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Effects of self-controlled knowledge of performance on motor learning and self-efficacy: A kinematic study

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Abstract

Study aim: To evaluate the effects of providing the learners with self-controlled knowledge of performance (KP) on motor learning and self-efficacy (SE) in a dart-throwing motor task.
Material and methods: The participants were thirty female university students who were divided into two groups including self-control and yoked groups. Participants performed five blocks of five trials in the acquisition phase, and retention and transfer tests of 10 trials one day later. Intra-limb coordination patterns (movement pattern), throwing scores, and SE (both movement pattern and movement outcome) were measured as dependent variables. Independent t test and one-way ANOVA with repeated measures were used as statistical tests.
Results: The self-controlled group performed significantly better than yoked group on movement pattern during the acquisition phase ($F_{1,28} = 24.239$, $p = 0.001$) and the retention test ($t_{28} = –3.074$, $p = 0.007$). However, there were no significant differences between groups in terms of throwing scores and SE during the acquisition, retention, and transfer phases (all $p > 0.05$).
Conclusion: Providing self-controlled KP can improve learning of movement pattern in the novices but do not necessary increase movement outcome or SE.

Keywords: Self-controlled feedback – Performance awareness feedback – Movement pattern – Self-efficacy

Introduction

Self-controlled (learner-controlled) practice is considered as a beneficial method to acquire motor skills [7, 8, 33]. Self-controlled practice refers to situations in which a person is allowed to control or choose some aspects of practice or performance [33, 34]. In previous studies, self-controlled condition has been studied in various ways such as self-controlled augmented feedback [6, 9, 13] or video demonstration [27, 35], and choosing the color of golf balls/mat under target [23, 32] or order of practice [31]. A common finding in these studies was that self-controlled practice can facilitate motor performance and learning (for a review see [33]). Moreover, majority of research has shown that self-controlled practice would increase self-efficacy (SE) and intrinsic motivation in comparison to a yoked condition [3, 6, 13, 22, 29, 30]. However, some studies have not found any enhancements in SE and/or intrinsic motivation following self-controlled practice [26, 27, 34].

Considering the literature of self-controlled practice in motor learning context, the majority of previous studies have examined the effects of self-controlled feedback in the form of knowledge of results (KR) on motor learning and motivational state. KR relates to how successfully a skill has been performed. This is usually associated with the outcome, such as the distance a javelin has been thrown [7]. It has been shown that self-controlled KR can facilitate motor learning when compared with the yoked condition (for a review, see [25]). For instance, Chiviacowsky and Wulf [7] found that self-controlled KR benefits motor learning of a sequential timing task. Moreover, by using a throwing skill, Chiviacowsky et al. [9] replicated these results and found that children benefited from self-controlled KR practice in the retention test. There are evidences that self-controlled feedback increases motivational state (e.g., SE). Some studies showed that participants of the self-controlled KR reported greater SE at the end of the practice in comparison to the yoked group [3, 6, 13, 29]. Wulf and Lewthwaite [34] integrated the results

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of research on self-controlled practice and proposed that self-controlled practice would increase performer's expectations and subsequently by making reward-related dopamine available for memory consolidation would facilitate motor performance and learning.

Although self-controlled KR has been generally found to be effective for learning of a variety of motor tasks, the effects of self-controlled knowledge of performance (KP) on motor performance and learning as well as motivational state are less studied. KP relates to the information about how the motor skill was performed such as how a javelin has been thrown [19]. A coach may provide feedback on a player's free-kick technique (e.g., KP) or he/she may provide feedback about the outcome of a shooting accuracy (e.g., KR). Regarding to KP, Janelle et al. [19] showed that self-controlled KP (by using video replay) in conjunction with verbal KP (provided by a coach) facilitated motor learning of a ball throwing with non-dominant hand, in terms of both movement form and accuracy, compared to the yoked condition. Furthermore, Aiken et al. [1] administered self-controlled KP (by using video replay) without additional verbal KP and found that the self-controlled group had significantly better motor learning of a Basketball free throw in terms of movement form scores during the transfer test. However, movement accuracy score was not positively affected by self-controlled KP. Finally, Kok et al. [21] examined the effects of self-controlled video feedback (by using video replay) on students' motor learning and SE in secondary school students and found that self-controlled video feedback brought no advantages for motor learning of a shot-put in terms of both movement form and outcome in comparison to externally-controlled video feedback. However, they observed significant increments in SE from pretest to retention test in self-controlled video feedback group but not in the externally-controlled video feedback group. Furthermore, participants of the self-controlled video feedback group reported a higher perceived learning effect, compared to those in the externally-controlled video feedback group.

