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Self-Controlled Feedback Is Effective if It Is Based on the Learner's Performance

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The study follows up on the contention that self-controlled feedback schedules benefit learning, because they are more tailored to the performers' needs than externally controlled feedback schedules (Chiviacowsky & Wulf, 2002). Under this assumption, one would expect learning advantages for individuals who decide whether they want to receive feedback after a trial rather than before a trial. Participants practiced a sequential timing task, and all could decide the trials on which they received feedback. One group ("self-after") decided after every trial whether they wanted to receive feedback for that trial, while another group ("self-before") made that decision before each trial. The self-after group showed learning benefits on a delayed transfer test (novel absolute timing requirements) with regard to overall timing and relative-timing accuracy. Thus, self-controlled feedback was more effective when the learner could make a decision about receiving feedback after the trial. This seems to support the view that self-controlled feedback benefits learning, because learners can make a decision about feedback based on their performance on a given trial.

Evidence for the learning benefits of practice that incorporates some form of self-control by the learner has increased over the past few years. Janelle and colleagues (Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Janelle, Kim, & Singer, 1995) were the first to examine the effectiveness of learner-controlled feedback for motor learning. For example, using a novel throwing task, Janelle et al. (1997) had learners decide when they wanted to receive feedback about movement form. Self-control group participants showed clear learning advantages compared to those who were yoked to a participant in the self-control group with regard to when and if they received feedback. That is, even though the feedback schedule was identical for both groups, learn-

ers who decided when to receive feedback benefited more than those with an externally controlled (yoked) feedback schedule. More recently, Chiviacowsky and Wulf (2002) found advantages of self-controlled feedback for learning a timing task. Furthermore, a study by Wulf and Toole (1999; see also Wulf, Clauss, Shea, & Whitacre, 2001) demonstrated that allowing participants to choose when to use physical assistance devices in learning a ski-simulator task led to more effective learning, relative to a yoked condition. Finally, in a recent study, Wulf, Raupach, and Pfeiffer (2005) found that giving learners the opportunity to decide when to see a video model enhanced their learning of a sport skill (basketball free-throw), relative to a yoked control condition.

Despite the relatively robust nature of this phenomenon, studies investigating the underlying reasons for the learning benefits of self-controlled practice are limited. According to early explanations, which were adapted from the verbal or cognitive learning domain (e.g., Carver & Scheier, 1990; Paris & Winograd, 1990; Zimmerman, 1989), the perception of self-control enhances learning, because it leads to more active involvement of the learner in the learning process. This, in turn, is assumed to promote a deeper processing of relevant information (e.g.,

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McCombs, 1989; Watkins, 1984; see also Chen & Singer, 1992). Furthermore, it has been suggested that giving learners control of the practice regimen might increase their motivation (Bandura, 1993; Boekaerts, 1996), promote the use of self-regulation strategies (Kirschenbaum, 1984), and encourage them to take charge of their learning process (e.g., Ferrari, 1996). Empirical studies to test these hypotheses appear to be lacking, however. With regard to motor learning, Wulf and Toole (1999) suggested that self-controlled practice might result in more effective learning, because it encourages learners to explore different movement strategies to a greater extent than practice without self-control. Wulf et al. (2001) provided some support for this hypothesis.

Chiviacowsky and Wulf (2002) suggested another possible explanation. They argued that self-controlled practice conditions may be more tailored to the learner's needs relative to yoked conditions. For example, learners may ask for physical assistance devices when they are insecure, or they may request feedback when uncertain about how to perform. Participant interviews and performance data supported this view (Chiviacowsky & Wulf, 2002). Self-controlled learners asked for feedback primarily after they thought they had a "good" trial— presumably as confirmation that they were on the "right track." In contrast, yoked learners did not have the privilege of feedback when they preferred to receive it (as indicated by their interviews and performance). It is, therefore, possible that the greater correspondence between performance on a given trial, the performer's desire for and delivery of feedback under self-controlled, relative to yoked conditions, is largely responsible for the learning benefits of self-controlled practice.

The purpose of the present study was to examine this hypothesis further. Specifically, we compared two self-control conditions: one in which learners decided *after* a trial whether to receive feedback (as was the case in previous experimental studies; e.g., Chiviacowsky & Wulf, 2002; Janelle et al., 1995, 1997), and one in which learners decided *before* a trial whether they to receive feedback after that trial. We argued that, if self-control benefits are primarily due to motivational factors, a more active involvement of the learner in the learning process or enhanced information processing (e.g., Bandura, 1993; Boekaerts, 1996; Ferrari, 1996; McCombs, 1989; Watkins, 1984), there should be no differences between groups, as participants in both groups could control feedback provision; the only difference between groups would be the time of their decision. However, if an advantage of self-controlled feedback is that learners receive feedback when want—*and* if this preference is a function of their (estimated) performance on a given trial—the learning benefits should be greater if learners can decide after a trial, rather than beforehand, whether to receive feedback after the trial. If learners

have to make this decision before a trial, they obviously won't know what the (subjective) outcome will be, and, thus, whether they will "need" feedback. Only when the learner performs the movement can he or she make an informed decision as to whether feedback is needed.

