The authors reported that the intraclass correlation coefficient values for intertester reliability in visual estimations were 0.83 for knee flexion and 0.82 for knee extension. Moreover, Croxford et al. revealed that intertester variation and measurement error in visual estimation are twice those of the universal goniometer (coefficient of variation: 69.4% for visual estimation, 34.87% for universal goniometer; measurement error: 11.1° for visual estimation, 5.5° for universal goniometer)[28]. As such, the extrinsic feedback provided to the learner by the instructor's visual estimation may be inadequate to cause an improvement in the learner's measurement skills. The feedback needs to be accurate because the learner corrects their performance based on the feedback information; using a device that can provide accurate extrinsic feedback is considered as effective. Therefore, motor learning occurred in the FB group, but did not occur in the non-FB group.

The influence of FB on the motivational aspect of the participants should also be considered in explaining the improved accuracy in the FB group. FB has the effect of guiding the learner's actions in a desirable direction, but also has motivational effects that have an important influence on learning[24, 29, 30]. As a theory focused on motivational aspect of motor learning, Wulf and Lewthwaite proposed optimizing performance through intrinsic motivation and attention[30]. In this learning theory, extrinsic feedback plays a major role in creating positive motivation in participants. In particular, extrinsic feedback that enhances expectancies for future performance, such as positive feedback[31], has been shown to enhance learner performance and motor learning outcomes by increasing intrinsic motivation. In the present study, the extrinsic FB may have motivated the participants in the FB group, resulting in increased motivation for improvements in their measurement skills. However, in the non-FB group, knowledge regarding the measurement error could not be given; thus, there is a possibility that motivation for learning gradually declined. This is consistent with the observed tendency for the measurement error to increase over the practice blocks in the non-FB group. However, we did not directly measure the motivation of the participants because the purpose of this study was to examine whether the use of a FB device enhances the improvement in measurement ROM skills. As this study has revealed that the use of a feedback device enhances the learner's measurement skills, further research is needed to directly investigate the effects of using feedback devices on learner motivation.

In addition, the results of the present study suggest that the information processing caused by the extrinsic FB affected the measurement time. Extrinsic FB was provided only during the practice trials to participants in the FB group. During this time, the participants had to perform information processing tasks, such as the recognition of the FB, collation of the result with the FB information, and generation of a measurement plan to correct the error[32, 33]. On the other hand, since FB was not provided to participants in the non-FB group, these information processing tasks were not performed. With the progress of practice, the error became smaller and the necessary correction became slight; thus, the measurement time was comparable to that in the non-FB group. Moreover, although the measurement time in the pretest was similar in both groups, the lower improvement rate in the FB group than in the non-FB group might be because there is more information to be recalled in the FB group than in the non-FB group. Participants in the FB group need to process a lot of information with regard to extrinsic FB during practice. In this group, it is considered that the measurement time is extended in the posttest measurement because the measurement is performed while recalling information. On the other hand, as there is limited information to be recalled in the non-FB group, the measurement time is considered to be short.

Finally, the present study has some limitations to acknowledge. First, we could not perform a priori sample size calculation in this study. The reason is that this is the first study to examine extrinsic FB from a FB device with regard to proficiency in the measurement of the joint ROM, and there was no previous study that could be referenced. In a further study, it is necessary to conduct a priori sample size calculation according to the results of this study. Second, since we evaluated only knee flexion ROM measurement, it is unclear as to whether the results can be generalized to other joints. Moreover, extrinsic FB was provided by the use of experimental equipment, such as an electrogoniometer and feedback logger, which are difficult to utilize in an educational setting. Thus, in the future, we plan to develop a FB provision method using widely popular devices, such as smartphones. Furthermore, we plan to construct a method that more easily allows the utilization of FB information.

In conclusion, the present study demonstrates that extrinsic FB during practice improves the measurement error in the measurement of the knee joint ROM using a universal goniometer, and that the learning effect persists after 24 hours. Thus, the utilization of extrinsic FB from a FB device is effective for enhancing ROM measurement skills. Furthermore, the findings obtained in this study suggest that physical therapy skills can be effectively improved by providing extrinsic FB. We believe that the application of extrinsic FB in physical therapy education will lead to effective educational methods.

Conflict of interest

The authors report no conflict of interest.

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