As it is obvious, the results of previous research on the effects of self-controlled KP on motor learning have shown relatively contradictory results. Some studies show a positive effect of this type of feedback on the acquisition of movement form and outcome, while others do not confirm these results. Moreover, these studies used motor tasks with different complexities and cognitive loads which may influence learning motor skills [11]. Thus, further research is required to determine the effects of self-controlled KP on motor learning. Furthermore, it is still unknown if verbal KP (provided by a coach, which is a popular method in real sport context) administered without any video feedback is an effective mode of feedback delivery within a self-controlled protocol. Finally, kinematical features of movement form were not assessed in previous studies. Therefore, the present study was designed to extent previous findings and further examine the effects of self-controlled KP (provided by a coach) on motor performance, learning, and motivational state by using a dart throwing motor task, specifically by analyzing kinematical features of movement form during the acquisition phase and retention and transfer tests. We hypothesized that participants in the self-controlled group would benefit from self-controlling the KP as demonstrated by better motor learning and higher SE in the retention and transfer tests compared to their counterparts in the yoked group.

Material and methods

Participants

The participants consisted of thirty female students (mean age of 22.4 years old) who were selected by a convenience sampling method from physical education classes at university and assigned to self-control and yoked groups (each group consisted of 15 students). All participants were right-handed and had no previous experience with motor task used in this study. This research protocol was developed and performed in accordance with the Declaration of Helsinki and was approved by the university institutional review board. Furthermore, all participants gave written informed consents.

Motor task

The motor task was throwing standard darts and hit the most desirable point on the target, i.e., the red, inner bullseye. The target was a standard dartboard numbered for the purpose of this study consisting of 10 concentric circles, each with a radius of 2.25 cm. If a dart landed in the red bullseye, participant would gain 10 points. Similarly, they would win lower points depending on where the dart landed, with 1 being the lowest score for the last circle. The participant would gain 0, when the target was completely missed. The dartboard was placed 3 meters from the oche (i.e., the line behind which the player must stand).

Apparatus

Dartboard: A standard dartboard numbered from 1 to 10 was used in the present study. The dartboard was hung 173 cm from the floor and 237 cm from the oche. In other words, the distance between the center of the bullseye and the oche was 293 cm. In this study, we used a national-level darts coach for providing the participations with initial instructions and following feedbacks during the acquisition phase as well as acting as an expert model. She was 41 years old and acted as darts coach of university team for several years. The coach gave the participants instructions as to how to stand and throw darts.

The participants were told to place their right legs on the front, to let their eyes, their hands and the dartboard form a 90-degree angle, and to hold their upper bodies upright while bending at the hips to move forward and get closer to the dartboard.

Motion analysis system: In the present study, Qualisys motion capture system was utilized to collect and analyze the data. Qualisys is one of the many motion capture and 2D/3D motion analysis systems in the world. Qualisys system is consisted of several hardwares (e.g., digital cameras, calibration system and reflective markers) and a software (Qualisys Track Manager 2.16). By using this system one can capture, process, edit, and analyze the kinematical data. To capture participants' throws, special markers were placed on their right wrist, elbow, shoulder and hip. Then, while throwing, digital cameras and system's software recorded dart throwing of the participants through tracking the reflective markers. The recorded throws were later analyzed kinematically using the system's software (Qualisys Track Manager 2.16).

Questionnaire: SE was assessed through a questionnaire consisting of 2 questions of "How certain are you that you will land one of the throws in this block in the 10-point circle" (i.e., Movement Outcome SE) and "How certain are you that your movement pattern in this block is a standard throwing pattern" (Movement Pattern SE). Likert rating scale of 10–100% was employed to evaluate SE in both questions.