We used the same sequential timing task used in the Chiviacowsky and Wulf (2002) study. Participants were required to press four keys in specified goal movement times (MTs). Both groups could request feedback about the actual MTs. However, the so-called "self-before" group had to decide before a given trial whether to receive feedback after this trial, whereas another group ("self-after") made this decision after the trial. As both groups had self-control, it was necessary to ensure that the amount of feedback each group received was identical. Thus, all participants were asked to choose 3 trials in every block of 10 for which they wanted to receive feedback. Although this procedure limited the degree of self-control somewhat, it was necessary to avoid a possible confound of condition (group) and feedback frequency.

We analyzed participants' performance in terms of accuracy in both absolute and relative timing in addition to their overall performance (as in Chiviacowsky & Wulf, 2002). Relative timing performance is often viewed as a measure of the underlying movement structure, or generalized motor program (GMP), whereas absolute timing performance is seen as a measure of the capability to parameterize an action appropriately (e.g., Schmidt, 1975, 1985). In the Chiviacowsky and Wulf (2002) study, differences between self-control and yoked group were found for absolute timing but not for relative timing. Thus, we wanted to determine whether the two self-control conditions would also have differential effects on the different aspects of movement proficiency. Participants practiced under the respective conditions on 1 day, and learning was assessed in retention and transfer tests without feedback 1 day later.

Method

Participants

Fifty undergraduate students (18 men and 32 women; *M* age = 21.9 years) participated in this experiment. All participants provided informed consent. None had prior experience with the experimental task, nor were they aware of our specific purpose in the study.

Apparatus and Task

A computer, color monitor, and keyboard were placed on a standard table. Participants were asked to sit on a chair and keep their arms unsupported while

executing the task. The task required them to depress four keys (2, 4, 8, and 6) sequentially on the numeric keypad portion of the keyboard, using the index finger of their right hand. The goal was to be as accurate as possible with regard to the absolute goal MTs for each of the three movement segments (between keys). The goal MTs for the 3 segments were 200, 400, and 300 ms (total MT: 900 ms) for the acquisition and retention phases. In the transfer phase, the goal segment times were 300, 600, and 450 ms (total MT: 1,350 ms). Thus, the relative timing (in percentages) for the three segments in all phases of the experiment was 22.2-44.4-33.3.

Procedure

Participants were randomly assigned to the self-before and self-after groups. Using a graphic representation, the task was explained to all participants. Participants in both groups were informed that they had to control their feedback schedule (i.e., they would not receive feedback unless they requested it). The only restriction was that they had to request feedback on 3 of 10 trials. They were also informed that they eventually would have to perform the task without feedback. They were told that the feedback, when presented, would be composed of the actual segment MTs as well as the goal segment MTs. The only difference between the self-before and self-after groups was that participants in the former group were to indicate *before* a trial whether they wanted feedback after that trial, whereas participants in the latter group had to ask for feedback *after* a trial.

All participants performed 60 trials during the practice phase, and 1 day after practice they performed a retention test consisting of 10 trials on the practice task version (200-400-300 ms). In addition, participants performed 10 transfer trials on the novel task version with the same relative timing but a longer absolute duration (300-600-450 ms). No feedback was provided in either retention or transfer.

Data Analysis

To assess overall timing performance, we computed the sum of the absolute differences between the goal MT and actual MT for each movement segment. This overall timing error takes into account inaccuracies in both relative and absolute timing and can, therefore, be regarded as an overall performance measure. To determine more specifically whether group differences, if any, occurred in relative or absolute timing, we used error measures that have been used previously (e.g., Lai, Shea, Wulf, & Wright, 2000; Wright & Shea, 2001; Wulf, Lee, & Schmidt, 1994; Wulf & Schmidt, 1988) to examine these aspects of performance. To assess absolute timing performance, the absolute error (AE) was computed by

the absolute difference between the overall goal MT and the actual overall MT ($AE_{abs..tim.}$). Relative timing performance was measured by the sum of the absolute differences between the goal proportions and the actual proportions for each segment, resulting in the AE in relative timing ($AE_{rel..tim.}$).

