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The Effect of Contextual Interference on the Acquisition and Learning of Motor Skill with an Emphasis on Cognitive Flexibility

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Abstract

Background: The effect of contextual interference (CI) on motor skill learning may be influenced by various factors, such as cognitive abilities.

Objectives: The purpose of the current research was to investigate the effect of CI on the acquisition and learning of soccer skills, with an emphasis on the role of cognitive flexibility (CF).

Methods: Eighty students, aged 9 - 12 years, were randomly selected and administered the Wisconsin Card Sorting Test. From this group, 60 students who scored the highest and lowest points were selected as the final subjects. After completing the pre-test on Moore-Christine's pass, shoot, and dribble skills, the subjects were divided into four groups of 15 participants each (high CF with Random Practice (RP) and Blocked Practice (BP), low CF with RP and BP). The subjects then engaged in practice sessions according to their assigned protocols for three sessions, with each session consisting of three blocks of 12 trials across all three skills—passing, shooting, and dribbling. Following the practice, acquisition, immediate retention, delayed retention, and transfer tests were conducted.

Results: The results showed that practice in all four groups had significant beneficial effects on the acquisition and learning of skills. Additionally, the high CF with RP group demonstrated better performance in all skills compared to the other groups.

Conclusions: Therefore, it can be concluded that RP may be more beneficial for individuals with higher CF. Teachers and educators should consider this when teaching sports skills.

Keywords: Cognitive Flexibility, Random Practice, Blocked Practice, Soccer

1. Background

The way of planning practice and the application of changes in practice can affect the performance and learning of skills (1). The variability of practice and the amount of contextual interference (CI) are factors that can affect performance and retention (2). Variability refers to the variety of contextual characteristics of practice that can have beneficial effects on learning (3). Increasing variability through the manipulation of parameters in tasks that are controlled by the same motor program can increase retention and transfer (4). The most important benefit of practice variability is enhancing the ability to perform skills in new situations, which is explained by the hypotheses of reconstruction, elaboration, and cognitive effort (5). From the dynamic systems perspective (DCP), it is believed that the active learner, as an explorer, is constantly searching for different solutions to perform the task and reach the goal. Also, based on DCP, changing and adjusting the constraints can provide the basis for active searching and discovering ways to achieve the task goal through the process of self-organization (6).

One of the factors that influence CI is individual constraints, such as characteristics and cognitive abilities (7). Since the hypotheses explaining the effects of CI are based on the individual's cognitive factors, the abilities and cognitive processes of individuals may play a crucial role in the impact of CI, which has been largely overlooked in previous research (8). Schweighofer et al. (9) showed that people with lower visuospatial working memory benefited more from blocked practice (BP). Similarly, Ramzanzadeh, H (10) concluded that working memory plays a significant role in learning motor skills among young people, stating that those with lower working memory benefit more from BP because it presents a greater challenge compared to those with higher working memory. When working memory is occupied with verbal instructions, individuals with stronger working memory perform better in retention tests (11). Recent findings demonstrate that working memory capacity can affect the learning of sequential motor tasks during observational learning, with individuals possessing higher working memory exhibiting better learning outcomes (12). Carnevale et al. (13) showed that executive functions play a role in football players' tactical functions, and to improve tactics, strengthening executive functions should also be considered. There is a positive correlation between fine motor skill learning and visuospatial memory (14).

These findings highlight the potential impact of CI in the context of individuals' cognitive capacities, making this an interesting area for research. One of the important dimensions of cognitive processes that has been less explored in interaction with motor learning is cognitive flexibility (CF), which refers to the mental ability to switch between different concepts or think about multiple concepts simultaneously (15). Cognitive flexibility allows individuals to adapt their behavior and thinking in response to changing environmental stimuli and contexts, enabling them to adjust their actions and thoughts when faced with new challenges and conditions (16). Since the goal of motor skill learning is to ensure its applicability in various contexts, CF may influence the extent of learning. Additionally, in random practice (RP), where different types of tasks are practiced in each session, a person's level of CF may impact the amount of learning that occurs. This relationship needs to be examined to better understand the potential effects. The interaction of CF as an individual constraint with CI as an environmental constraint and its effects on motor skill learning has not been thoroughly addressed, making it an important area for investigation.