Procedure

The participants were tested individually in two stages: the first was acquisition phase and the second included the retention and transfer tests. Twenty-five attempts were made in 5 blocks of 5 trials during the acquisition phase, and retention and transfer tests of 10 trials were conducted 24 hours later. The Snellen Chart was used to measure the visual acuity of the participants before the dart throwing test. A coach provided general instructions for each participant on how to hold a dart, how to throw it, and how the dartboard scoring system worked. The experimenter would then attach 4 markers to a participant's right shoulder, elbow, wrist, and hip. Each participant could throw 2 training trial darts the scores of which were not kept by the experimenter so that she could familiarize herself with the test setting and throwing conditions. At the start of the acquisition phase and on the experimenter's mark, the learner would have 4 seconds to focus and throw. Self-control participants were told that they would be allowed to receive feedback of their shooting form (e.g., KP) after any trial during acquisition. They were also told that they would not receive feedback unless they requested it. To provide feedback, a checklist was provided prior to experiment in which the most important components of a dart throwing such as movements of arm, wrist and fingers, standing posture and holding the dart were determined. When the participant in the self-control group requested feedback, the coach gave her only "one comment" regarding her most important movement error. The yoked group's participants, who were paired with the self-controlled group's participants, were also given feedback every time the self-control group asked for feedback on an attempt. Similar to the self-control group, the participant in the yoked group was also given only "one comment" regarding her most important movement error. In fact, the difference between self-control and yoked group on receiving feedback was that self-control participants received feedback anytime they requested and yoked participants had no choice on requesting the feedback. The participants in both groups were not allowed to ask any question during the acquisition phase and all feedbacks were based on the coach's view. The experimenter recorded the scores and the times the self-control group had asked for feedback during all the stages. No feedbacks were provided by the coach during the retention and transfer tests. The participants threw darts using their left hands during the transfer test. All along the acquisition, the retention, and the transfer test, the participants could observe where the dart had hit, however, no externally KR was provided. The participants were asked the SE questions before each block and the retention and transfer tests and the experimenter recorded their answers. Eight motion analysis cameras recorded all throws of the participants.

Kinematical analysis

In the present study, intra-limb coordination and movement pattern error were used to measure and evaluate participants' throwing form.

Intra-limb coordination: The term "coordination" in movement science refers to the general coordination between an individual's limbs while performing a movement. Intra-limb coordination refers to the coordination of 2 joints of the same limb during a movement, e.g., the coordination between elbow and wrist while throwing a dart. Intra-limb coordination was used to analyze dart throws in the present study. For this purpose, the right wrist, elbow, shoulder and hip formed shoulder and elbow angles during the dart throw, resulting in the shoulder-elbow intra-limb coordination. To demonstrate this coordination, angle-angle diagrams were used to show spatiotemporal variations of joint movements (a schematic view of angle-angle diagrams used in this study can be observed in Figure 2).

Movement pattern error: Normalized Root-Mean-Square Difference (NoRM-D) was utilized to determine the participants' movement pattern error [14, 15, 18]. In this method the deviation of the movement made by the participant from the movement made by an expert model (in this study the coach was used as an expert model) was

measured and the error was calculated. For this purpose, first a fixed number of video frames (for example 100 frames) had to be determined for both the expert model and the participants. Each frame represented the angle that a joint (such as the shoulder or the elbow in the present study) had formed at a particular point of time while performing the movement. The frames had a different arrangement initially as the time for each movement executed by participants was different and, for example, a participant might throw the first dart in 2.20 seconds and the second dart in 2.40 seconds, resulting in a different number of captured frames for each movement. Therefore, to adjust the range of motion of the participants and the expert model, first the starting and ending points of the movement were determined and then the linear interpolation method was applied to standardize the number of frames to 100 frames for both the expert model and all participants. To record the movement pattern of an expert model, we asked the coach to throw a dart with her right hand as well as her left hand (to conduct the transfer test) 3 times, and all throws were captured by eight cameras of the motion analysis system. Then a shot of her choice was selected as the best throw to be used as the movement pattern of an expert model and to measure and evaluate the movement errors of participants. After adjusting the number of frames, the deviations of the angles made by the expert model and the participants in each frame were measured through a specific formula (see [24] for detail) and, finally, the error (difference) was estimated for that movement, which indicated the movement pattern error of participants while throwing darts. The smaller the NoRM-D, the smaller the deviation of coordination pattern of the participant from that of the model.