Overall timing error, $AE_{rel..tim.}$ and $AE_{abs..tim.}$ were analyzed in 2 (group) x 6 (blocks of 10 trials) analyses of variance (ANOVAs), with repeated measures on the last factor for the practice phase, and in separate one-way ANOVAs for the retention and transfer tests.

Results

Practice

Overall Timing Errors. Errors in overall timing were similar for both groups during practice (see Figure 1, left)[1]. Both groups showed a consistent reduction in errors across blocks. The main effect of block was significant, with $F(5, 205) = 14.89$, $p < .001$. The main effect of group, $F(1, 41) < 1$, and the Group x Block interaction, $F(5, 205) < 1$, were not significant.

Relative Timing Errors. There was a general reduction in $AE_{rel..tim.}$ across practice, with the self-after group demonstrating smaller errors throughout practice (see Figure 2, left). The main effect of block was significant, $F(5, 205) = 8.42$, $p < .001$. However, the group main effect, $F(1, 41) = 1.54$, $p > .05$, and the interaction of group and block were not significant, $F(5, 205) < 1$.

Absolute Timing Errors. The self-before and self-after groups showed similar errors in absolute timing throughout practice, with $AE_{abs..tim.}$ consistently reduced across blocks (see Figure 3, left). The main effect of block was significant, $F(5, 205) = 13.05$, $p < .001$, while the group main
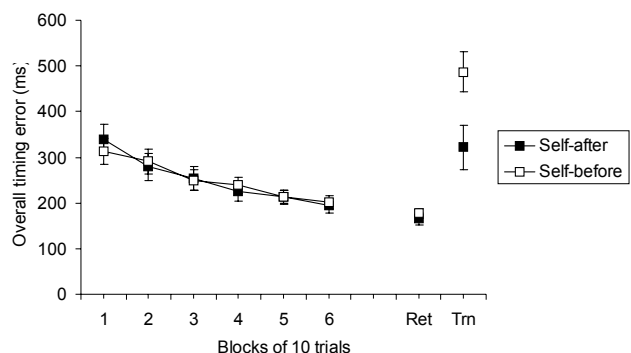

Figure 1. Overall-timing errors (and standard errors) for the self-before and self-after groups during practice, retention, and transfer.

effect was not significant, $F(1, 41) < 1$. Also, the Group x Block interaction was not significant, $F(5, 205) < 1$.

Retention and Transfer

Overall Timing Errors. There were no group differences in retention, and errors were generally comparable to those seen at the end of practice (see Figure 1, right). The main effect of group was not significant, $F(1, 41) < 1$. While both groups demonstrated an increase in overall errors when novel absolute MTs were required in transfer, the self-before group showed a considerably greater performance decrement than the self-after group. Group differences in transfer were significant, $F(1, 41) = 6. 28$, $p < .05$, with the self-after group showing clearly more accurate performance.

Relative Timing Errors. The self-after group had numerically smaller $AE_{rel..tim.}$ in both retention and transfer, compared to the self-before group (see Figure 2, right). While the group differences failed to reach significance in retention, $F(1, 41) = 1.89$, $p > .05$, they were significant in transfer, $F(1, 41) = 4.98$, $p < .05$.

Absolute Timing Errors. $AE_{abs..tim.}$ were similar for both groups in retention, $F(1, 41) < 1$ (see Figure 3, right).
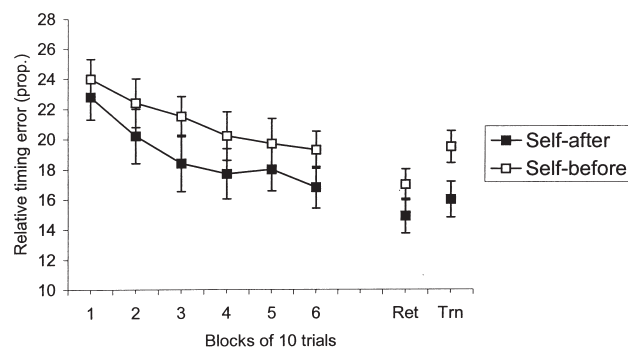

Figure 2. Relative-timing errors (and standard errors) for the self-before and self-after groups during practice, retention, and transfer.
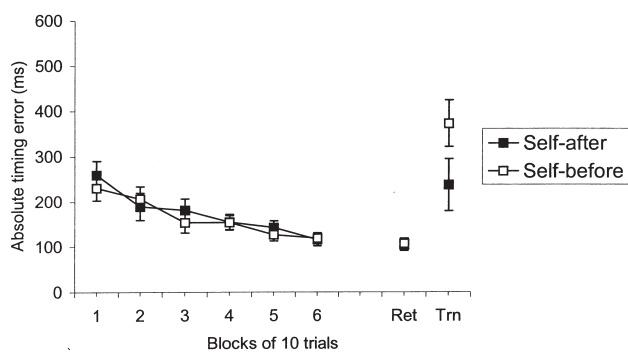

Figure 3. Absolute-timing errors (and standard errors) for the self-before and self-after groups during practice, retention, and transfer.