2. Objectives

Therefore, based on the aforementioned points, the present research aimed to investigate the effects of CI on the acquisition, retention, and transfer of motor skills by examining the role of CF in 9 to 12-years-old. The reason for choosing this age range is that teaching basic sports skills, along with understanding the variables that affect them, can be crucial during childhood.

3. Methods

3.1. Subjects

The statistical population of the research included healthy boys aged 9 to 12 from Hamadan province. The criteria for participating in the research included being in perfect health (measured using a general health questionnaire), not having a history of performing the Wisconsin card sorting test (WCST), not participating in physical activities beyond daily routines, not consuming caffeinated drinks for at least 6 hours before the cognitive test, and not having a background as a member of a futsal or soccer team or participating in related exercises.

After obtaining written consent, 80 volunteers who met the entry criteria participated in the WCST. Based on the perseverative errors in this test, 30 participants with high scores and 30 with low scores were selected. The subjects were then assigned to four groups: High CF with RP (HCF + RP), high CF with BP (HCF + BP), low CF with RP (LCF + RP), and low CF with BP (LCF + BP).

3.2. Task and Apparatuses

3.2.1. Motor Skill Measurement Tests

Three standard Moore-Christine soccer tests (shooting, dribbling, and passing) were used to measure movement skills (17).

3.2.2. Wisconsin Card Sorting Test

In this research, the Persian and computerized version of the WCST was used. In this test, the number of perseverative errors was used as an indicator and criterion of the subjects' performance. A perseverative error occurs when the person continues to sort the cards based on a previous rule, instead of following the current and new rule (18).

3.3. Procedure

After selecting the participants and conducting the pre-test, the participants entered the practice phase, where all groups practiced for three sessions. The participants in the HCF + BP and LCF + BP groups practiced passing, shooting, and dribbling skills in the first, second, and third sessions, respectively. Each skill practice in each session consisted of three blocks of 12 attempts, with 30 seconds between each attempt and one minute of rest between each block (19). Immediately after the completion of each BP session, the acquisition test was conducted, and 10 minutes after the end of the session, the immediate retention test was performed. Additionally, 48 hours after the end of the practice session and at the beginning of the next session, the delayed retention and transfer tests related to the skill from the previous session were conducted, followed by the practice of the relevant skill.

In the HCF + RP and LCF + RP groups, all three skills (passing, shooting, and dribbling) were practiced in a random arrangement during all three sessions, ensuring that the same skill was not practiced twice in a row. In each session, the participants practiced each skill 12 times. In these groups, the acquisition test was performed immediately after the end of the third session, the immediate retention test was performed 10 minutes after the end of the third session, and the delayed retention and transfer tests were conducted 48 hours after the final session.

In the transfer test, for passing and shooting skills, the task was performed from a distance of 20 meters, and for the dribbling skill, the distance between the cones was 3.5 and 5.5 meters, respectively. In the delayed retention and transfer tests, to avoid a warm-up decrement, a preliminary attempt was performed before the main tests.

3.4. Data Analysis

The Shapiro-Wilk test was used to check the normality of data distribution ($P > 0.05$). Following the relevant assumptions, two-way analysis of variance (ANOVA), ANOVA with repeated measures, and *t*-tests were used. The data were analyzed using SPSS software version 26 at a significance level of $P \leq 0.05$.

4. Results

Table 1 presents the descriptive characteristics of the subjects and research variables.

In all three skills of passing, shooting, and dribbling, the results of the ANOVA with repeated measures showed that exercises performed in all groups led to learning ($P < 0.05$), as illustrated in Figures 1 - 3. Below is a detailed analysis of the between-subject differences for each skill.

4.1. Passing

In the passing skill, for the acquisition and immediate retention phases, the results of two-way ANOVA showed that the main effects of CF, practice type, and the interaction effect were not significant ($P > 0.05$). However, for the delayed retention phase, the results indicated that while the main effect of CF was not significant ($F(1,56) = 3.598$, $P = 0.063$), the effect of practice type ($F(1,56) = 12.651$, $P = 0.001$) and the interaction effect ($F(1,56) = 11.020$, $P = 0.002$) were significant. The independent *t*-test revealed that under high CF conditions, the RP group performed better than the BP group ($t(28) = 4.882$, $P < 0.001$). Under low CF conditions, no significant difference was observed between the BP and RP groups ($t(28) = 0.167$, $P = 0.869$). In the RP condition, the difference between high and low CF groups was significant ($t(28) = 3.460$, $P = 0.002$), but in the BP condition, the difference between high and low CF was not significant ($t(28) = 1.083$, $P = 0.288$).