Data analysis

In the present study, mean and standard error were used to demonstrate descriptive characteristics of the research variables in diagrams. To evaluate the progress of the participants in the acquisition phase, a mixed 2 (GROUP: self-control & yoked) × 5 (BLOCK: AQ1-AQ5) ANOVA with repeated measures on BLOCK was applied. Here, eta-squared (η^2) values are reported for all significant effects. Independent *t*-test was also conducted to compare the means of groups during retention and transfer tests. The significance level was set at 0.05.

Results

KP frequencies

During the acquisition phase, the average of request for KP for the self-controlled group was 44.76%. In particular, the average of request for KP for acquisition blocks of 1 to 5 was 60.0%, 53.3%, 45.3%, 38.6%, and 26.6%, respectively. In fact, the participants had more requests for KP in the beginning of acquisition phase.

Outcome scores

Mean and standard error of throwing scores of the self-controlled and yoked groups are presented in Figure 1. Overall, the throwing scores of both groups were relatively low. During the practice period, the participants of the self-controlled and yoked groups reached the dart to the bull's eye for 5.3% and 4.5% of their throws, respectively. During the acquisition phase, the results showed that the main effects of GROUP ($F_{1,28} = 0.893$, $p = 0.355$), BLOCK ($F_{4,112} = 2.460$, $p = 0.052$), and the interaction of GROUP × BLOCK ($F_{4,112} = 0.582$, $p = 0.677$) were not significant.

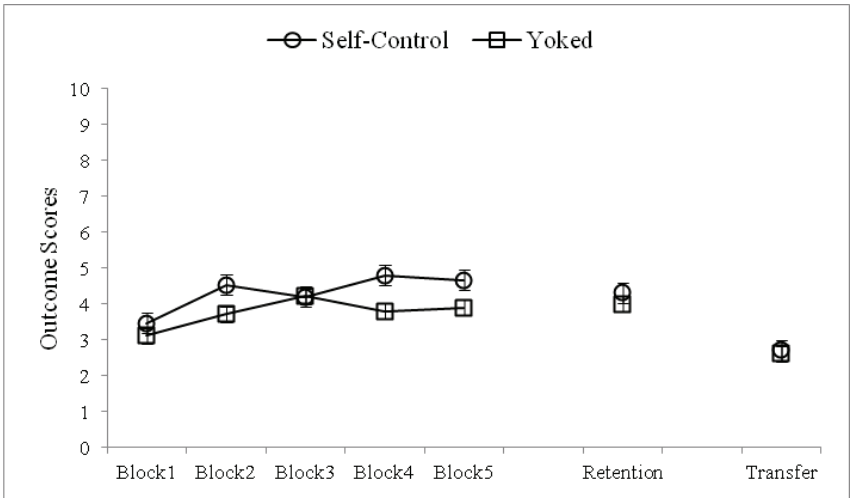


Figure 1. Mean and standard error of throwing scores for the self-controlled and yoked groups across the acquisition blocks and retention and transfer tests

There was no significant difference between the research groups in the retention ($t_{28} = 0.772$, $p = 0.449$) and transfer ($t_{28} = 0.198$, $p = 0.845$) tests.

Intra-limb coordination

Angle-angle plots of shoulder-elbow intra-limb coordination for the expert model and the self-controlled and yoked groups across the acquisition phase and retention and transfer tests are presented in Figure 2. It should be noted that in Figure 2, plots of the acquisition phase include the average of all participants across all trials of the acquisition phase. Furthermore, plots of the retention and transfer tests include the average of all participants across all trials. The angle-angle plots show that shoulder-elbow coordination of the participants differs in self-controlled and yoked groups from that of the expert model. However, the participants in the self-controlled group tended to show more similar movement pattern to that of the expert model.