Although the self-after group appear to show advantages in transfer, the group effect failed to reach significance, $F(1, 41) = 3.10$, $p = .086$.

Discussion

Increasing evidence for the benefits of giving learners control over some aspect of practice (e.g., Chiviacowsky & Wulf, 2002; Janelle et al., 1995, 1997; Wulf & Toole, 1999; Wulf et al., 2001) makes this phenomenon intriguing from both practical and theoretical perspectives. Attempts to examine the reasons for these benefits have been scarce, however (for exceptions, see Chiviacowsky & Wulf, 2002; Wulf et al., 2001). The present study followed Chiviacowsky and Wulf's (2002) suggestion that self-controlled practice schedules may be more congruent with the learner's needs than prescribed (yoked) conditions. Specifically, we sought to provide more evidence for this hypothesis by manipulating self-control performers' capability to determine their "needs." By asking one group of participants to decide before each trial whether or not they wanted feedback after that trial (self-before), they were essentially prevented from using their (estimated) performance as a basis for this decision. In contrast, participants who could make this decision after the trial (self-after) could do so based on their performance. Thus, if this factor is critical for the benefits of self-controlled feedback, the self-before condition should result in less effective learning than the self-after condition.

The present results support this hypothesis. Although the two groups did not differ significantly during practice and retention, the transfer test indicated clear learning differences.[2] The self-after group was superior to the self-before group in overall performance accuracy, and additional analyses revealed this advantage was mainly due to the self-after group's greater accuracy in relative timing (although there was also a relatively strong tendency for more effective absolute timing performance). Thus, the opportunity to delay the decision about feedback until after completing a trial resulted in more effective learning than the lack of this opportunity. This result, with the findings of Chiviacowsky and Wulf (2002), strongly suggests that self-control per se—and perhaps associated increases in motivation (Bandura, 1993; Boekaerts, 1996)—is not the determining factor for the benefits of self-controlled feedback. In this case, no group differences should have been found, as both groups received the same degree of self-control, and the only difference between groups was the timing of the decision-making process. That the self-after group demonstrated more effective learning is in line with the contention that learners "normally" request feedback when it is most useful to them (Chiviacowsky & Wulf, 2002). Because determining

whether feedback is useful in a particular instance requires (subjective) information about the movement outcome, the benefits of self-controlled feedback were greater for the group who could make this decision after a trial.

Chiviacowsky and Wulf (2002) found that self-control learners asked for feedback predominantly after they thought they had a "good" rather than "bad" trial. To determine whether these findings were replicable, we calculated the average relative timing errors for trials on which participants did or did not ask for feedback during the first and the second half of practice (similar to the analysis done by Chiviacowsky and Wulf, 2002). As can be seen in Table 1, errors were lower on trials for which participants received feedback, as compared to no-feedback trials. The main effect of trial type (feedback vs. no feedback) was significant, $F(1, 41) = 5.52$, $p < .05$. (Also, not surprisingly, errors were generally lower in the first relative to the second half of practice, $F(1, 41) = 20.7$, $p < .001$.) Interestingly, *both* groups had smaller errors after feedback trials. For the self-after group, this result nicely replicates the Chiviacowsky and Wulf (2002) study and confirms that learners prefer to receive feedback after good trials; yet, it might seem somewhat surprising that the self-before group also demonstrated smaller errors on trials for which they requested feedback. It is plausible, however, that learners "tried harder" after deciding they wanted feedback after a particular trial—corroborating the view that learners prefer to have a "success experience" when they receive feedback. Thus, both groups may have benefited from a motivational influence of self-control. Of course, this factor alone cannot explain the learning advantages of the self-after condition. Clearly, there must be additional benefits to receiving feedback after a given trial. Otherwise, no group differences would have been found.