For the transfer phase, the results showed that the main effect of practice type ($F(1,56) = 2.563$, $P = 0.117$) was not significant, but the effect of CF ($F(1,56) = 7.045$, $P = 0.010$) and their interaction effect ($F(1,56) = 4.069$, $P = 0.048$) were significant. The independent *t*-test showed that in RP conditions, the high CF group performed better than the low CF group ($t(28) = 3.460$, $P = 0.002$). In BP conditions, no significant difference was observed between the high and low CF groups ($t(28) = 0.432$, $P = 0.669$).

In the high CF groups, the RP group performed better than the BP group ($t(28) = 2.345$, $P = 0.026$). In the low CF group, no significant difference was observed between the BP and RP groups ($t(28) = 0.333$, $P = 0.742$).

4.2. Dribbling

In the dribbling skill, for the acquisition, immediate retention, and transfer phases, the results of two-way ANOVA showed that the main effects of CF, practice type, and their interaction effect were not significant ($P > 0.05$).

However, for the delayed retention phase, the results indicated that the main effects of CF ($F(1,56) = 11.053$, $P = 0.002$) and practice type ($F(1,56) = 7.759$, $P = 0.007$) were significant, though the interaction effect was not significant ($F(1,56) = 2.333$, $P = 0.132$). Based on the significance of the main effects, the findings demonstrated that subjects with high CF performed better than those with low CF, and random practice was more beneficial than blocked practice (BP).

4.3. Shooting

In the shooting skill, for the acquisition, immediate, and delayed retention phases, the results of two-way ANOVA showed that the main effects of CF, practice type, and their interaction effect were not significant ($P > 0.05$).

However, for the transfer phase, the main effects of CF ($F(1,56) = 3.790$, $P = 0.057$) and practice type ($F(1,56) =$

Table 1. Descriptive Characteristics of the Subjects and Variables [a]

Group and Measurement Steps	Pass Skill Score	Dribble Skill (sec)	Shooting Skill Score	Age (y)	Number of Perseverative Errors (WCST)
HCF + RP				10.72 ± 0.48	2.24 ± 1.01
Pre-test	5.86 ± 1.18	55.66 ± 1.95	49.26 ± 3.15		
Acquisition	9.26 ± 1.03	50.20 ± 1.47	64.80 ± 4.45		
Immediate retention	8.66 ± 0.97	51.73 ± 1.27	62.66 ± 3.73		
Delayed retention	9.00 ± 1.06	51.33 ± 1.23	61.66 ± 4.93		
Transfer	8.46 ± 1.24	51.53 ± 1.64	57.93 ± 3.67		
HCF + BP				10.87 ± 0.57	2.15 ± 1.10
Pre-test	5.80 ± 1.20	55.53 ± 1.59	49.40 ± 1.08		
Acquisition	9.00 ± 1.13	50.86 ± 1.35	64.86 ± 4.92		
Immediate retention	8.60 ± 0.91	52.13 ± 1.99	63.20 ± 4.63		
Delayed retention	7.06 ± 1.09	52.93 ± 1.48	59.20 ± 3.54		
Transfer	7.06 ± 1.43	54.26 ± 1.53	53.00 ± 4.14		
LCF + RP				10.96 ± 0.60	4.26 ± 1.11
Pre-test	6.06 ± 1.16	55.73 ± 1.38	49.13 ± 2.53		
Acquisition	9.20 ± 1.20	51.00 ± 1.69	64.73 ± 5.90		
Immediate retention	8.73 ± 0.88	51.80 ± 1.88	62.20 ± 5.30		
Delayed retention	8.66 ± 0.81	53.13 ± 1.18	58.53 ± 4.54		
Transfer	7.00 ± 1.06	54.00 ± 1.41	52.73 ± 2.98		
LCF + BP				10.80 ± 0.61	4.37 ± 1.18
Pre-test	6.06 ± 1.27	56.06 ± 1.62	49.20 ± 3.50		
Acquisition	9.06 ± 1.27	50.53 ± 1.72	63.86 ± 5.22		
Immediate retention	8.53 ± 0.99	52.06 ± 1.83	61.66 ± 5.36		
Delayed retention	7.46 ± 0.91	53.60 ± 1.70	58.13 ± 5.24		
Transfer	7.13 ± 1.12	53.93 ± 1.03	53.93 ± 5.70		

Abbreviations: HCF, high cognitive flexibility; LCF, low cognitive flexibility; RP, random practice; BP, block practice; WCS, Wisconsin card sorting test.