NoRM-D scores

Mean and standard error of NoRM-D scores of the self-controlled and yoked groups are presented in Figure 3. During the acquisition phase, the results showed that the main effects of GROUP was significant ($F_{1,28} = 24.24$, $p = 0.001$, $\eta^2 = 0.536$). Here, the participants in the self-controlled group demonstrated significantly lower NoRM-D scores in comparison to those in the yoked group which indicates that self-controlled group demonstrated less deviation from the pattern produced by the expert model. However, the results showed no significant main

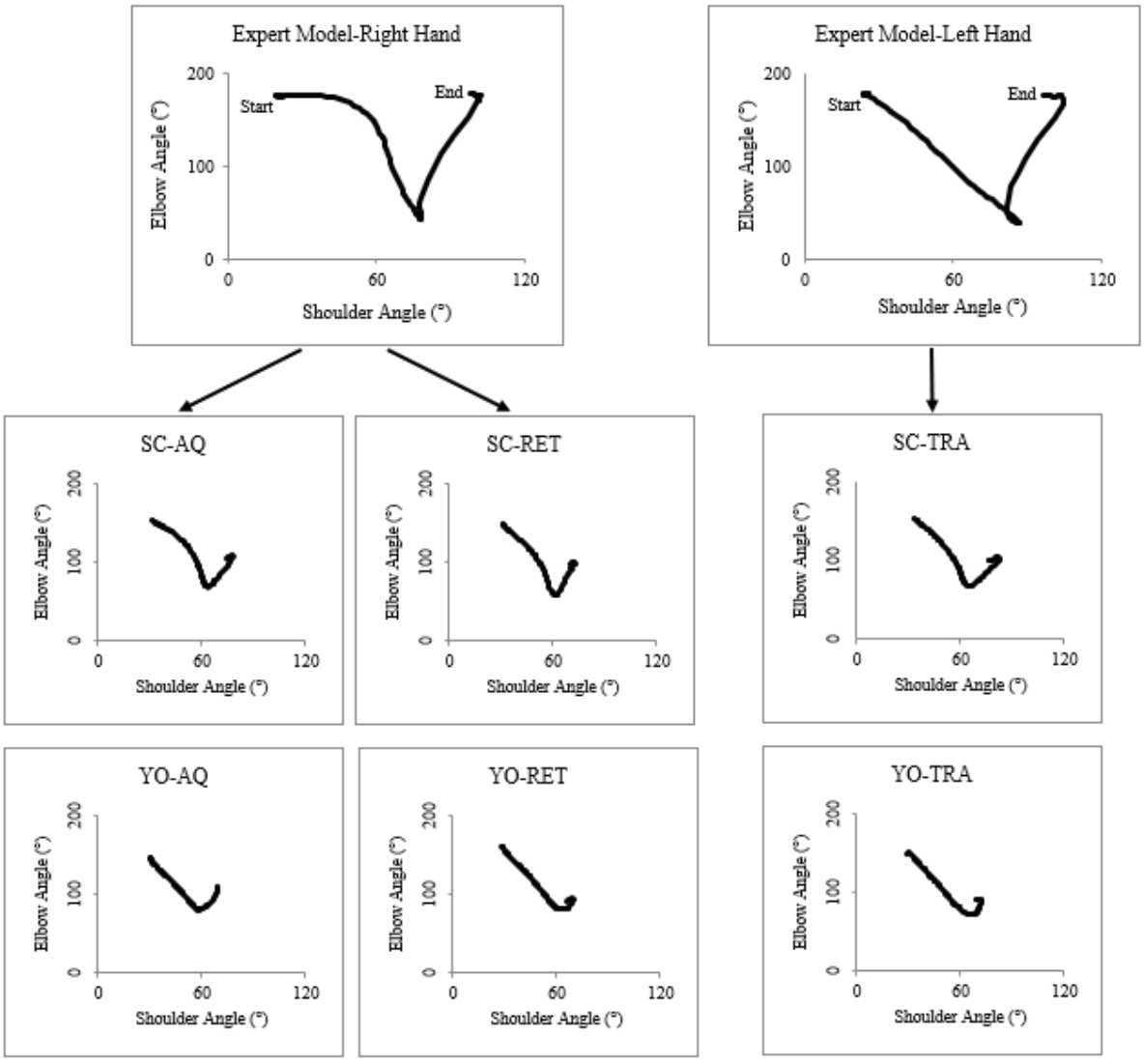


Figure 2. Angle-angle plots of shoulder-elbow intra-limb coordination for the expert model and the self-controlled and yoked groups across the acquisition phase (average of all participants across all trials of the acquisition phase) and retention and transfer tests (average of all participants across all trials). SC: Self-control; YO: Yoked; AQ: Acquisition; RET: Retention; TRA: Transfer