Thus, the question remains: How, exactly, does self-controlled feedback enhance learning (if the decision about its delivery is made after a trial)? When a learner can decide after a trial whether to receive feedback, the decision process presumably involves an estimation of performance on that trial. Based on the outcome of this estimation process (and perhaps certain criteria the learner might have), the learner would then decide whether or not to request feedback. Error estimations have been assumed to benefit learning, because they encourage learners to attend to their intrinsic feedback and compare it to the extrinsic feedback, which, in turn, promotes the learner's independence from the extrinsic source of information (e.g., Guadagnoli & Kohl, 2001; Swinnen, 1988; Swinnen, Schmidt, Nicholson, & Shapiro, 1990; see also Salmoni, Schmidt, & Walter, 1984; Schmidt, 1991). Therefore, it seems plausible to assume error estimation processes inherent in (regular) self-controlled feedback conditions contribute to the learning advantages. In contrast, error estimation is not feasible if a decision about feedback must be made before a trial. Similarly, error estimation may not be necessary under yoked conditions, in which the learner has no control over the feedback schedule. Thus, spontaneous error estimations under self-control conditions (self-after) may be another reason for the learning benefits seen under these conditions. This assumption could be tested in future studies by requiring self-control and yoked (or "self-before") groups to estimate their errors after each trial. If participants under self-control conditions estimate their performance spontaneously, no learning differences should be found between self-control participants required to estimate and those not required to estimate their errors. However, learning differences should be found between yoked (or "self-before") participants with and without error estimation.

A secondary issue we wanted to address in the present study was how the self-before and self-after conditions influenced relative versus absolute timing. It appeared that the effect on relative timing was stronger than on absolute timing. Both groups had similar absolute-timing errors in practice and retention, and only the self-after group showed more effective absolute-timing performance in transfer. In contrast, self-after group participants were more accurate in relative timing throughout practice and retention, and they showed significantly more accurate relative timing in transfer, which was also reflected in their overall timing accuracy. Thus, manipulating the time of the decision about feedback delivery apparently affected learning of the fundamental movement structure (or generalized motor program; Schmidt, 1975, 1985). Learning to parameterize the (novel) responses was affected to a lesser extent. This is opposite to what Chiviacowsky and Wulf (2002) found for self-control (self-after) and yoked conditions. Using the same task, they found advantages in absolute timing for self-control relative to yoked participants in transfer, while there were no differences in relative timing. However, aside from differences in the practice conditions used in their study and the present study (yoked vs. self-before), the degree of self-control was more restricted in the present study than in the Chiviacowsky and Wulf

Table 1. Relative timing errors ($AE_{rel.tim.}$) for the self-before and self-after groups during the first and second half of practice for trials with and without feedback

Half	Self-before				Self-after			
	Feedback		No feedback		Feedback		No feedback	
	M	SE	M	SE	M	SE	M	SE
1	21.2	1.4	22.2	1.5	20.2	1.6	21.8	1.6
2	18.5	1.4	20.0	1.4	17.3	1.6	18.2	1.5

Note. M = mean; *SE* = standard error.

(2002) study. Future research will be necessary to determine the extent these two aspects of movement proficiency are affected by conditions differing in the degree of self-control granted to the learner.

It should be noted that, in the present study, the degree of self-control was more restricted than in previous studies (e.g., Chiviacowsky & Wulf, 2002; Janelle et al., 1995, 1997). Typically, self-control learners are free to decide how often and when to receive feedback (and often there are large interindividual differences). In the present study, learners were required to choose 3 of every block of 10 trials for which they received feedback. Thus, the frequency of feedback (30%) was fixed, and self-control was also relatively limited with regard to the time of delivery. That group differences were seen despite these limitations underscores the powerful influence self-control of feedback has on learning.

The goal of the present study was to shed further light on how self-controlled feedback improves motor skill learning. The results showed that self-control per se (and perhaps associated increases in motivation) are not responsible for the typically seen learning benefits. Rather, a critical factor for its effectiveness appears to be the opportunity to request feedback as a function of one's performance. The error estimation processes necessary to assess one's performance might contribute to the advantages of self-controlled feedback. Yet, this issue should be investigated more directly in future studies. Further investigations into the reasons for the benefits of self-controlled practice should lead to a better understanding of this intriguing phenomenon and eventually to the design of more effective practice conditions.

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Notes

1. Some participants had extremely high error scores in either absolute or relative timing (and, thus, overall timing) in retention and/or transfer. These outliers (+/-2 standard deviations from the group mean) were removed, resulting in 19 participants in the self-after and 24 participants in the self-before group.

2. It should be noted that it is not unusual to find group differences in transfer but not in retention (e.g., Chiviacowsky & Wulf, 2002; Lai & Shea, 1998; Wrisberg & Wulf, 1997; Wulf & Lee, 1993). The ability to generalize from one's practice experience to novel task requirements is, presumably, a more sensitive measure of learning than the retention of a previously practiced task.

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