[a] Data are presented as mean ± SD.

2.901, P = 0.094) were not significant, but the interaction effect was significant (F (1,56) = 7.831, P = 0.007).

The independent *t*-test results showed that in the high CF condition, the RP group performed better than the BP group (*t* (28) = 3.452, P = 0.002). In the low CF condition, no significant difference was observed between the BP and RP groups (*t* (28) = 0.722, P = 0.476). In the RP condition, the difference between the high and low CF groups was significant (*t* (28) = 4.253, P < 0.001), but in the BP condition, the difference between high and low CF was not significant (*t* (28) = 0.063, P = 0.612).

5. Discussion

The present research was conducted to investigate the effect of BP and RP on the acquisition and learning of passing, dribbling, and shooting skills in football, focusing on the role of CF. The results showed that in all three skills, practice in all groups led to improvements in the subjects' performance during the acquisition and learning phases. In general, it can be concluded that relevant exercises improved acquisition and learning across all skills and subjects, but the HCF + RP group demonstrated better learning outcomes than other groups in all three skills.

According to the dynamic systems perspective (DSP), individuals with high CF, who are more adept at shifting their attention to suitable environmental stimuli, were better able to benefit from RP conditions, which include more cognitive stimuli compared to BP, thus leading to greater learning (6). Based on the cognitive effort hypothesis, acquiring learning from practice requires creating opportunities for mental and cognitive activity (20). In this study, RP increased the cognitive effort of subjects in the HCF + RP group through error detection activities, leading to enhanced learning compared to other groups. In a way, RP encouraged more cognitive activities and better learning in the subjects due to the spacing between the execution of skills. The beneficial effects of RP can also be explained by the Elaboration and Reconstruction hypotheses (21).

From a neurological perspective, we can consider the interaction of BP and RP with brain and cognitive

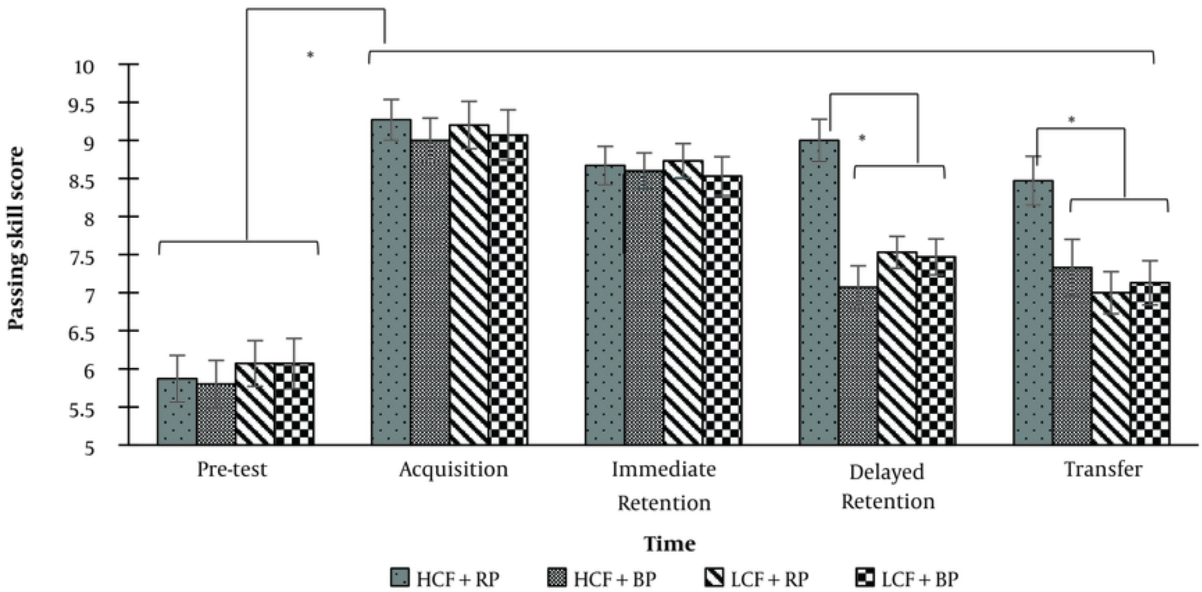

Figure 1. The average scores of different groups in passing skill. Note *P ≤ 0.05; Abbreviations: HCF, High cognitive flexibility; LCF, Low cognitive flexibility; RP, Random practice; BP, Block practice.

