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Expert article

Self-controlled practice enhances motor learning: implications for physiotherapy

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Abstract

Studies examining the effects of self-controlled (learner-controlled) practice on motor skill learning are reviewed. The findings show that allowing learners to control the delivery of feedback, use of physical assistive devices, or the presentation of movement demonstrations can enhance learning compared with external control of these factors. Possible reasons for the learning benefits of self-controlled practice are discussed. In particular, self-control seems to enhance the learner's motivation, which, in turn, results in deeper information processing and ultimately improves retention and transfer. Implications of these findings for physiotherapy are outlined. For example, feedback or demonstrations of the goal movement might be more effective if patients had some control over its frequency and time of delivery. Furthermore, giving patients the opportunity to decide when and how often they use an assistive device might speed up the recovery process. However, patient studies are still lacking and more research is needed to examine the extent to which the findings reported here can be generalised to various patient populations.

Keywords: Motor learning; Self-control; Feedback; Assistive devices; Demonstration

In most training situations that involve the learning of motor skills, the instructor determines the details of the training protocol. This is similar in physiotherapy, where the therapist prescribes, for example, the exercises that he or she wants the patient to perform, the order of different exercises, and the number of sets and repetitions for each. The physiotherapist also provides feedback to the patient about correct or incorrect parts of the movement, and may give demonstrations of the goal movement pattern. Thus, while the therapist controls almost all aspects of the therapeutic intervention, the patient assumes a relatively passive role. This is understandable given the typically vast differences in the competency levels of therapists and patients.

However, a number of studies have shown that the effectiveness of motor skill learning can be enhanced considerably if the learner is given at least some control over the practice conditions. That is, training protocols that grant the learner at least some degree of self-control generally result in more effective learning than training protocols that are completely prescribed. The goal of this article is to provide an overview of some of these findings, and to outline the implications that these results have for physiotherapy. Specifically, the focus will be on studies that examined self-control with respect to the delivery of feedback, the use of physical assistance devices, and demonstrations of the goal movement. Although studies involving patient populations are still lacking, the relative robustness of the benefits of self-controlled practice suggest that the effects may be generalisable to a relatively wide range of populations. The incorporation of self-controlled training into physiotherapy practice has the potential to reduce the time and costs of interventions. In this way, the impact of a relatively simple change in the organisation of training could be substantial.

Experimental findings

Feedback

The first studies to examine the effects of self-controlled feedback schedules on motor learning were conducted by

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Janelle et al. [1,2]. In one of those studies, young, healthy volunteers practiced throwing a ball at a target with their non-dominant arm [1]. One group of learners ('self-control') was allowed to decide when they wanted to receive feedback regarding movement form. If requested, the experimenter would provide 1 of 10 feedback statements that was most appropriate, based on the participant's performance in the previous trials. Each participant in the self-control group was yoked to one participant in another group, the so-called 'yoked group', such that the yoked counterpart received feedback (about his or her own performance) in the same trials in which the respective self-control learner had requested feedback (e.g. Trials 1, 3, 4, 7, etc.). The purpose of such a yoking procedure, which is typically used in studies on self-controlled practice, is to control for the amount and scheduling of feedback (or whatever factor is controlled by the learner). As, on average, the frequency and timing of feedback are identical in the self-control and yoked groups, any group differences that emerge on retention or transfer tests can be attributed to the fact that one group had control over a certain variable while the other group did not. In the study by Janelle et al. [1], self-control participants demonstrated more effective learning of the movement form than yoked participants. In a retention test without feedback, which was performed 4 days after the practice phase, the self-control group's average form scores were about 15% higher than those of the yoked group. In addition, their throwing accuracy was enhanced. Thus, although the frequency and scheduling of feedback was identical under both conditions, giving learners the opportunity to decide for themselves when they wanted to receive feedback was more beneficial than the externally controlled (yoked) feedback schedule.

Other studies have found learning advantages of self-controlled feedback for sequential timing tasks [3,4]. For example, Chiviacowsky and Wulf [4] used a task that required participants to press four keys (2, 4, 8 and 6) on the numerical keypad of a computer keyboard in a prescribed temporal sequence. The goal movement times for each of the three movement segments (between keys) were 200, 400 and 300 milliseconds. Feedback consisted of the actual movement times, as well as the goal movement times, for each movement segment. When the production to novel goal movement times (300, 600 and 450 milliseconds) was required in a transfer test, the self-controlled feedback group again outperformed the yoked group. The average deviations from the goal movement time were 197.8 milliseconds [standard deviation (S.D.) 115.9] for the self-control group and 310.9 milliseconds (S.D. 142.9) for the yoked group. This finding demonstrates that self-controlled feedback cannot only enhance the retention of motor skills, but can also transfer to novel variations of the skill.