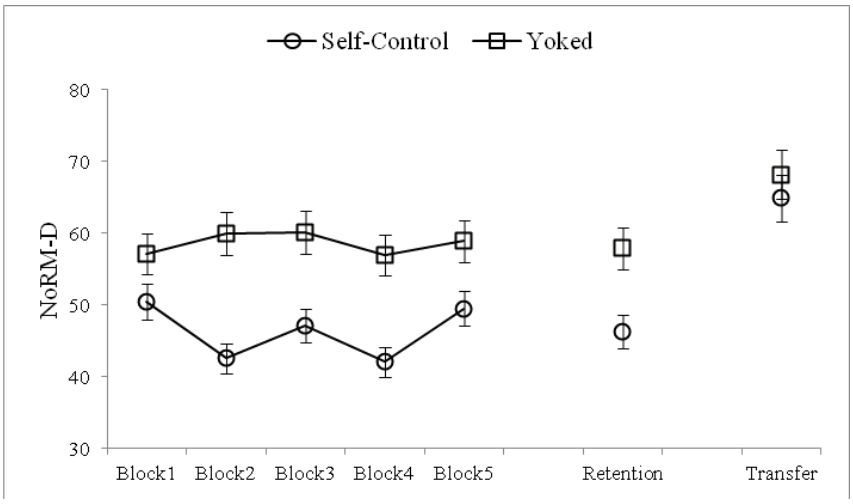


Figure 3. Mean and standard error of NoRM-D scores for the self-controlled and yoked groups across the acquisition blocks and retention and transfer tests

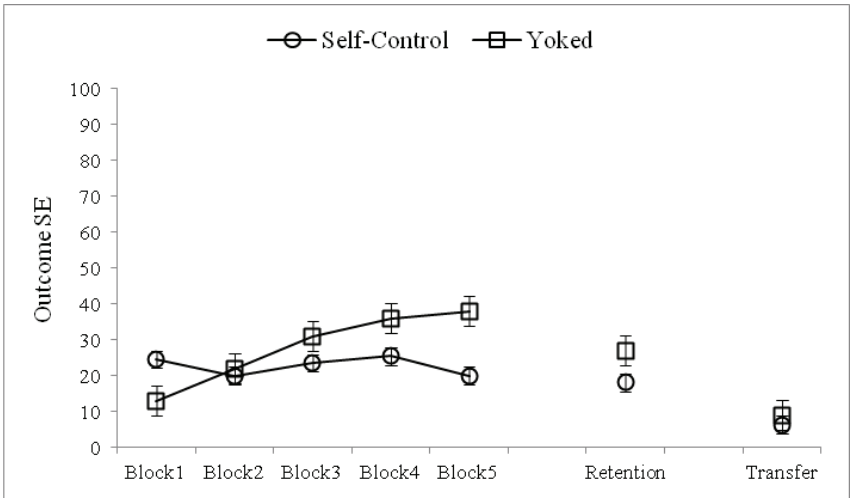


Figure 4. Mean and standard error of movement outcome SE scores for the self-controlled and yoked groups across the acquisition blocks and retention and transfer tests

effects for BLOCK ($F_{4,112} = 1.839$, $p = 0.129$), and the interaction of GROUP × BLOCK ($F_{4,112} = 2.098$, $p = 0.088$) were not significant. In the retention test, the results demonstrated that there was a significant difference between the research groups ($t_{28} = –3.074$, $p = 0.007$). Here, the participants in the self-controlled group had significantly lower NoRM-D scores compared with those in the yoked group which indicates that they performed the movement pattern more similar to that of the expert model. Finally, no significant difference was observed between research groups in the transfer test ($t_{28} = 0.568$, $p = 0.577$).