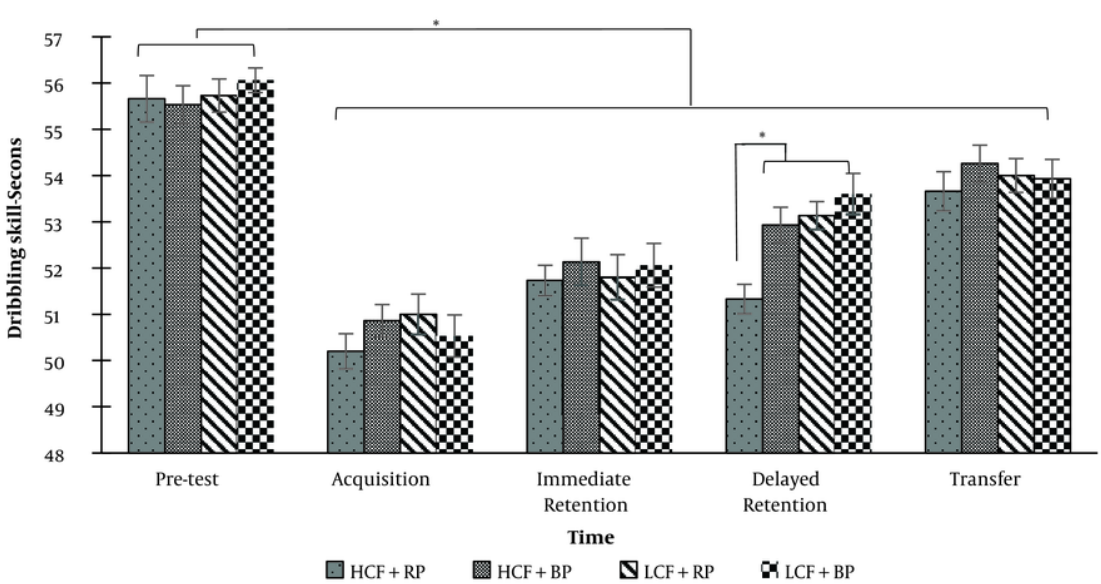

Figure 2. The average scores of different groups in dribbling skill. Note *P ≤ 0.05; Abbreviations: HCF, High cognitive flexibility; LCF, Low cognitive flexibility; RP, Random practice; BP, Block practice.

processes. Different exercise programs activate areas such as the primary motor area, premotor area,