An interesting aspect of Chiviacowsky and Wulf's study [4] was a questionnaire designed to find out when self-control learners decided to request (or not to request) feedback, and when yoked learners would have preferred to receive feedback. The findings revealed that both groups of participants preferred feedback after they thought they had a 'good' trial. Out of 15 self-control participants, 10 indicated that they asked for feedback predominantly after good trials, while only 4 said that they had asked for feedback mainly after poor trials. In the yoked group, seven participants indicated that they would have preferred to receive feedback after good trials, whereas only one participant would have preferred feedback after poor trials. The remaining participants gave other responses. Also, self-control learners asked for feedback predominantly after relatively successful trials, as demonstrated by a comparison of their error scores in trials for which they requested, or did not request, feedback. Thus, learners apparently had a relatively good feel for how they performed. For yoked learners, of course, no such relationship between feedback/no feedback trials and performance was evident. This provided preliminary support for the idea that self-controlled practice may be more effective because it is more tailored to the learner's needs or preferences.

Additional evidence for this view comes from another study by Chiviacowsky and Wulf [5]. In contrast to typical studies on self-controlled feedback [1,2,4] where learners make a decision about feedback *after* a trial, one group of learners decided after each trial, whereas another group decided before each trial. The results showed that asking learners *before* a trial to decide whether they wanted to receive feedback after that trial was not as effective as allowing them to defer this decision until the trial was complete. This is in line with the view that when individuals are given the opportunity to make that decision afterwards, they take into account their (perceived) performance in that trial. If they believe that their performance was good, they tend to ask for feedback, presumably as a confirmation that they are on the 'right track'.

While studies on self-controlled practice have almost exclusively used adults as participants, a more recent experiment examined whether similar benefits of self-controlled practice would also be found for children [6]. In that study, 10-year-old, healthy children practiced tossing beanbags at a target with their non-dominant arm. The circular target had a radius of 10 cm and was placed on the floor at a distance of 3 m from the participant. Concentric circles around the target marked zones (10 cm in width) to assess the accuracy of the throws. Participants were blindfolded and therefore had to rely on the feedback given to them by the experimenter. Feedback indicated whether the target was under- or overshot, whether the beanbag landed to the left or right of the midline, and whether it landed in the inner or outer 5 of the 10 zones around the target (e.g., 'long, left, near'). One group received feedback regarding the accuracy of their throws at their request, while another (yoked) group had no control over the feedback schedule. The accuracy of the throws was scored in the following manner. If the beanbag landed in the centre of the target, 100 points were awarded. If it landed in one of the other zones, 90, 80, 70, 60, etc., points were recorded, respectively. The results showed that, similar to adult learners, self-control feedback resulted in a significant learning advantage (i.e. more accurate throws) in a retention test without feedback that was performed 1 day after practice. While the self-control group had an average accuracy score of 41.2 (S.D. 20.7), the yoked group had an average score of only 25.1 (S.D. 18.3) in retention. Interestingly, children in the self-control group also asked for feedback more frequently after relatively good trials than after poor trials (similar to the adults in Chiviacowsky and Wulf's study [4]). This suggests that the children had a fairly good feel for the accuracy of their throws.

Overall, these studies provide converging evidence that giving learners the opportunity to choose feedback is more advantageous to learning than prescribed feedback schedules. Interestingly, the percentage of practice trials in which self-control learners requested feedback varied widely between studies, ranging from 11% [1] through 28% [6], 35% [4] up to 97% [3]. The frequency of feedback requests may depend on the nature of the task or on the exact instructions given to participants (i.e. to what extent they encourage the learner to ask for feedback). However, it appears that the feedback frequency is clearly less important than the learner's ability to choose or not to choose feedback. Otherwise, it would be difficult to see why learning advantages for self-controlled feedback occurred when the feedback frequency was almost 100% [3]. This also suggests that motivation plays an important mediating role in this context. Possible explanations for the effects of self-controlled practice are discussed in more detail in a later section.

Assistive devices

Other studies have looked at the self-controlled use of physical assistive devices in the learning of balance skills [7–9]. In one study, young, healthy university students practiced a ski-simulator task [9]. The ski simulator consists of a pair of bowed rails and a platform on wheels attached to the end of the apparatus by rubber belts. The platform, on which the performer stands, can be made to move sideways on the rails by making slalom-type movements. The participant's task was to produce the largest possible amplitudes. The physical assistance devices used in this study were ski poles [9]. These generally facilitate the maintenance of balance and have been shown to enhance the learning of this task [10]. The poles were placed on the floor in front of the ski simulator and remained in contact with the floor throughout the whole trial. Participants in the self-control group were allowed to choose the trials in which they wanted to use the poles during practice. While there were no differences between this group and a yoked control group during practice, the self-control participants clearly showed more effective learning in a retention test than did their yoked counterparts. That is, they produced significantly larger amplitudes without the assistive devices on the following day. The average movement amplitude for the self-control group was 46 cm, with the maximum amplitude to either side being 55 cm, whereas the yoked group had an average amplitude of 39.5 cm.