SE scores

Movement outcome SE: Mean and standard error of movement outcome SE scores of the self-controlled and yoked groups are presented in Figure 4. During the acquisition phase, the results showed that the main effect of GROUP ($F_{1,28} = 0.382$, $p = 0.544$) was not significant. However, the main effect for BLOCK ($F_{4,112} = 4.562$, $p = 0.002$, $\eta^2 = 0.194$) and the interaction of GROUP × BLOCK ($F_{4,112} = 5.137$, $p = 0.001$, $\eta^2 = 0.213$) were significant. These results indicate that yoked groups improved their self-report outcome SE scores during the acquisition phase, but self-controlled group tended to decrease their self-report outcome SE scores during the acquisition phase. Finally, there was no significant difference between the research groups in the retention ($t_{28} = –1.011$, $p = 0.325$) and transfer ($t_{28} = –0.469$, $p = 0.644$) tests.

Movement pattern SE: Mean and standard error of movement pattern SE scores of the self-controlled and yoked groups are presented in Figure 5. During the acquisition phase, the results showed that the main effect of

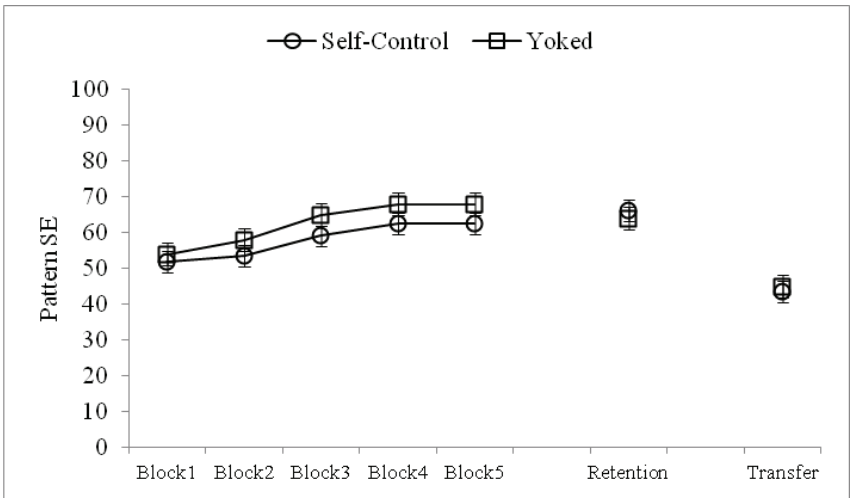


Figure 5. Mean and standard error of movement pattern SE scores for the self-controlled and yoked groups across the acquisition blocks and retention and transfer tests

GROUP ($F_{1,28} = 0.254$, $p = 0.620$). However, the main effect of BLOCK was significant ($F_{4,112} = 14.14$, $p = 0.001$, $\eta^2 = 0.427$). Moreover, the main effect for the interaction of GROUP × BLOCK ($F_{4,112} = 0.233$, $p = 0.919$) was not significant. These results indicate that both groups improved their self-report pattern SE scores during the acquisition phase. Finally, there was no significant difference between the groups in the retention ($t_{28} = 0.269$, $p = 0.791$) and transfer ($t_{28} = –0.129$, $p = 0.899$) tests.

Discussion

Previous research has clearly demonstrated that self-controlled KR versus yoked condition enhances motivational state and motor learning in novice performers [6, 7, 9, 13, 29]. However, the effects of self-controlled KP on motor learning and motivational state of the novices are rarely studies. The present study was designed to investigate the effects of self-controlled KP on performance, learning, and SE in a dart throwing task, especially by focusing on kinematical movement pattern. We hypothesized that participants in the self-controlled condition would benefit from self-controlling the KP as demonstrated by better motor learning and higher SE in the retention and transfer tests compared to their counterparts in the yoked group.

With regard to the movement pattern, the results of the present study showed that self-controlled KP had positive and significant effects on movement pattern acquisition (as measured by angle-angle plots and NoRM-D scores), compared to the yoked conditions in which the feedback was not self-controlled. These findings are consistent with the findings of Janelle et al. [19] and Aiken et al. [1], who found that the effects of self-controlled KP (in the form of a replayed video of the participant's movement) could improve the movement pattern acquisition compared to the yoked group. The results of the present study, in turn, can be considered as novel and interesting results in the field of research on the use of feedback in motor learning. On the one hand, it expands the existing knowledge in this field by examining the effects of self-controlled KP (provided by a coach) on motor learning. On the other hand, it can add to the results of previous studies which merely examined the movement outcome, and broaden our knowledge of the effects of self-control KP on motor learning. Although we found no influence of self-control KP on learning a dart-throwing pattern in left hand, some behavioral and neurological research provided support for interhemispheric transfer between the brain halves in early stages of motor learning [28]. This could be investigated in future research. Furthermore, we applied this kind of transfer test (e.g., throwing with left hand), because we aimed to measure intra-limb coordination of left hand, too. As the results of this study showed, participants were not able to apply what they learned from the acquisition phase in the transfer stage. We suggest that future studies focus on other kinds of transfer test such as changing throwing distance of size of dartboard.