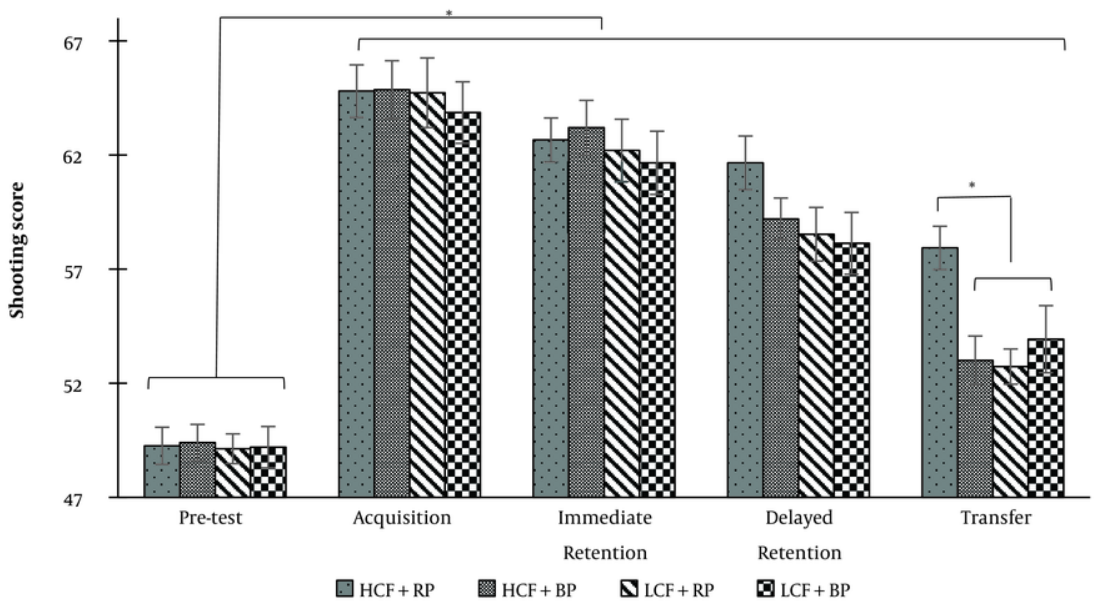

Figure 3. Average scores of different groups in shooting skill. Note *P ≤ 0.05; Abbreviations: HCF, High cognitive flexibility; LCF, Low cognitive flexibility; RP, Random practice; BP, Block practice.

posterior-parietal cortex, and posterior-lateral prefrontal cortex in different ways. For instance, during the acquisition phase of RP, compared to BP, the primary motor area exhibits greater activity and excitability. It can be said that the neural structures involved in planning and executing skills are more active during RP compared to BP in the acquisition phase. Additionally, RP leads to decreased activation in different brain areas during retention tests (22). Random practice increases activation in the posterior-lateral prefrontal cortex, sensory and motor areas, and increases beta wave activity in the frontal lobe (13, 23). Cognitive processes for motor actions are directly related to increased beta wave and decreased alpha wave activity in the frontal lobes (23, 24). An increase in alpha waves in the parietal and central regions indicates increased sensory and motor memory integration (24, 25). Studies show that RP leads to the highest beta wave activity in the prefrontal cortex, while BP results in the lowest beta wave activity in this region. An increase in beta waves in the prefrontal cortex is associated with working memory processes during movement, and this increase in beta waves is indicative of cleared working memory observed during RP (26, 27).

Buszard et al. (11) concluded in their research that when working memory is occupied with verbal instructions, individuals with stronger working memory perform better in retention tests. In the current study, subjects with higher CF also demonstrated better learning in the RP condition. Afsharpour et al. (12) stated that working memory capacity can affect the learning of sequential motor tasks, with individuals who have higher working memory achieving better learning outcomes. In this study, individuals with higher CF performed better than others in the RP condition. It can be said that individuals with high CF have a greater ability to adapt to various environmental changes and stimuli, applying necessary adjustments to their behavior. This may explain why these individuals performed better in RP, which requires recalling action plans from memory during each attempt, leading to improved learning.

The findings of this research contrast with studies that show individuals with lower working memory benefit more from BP. However, in the current research, no significant difference was observed between the high and low CF groups in the BP condition. This discrepancy may be due to differences in the types of tasks, subjects, and their levels of experience (9, 10).

In most research on the acquisition phase, the BP group performed better than the RP group (28, 29). However, in the present study, no significant difference was observed between the groups during the acquisition phase for all three motor skills. Generally, the weaker effect of RP in the acquisition phase in other studies is attributed to the negative impact of RP on motivation, which can hinder progress during training (30). However, in this study, the football skills used, which are particularly engaging for children, likely maintained high motivation in the RP group, preventing a decrease in performance during the acquisition phase.

According to the Elaboration and Reconstruction theories, inter-task variation is a key source of cognitive effort in RP. This increased cognitive effort leads to better learning outcomes compared to BP (21). Overall, both BP and RP, under conditions of high and low CF, improved children's football motor skills. There was no difference in the acquisition and immediate retention phases between the different practice groups. However, the HCF + RP group resulted in the best learning outcomes. Therefore, when designing practice sessions and applying CI, it is important to consider not only characteristics such as age, experience level, and learning style but also the cognitive abilities of the participants.

One limitation of this research is that it did not address other components of executive functions, such as reasoning, planning, and organization, which future research could explore. It is recommended that coaches and trainers consider the CF level of participants when using CI in teaching sports skills, as those with high CF are likely to benefit the most from RP.

Footnotes

Authors' Contribution: Conception and design of the study: Sh. T. B. and M. B.; data collection: M. B. and M. M.; data analysis and/or interpretation: Sh. T. B., M. B., and M. M.; drafting of manuscript and/or critical revision: Sh. T. B. and M. B.; approval of final version of manuscript: Sh. T. B., M. B., and M. M.

Conflict of Interests Statement: The authors declare that there is no conflict of interest in the present study.

Data Availability: The dataset presented in the study is available on request from the corresponding author during submission or after publication.

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Informed Consent: Informed consent was obtained from all participants.

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