While the participants practiced individually in this and other studies [1,2], Wulf et al. [8] had self-control and yoked participants practice the ski-simulator task in dyads (pairs). Participants were young, healthy volunteers. Despite the potentially powerful effects of learners being able to observe, and perhaps compete with, each other [11,12], which may have negated any effects of self-control, the self-controlled use of ski poles still resulted in more effective learning. Although there were no differences between groups in amplitude and frequency, i.e. aspects of the movement that can be easily observed, the self-control group demonstrated a more efficient technique (as indicated by the weight shift from one leg to the other). This suggests that self-control learners engaged in different information processing activities, such as a search for the optimal movement pattern, or that these activities were facilitated by their ability to choose, or not to choose, the assistive devices.

In a recent study, Hartman [7] used another balance task (stabilometer) and allowed one group of young, healthy university students to decide the trials in which they wanted to use poles as assistive devices. The stabilometer consists of a platform that tilts 15° to the left or right, and the performer's task is to try to keep the platform horizontal. The platform was considered to be 'in balance' if it is within a range of ±3° to either side. After 20 practice trials, each of 30-seconds duration, under either self-control or yoked conditions, participants performed a retention test without the use of a pole. Hartman [7] found that the self-controlled use of poles again significantly enhanced the learning of this task compared with a yoked condition. In the retention test, the average time in balance was 21.1 seconds (S.D. 2.98) for the self-control group and 16.6 seconds (S.D. 3.64) for the yoked group. This is particularly interesting because, in a pilot study, Hartman did not find any advantages of using the poles, as compared to not using poles, for the learning of this task. This suggests that control over an assistive device can have a beneficial effect on learning, even if that device in and of itself is relatively ineffective.

Demonstrations

Learning through observation, or modelling, is a commonly used technique when it comes to teaching motor skills [13,14]. This includes physiotherapy, where the therapist may demonstrate the goal movement to the patient. A recent study looked at whether providing model presentations at the learners' request would enhance learning, compared with providing them without consideration for their preferences [15]. In that study, young, unimpaired participants practiced a basketball jump shot. A video of a skilled model could either be requested (self-control) or was provided at the respective times (yoked) during the practice phase. The main performance measure of interest was the quality of the movement form, as measured by expert ratings (maximum possible score 10). After a 7-day retention interval, the self-control group had significantly higher form scores (mean 4.1, S.D. 3.1) than

Table 1
Reasons for the advantages of self-control

• Practice is more tailored to learners' needs (e.g. feedback, assistive devices, movement demonstrations)
• Learners have the option of receiving feedback after 'good' trials
• Learners may extract more, or more relevant, information from model presentation
• In general, self-control leads to increased motivation, more active involvement of the learner, and 'deeper' information processing

the yoked group (mean 3.6, S.D. 2.8). Moreover, in contrast to yoked learners, self-control participants did not show a performance decrement across the retention interval. Interestingly, the differential learning effects occurred despite a relatively low frequency of model presentations (5.8% of the practice trials).

Explanations for the benefits of self-controlled practice

Self-controlled practice conditions have been assumed to enhance learning because they lead to more active involvement of the learner in the learning process, and encourage learners to take charge of their own learning process. This, in turn, may make learning more motivating and increase the effort invested in practice [16–18]. In addition, as Chiviacowsky and Wulf [4] have argued, self-controlled practice conditions may be more in line with the learner's needs or preferences compared with externally controlled conditions. For example, with regard to the use of assistive devices, self-controlled practice may result in more effective learning because it allows learners to explore movement strategies to a greater extent than practice without self-control [9]. That is, the learner may try out a certain strategy with the assistive devices in one trial, and then without devices in the next trial. Recent results by Hartman [7] provide support for this view. In interviews, his participants indicated that they requested balance poles primarily when they wanted to try out a new strategy to help them maintain their balance on the stabilometer. In contrast, the majority of yoked participants said that they did not receive the poles at the right times. The predetermined, essentially random, schedule presumably thwarted any of their attempts at exploring different ways to perform more effectively.

Similarly, Chiviacowsky and Wulf [4] suggested that self-controlled feedback may be more effective than externally controlled feedback because it corresponds more to the learner's needs. The findings of their study supported this contention in that self-controlled learners not only indicated that they preferred feedback after 'good' trials, but their performance data also showed that they asked for feedback mainly after relatively successful trials. This, of course, was not the case for yoked learners. Interestingly, a recent follow-up study demonstrated that feedback is, in fact, more effective for learning when it is presented after good rather than poor trials [19]. While this finding contrasts with the current predominant view of feedback, according to which feedback after larger errors should be more beneficial than feedback after smaller errors (referring to informational properties of feedback) [20,21], it indicates that the motivational properties of feedback also seem to have a significant effect on learning.