However, there were not any significant differences between self-control and yoked groups in terms of movement outcome. A possible reason why self-controlling KP did not lead to positive effects on movement outcome might be that the participants focused more on improving movement form and less on movement accuracy, particularly among those in the self-controlled group, since they usually concentrated more on the requested feedback. Furthermore, we found no positive effects for self-controlling

KP on movement pattern SE as well as movement outcome SE. These results are consistent with the previous research indicating that self-controlled KP does not positively affect movement outcome or motivation [1, 21]. However, these findings are inconsistent with some studies demonstrating that self-controlled outcome feedback positively affects learners' motivation and motor learning, which are generally measured by movement outcome, compared to yoked conditions [6, 7, 9, 13, 29, 33].

The present findings along with previous studies might indicate that self-controlled KP do not necessarily improve movement outcome and motivational state, and therefore, do not provide supports for the motivational approaches of self-controlled practice which state that self-controlled practice optimize motor learning through enhancing motivational state (see [33] for more detail). Some researchers proposed alternative explanations for the motivational approach to motor learning [2, 4, 5, 16]. Accordingly, self-controlled feedback engages learners in cognitive processes which in turn involve them in more complicated information processing, thereby improving learners' cognitive ability to identify their own errors and to facilitate their motor learning. In fact, providing feedback involves the individual in the problem-solving process and can improve the learner's cognitive function [17]. This can be achieved through increasing information processing processes. The difference in movement pattern errors between the self-controlled and yoked groups in the retention test might appear that those in the self-controlled environment processed information deeper and more efficiently and were able to retain information more effectively than those in the yoked condition. The participants in self-controlled group were free to employ a learning-strategy feedback schedule that is the most comfortable and, as a result, they were possibly able to process movement-relevant information more efficiently. However, those in yoked condition received feedback in various times during the skill acquisition but without their request which might made it difficult for them to process information efficiently and use it for their next throwing. Finally, given that in the present study, learners' motivation did not increase as a result of self-controlled KP, it can probably be proposed that improved movement pattern in self-controlled conditions compared to the yoked conditions can be a result of better processing of the information of participants of the self-controlled group compared to the yoked group, independent of motivational influences.

Among the limitations of the present study is the fact that a dart-throwing motor task is not considered as a highly complex, dynamic, and multi-limb motor task. Using more complex and multi-limb motor tasks such as Baseball-pitch might bring better conclusion of the effects of the self-controlled KP on learning of complex sport skills. Finally, we measured motivation by using a single-item SE scale reflecting the most difficult value of dart throwing (i.e., the bull's eye for movement accuracy and the standard throwing pattern for movement form). This type of measurement might threaten participants' perceptions of competence [10] and could affect the SE levels found in the self-controlled group. Using SE scales with more response options and multiple gradations as well as other related-motivational aspects such as perceived choice and perceived competence might reveal to more accurate research findings.

In conclusion, this study examined whether self-controlled KP improves learners' motor learning and SE. The results showed that although self-controlled KP led to improved movement pattern acquisition, this type of feedback bears no effects on the movement outcomes as well as SE. These results do not provide supports for the motivational approaches of self-controlled practice. However, deeper and more efficiently movement-relevant information processing by the learner as a result of self-controlled KP might be considered as an alternative explanation for better motor learning of the self-controlled group compared with the yoked group. Future studies by applying neuroscience methods in examining the effects of self-controlled KP on feedback information processing can draw more tangible results [12, 20]. The results of this study can also have practical implications. Given the benefits of self-controlled practice in movement pattern acquisition, this type of practice can be employed by instructors as an effective and useful way to teach motor skills to beginners.

Conflict of interest: Authors state no conflict of interest.

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