With respect to observational learning, learners may extract more, or more relevant, information from the model presentation when they have the opportunity to request information. For instance, self-control learners may pay particular attention to aspects of the movement of which they are uncertain, either to identify errors or to obtain confirmation that their movement is correct. In contrast, learners without the opportunity to request demonstrations may be less inclined to engage in such information processing activities due to the unpredictability of the model presentations.

Overall, the picture that emerges from these studies is that the benefits of self-controlled feedback are due primarily to more active involvement of the learner in the learning process, with a concomitant increase in motivation. This, in turn, seems to lead to deeper information processing and ultimately to enhanced learning (see Table 1).

Implications for physiotherapy

Although studies examining the effectiveness of self-controlled practice in patients are lacking, those conducted with young, healthy adults or children suggest that this factor has a strong and robust effect on learning. In addition, learning advantages of self-controlled practice conditions have been shown for a variety of variables (i.e. feedback, assistive devices, movement demonstrations). The reliability of this phenomenon also increases our confidence that the effects may be generalisable to other populations, such as various patient populations.

However, it should be noted that in experimental studies, self-control conditions are typically compared with yoked conditions in which feedback, demonstrations, etc., are provided essentially randomly. This may be different from most physiotherapy settings, where the therapist provides the patient with feedback, etc., when she or he appears to need it. Thus, it is possible that the benefits of self-controlled practice in practical settings would not be quite as large as they are in the laboratory. However, the motivational effects associated with the opportunity to have an influence on the practice conditions are likely to have a positive impact on the outcome of the therapeutic intervention. Nevertheless, the potential implications for physiotherapy outlined below should be viewed with caution, and with the understanding that research studies with patient populations do not yet exist.

The factors examined in previous studies on self-control, i.e. feedback, physical assistive devices and demonstrations, have applicability to physiotherapy practice. Assistive devices, such as walkers or crutches, are often used as an aid in the patient's recovery, with the goal being the patient's independence from those devices as soon as the desired movement goal has been achieved. Based on the findings discussed above [7–9], giving patients the opportunity to decide when and how often they use an assistive device may speed up the recovery process. As well as helping to overcome some of the patient's resistance when the decision is made by their physical therapist, it may also promote the patient's confidence in performing without the assistive device [22]. Thus, because of the patient's greater involvement in this process, he or she may (re-)learn the goal movement pattern faster and become less dependent upon the device at an earlier stage.

Feedback is another factor that could presumably be used more effectively if patients had some control over its frequency and time of delivery. While practitioners may be concerned that patients would perhaps request feedback too infrequently or not at the right times, there is evidence to suggest that this concern may not be justified. First, a common assumption is that feedback should be given frequently, so that errors are avoided as much as possible and incorrect movement patterns do not become automated. However, this view has been refuted by experimental research. Numerous studies have shown that feedback provided after every trial can even be detrimental to learning compared with a reduced frequency of feedback [21,23]. However, it should be noted that the learning of complex, as opposed to simple, motor skills does not seem to suffer from frequently provided feedback [24]. Second, it appears that individuals often have a good feel for how they perform [4,19], although this remains to be demonstrated for patient populations (e.g. those with stroke) and for more complex tasks, and that they prefer feedback after 'good' trials. While this preference seems to contradict the common notion that feedback should be more effective after less successful trials, feedback after successful trials has, in fact, been shown to be more effective [19]. Thus, it appears that the concern that patients may not have the competency to make decisions regarding feedback or other aspects of their rehabilitation process may be unfounded. Rather, the findings discussed here should encourage physiotherapists to conduct their own 'experiments' by giving their patients the opportunity to have at least some control over the practice regimens.

Finally, it should be pointed out that the benefits of self-controlled practice are not always immediately apparent. In many experimental studies, performance differences between self-control and yoked groups did not occur until retention or transfer testing at a later time. Thus, it appears that self-control and yoked conditions have different effects on practice performance compared with learning (retention/transfer). As self-controlled practice presumably involves continuous assessments of one's performance and decision-making processes regarding feedback or movement demonstrations, for example, it may make practice more 'difficult', temporarily depressing performance. However, it is exactly these additional information processing activities that are presumably the reason for the benefits of self-controlled practice in the long term. Physiotherapists (and patients) should be aware of the fact that the beneficial effects of self-controlled training may be delayed, and any lack of immediate performance enhancement should not deter them from relinquishing some control over the practice conditions to their patients. Taking advantage of the effects discussed here may have the potential to enhance the effectiveness of training, and to result in concomitant savings in terms of the time and costs involved in physiotherapy.

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