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Original Article

Optimal inter-trial intervals spacing for learning volleyball overhand serve

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Abstract
Studies on spacing of practice investigate the effects of the execution/rest ratio on the acquisition of motor skills. For research purposes, this spacing of practice is dichotomized as massed or distributed practice. It can be manipulated as the inter-trial interval, corresponding to the period of time between the end of one attempt and the beginning of the next, separating the responses. Most studies investigated the inter-trial interval with simple tasks, but results are not conclusive when testing with complex sports motor skills. **Purpose:** This study explored the spacing of practice through three inter-trial intervals on learning a complex sports motor skill. **Material and Methods:** Participants (n=36, aged 13.8 ± 1.0) performed the volleyball overhand serve from one side of the court, aiming to reach a target on the other side. Three experimental groups were carried out: one massed practice (1-second inter-trial interval) and two distributed practices (inter-trial intervals of 15-second and 40-second). All groups performed 12 trials in the pre-test, 200 in the acquisition phase, and 12 in the retention test. **Results:** The results revealed higher performance accuracy and consistency of the shorter inter-trial interval than longer inter-trial intervals, observed during the acquisition and retention test, indicating better learning for the massed inter-trial interval. **Conclusions:** The inter-trial interval spacing led to different levels of learning of volleyball overhand serve. The shorter inter-trial interval was demonstrated to be better for parameters learning of sports motor skills, allowing information to be processed more efficiently in working memory, contributing to enhanced learning of sports motor skills. Massed practice, in this context, did not induce fatigue for performance loss. The coaches are advised to optimize training schedules incorporating massed practice for the development of complex sports motor skills.
Key Words*:* Motor Learning; massed practice; distributed practice; complex sports motor skill; parameters learning.

Introduction

Organizing practice to provide the best learning is at the core of the teachers' and coaches' concerns. They must decide on many aspects of designing the practice schedule, such as the spacing or distribution of practice. This decision deals with the amount of rest interval between trials or practice sessions (Carpenter et al., 2012; Edwards, 2011; Honeybourne, 2006; Lee & Wishart, 2005; Schmidt et al., 2018; Ugrinowitsch & Benda, 2011).

The spacing of practice has been investigated since the middle of the 20th century (Carron, 1969) and became a foundational topic of investigation in motor learning (Adams, 1987; Cook & Hilgard, 1949; Lee & Genovese, 1988, 1989). Studies on the spacing of practice were developed by manipulating two main practice conditions: massed and distributed. The former has the amount of time spent in execution being relatively longer than that of the rest interval (Magill, 1988; Magill & Anderson, 2017). Conversely, the latter has the amount of time in rest interval being relatively longer than that spent on performance (Lee & Genovese, 1988, 1989; Magill & Anderson, 2017; Newell et al., 1988; Panchuk et al., 2013). Although these terms are relative, when applied to the inter-trial interval, massed practice generally refers to a practice schedule where the amount of rest between trials is very short and distributed practice refers to a schedule where the amount of practice between trials is relatively long (Magill, 1988; Panchuk et al., 2013; Magill & Anderson, 2017). In addition, this definition of massed practice has yet to be able to characterize the execution/rest ratio for discrete and serial tasks in the sports context. For complex sports motor tasks (e.g., volleyball service), the definition of massed practice should also consider ball flight trajectory time until it reaches the environmental goal rather than just skill execution time (i.e., that finishes when hitting the ball).

Two meta-analyses conducted on the subject (Lee & Genovese, 1988; Donovan & Radosevich, 1999) indicated that longer spacing of practice (i.e., distributed practice) is more beneficial to performance and motor

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skill learning, although Donovan & Radosevich (1999) highlighted that intervals shorter than one minute showed a small effect (d = .07) in simple lab tasks and complex motor tasks, such as sports motor skills. However, results obtained in lab settings have to be tested with more complex motor skills (Christina, 1987) because they have not been translated to application settings (Wulf & Shea, 2002). Moreover, the interpretation of the results of studies on spacing of practice may have a bias because studies that manipulated the inter-session interval (Singer, 1965; Shea et al., 2000; Dail & Christina, 2004; Krigolson et al., 2021) were adopted to infer the result of inter-trial interval (Lee & Genovese, 1989; Panchuk et al., 2013). Consequently, practice through a longer inter-trial interval (i.e., distributed practice) may not be the most effective for learning complex motor skills.

The main hypotheses in this subject are that the distributed practice would promote better learning than massed because the latter would imply (i) higher levels of fatigue and demotivation, (ii) reduced inter-trial cognitive effort, and consequently (iii) shorter time for memory consolidation resulting from inter-task processing (Benjamin & Tullis, 2010; Edwards, 2011; Magill & Anderson, 2017; McMorris, 2014).

Although studies with inter-session interval spacing have received the most attention (Dail & Christina, 2004; Aghdasi & Jourkesh, 2011; Swandewi, Mintarto, & Nurkholis, 2017), few studies have been conducted with inter-trial interval spacing, especially in learning complex motor skills. Considering all the aforementioned factors, we found only three studies manipulating the inter-trial interval with complex motor skills learning. Spittle, McNeil, and Mesagno (2012) used a continuous motor task (soccer dribbling) to compare massed (1 s) and distributed practice (30 s) inter-trial intervals, respectively. No difference between the two practice conditions was revealed. Panchuk et al. (2013) used a discrete motor task (handball pass) comparing 1 s with 30 s inter-trial interval, and the massed practice had better performance than distributed during the learning phase, but there was no difference in the delayed retention test. At last, Fuentes-García et al. (2022) manipulated two inter-trial intervals, 0 s (no interval) and 10 s of a discrete skill (forehand shot in tennis). No difference between the two practice conditions was revealed.

Given this set of results, we hypothesize that such similar results between massed and distributed practice occurred because both experiments (Panchuk et al., 2013; Fuentes-García et al., 2022) had inexperienced participants in the sample, requiring the skill structure (i.e., the relationship between components of the skill), and movement parameterization learning (Lai et al., 2000). We argue that results can be different whether the experiment requires only parameterization learning. Parameterization refers to adding a time value or force control into the structure of a complex motor skill (Magill & Anderson, 2017; Schmidt et al., 2018; Lai et al., 2000). Based on this statement, massed practice requiring only parameters adjustment may not have implied higher levels of fatigue and demotivation, reduced inter-trial cognitive effort and short time for memory consolidation resulting from inter-task processing (Lelis-Torres et al., 2017; Buch et al., 2021). In other words, since the learner has built or retrieved the same skill structure from long-term memory, it would remain in working memory because it would be run in the subsequent trials (Magill & Anderson, 2017; Oberauer, 2019). In this context, massed practice through the shortest inter-trial interval would allow information to be processed in working memory; on the other hand, distributed practice through the longest inter-trial interval could promote information deterioration in working memory (Oberauer, 2019; Bancroft et al., 2019; Buch et al., 2021) impairing motor learning. Therefore, this study sought to investigate the hypothesis that the massed condition would promote beneficial effects on learning when the practice involved only parameterization of a complex motor skill.

Material & methods

Participants

Thirty-six unexperienced boys (n = 20) and girls (n = 16), with an average age of 13.8 years (± 1.00), took part voluntarily in this experiment. Before the experiment, all participants and their guardians read and signed the informed consent form. The local Ethics Committee approved all procedures.

Task and instrument

The task was the overhand volleyball serve. It consists of throwing the ball forward and above the head with the non-dominant arm and hitting it with the dominant arm so that the ball reaches the ground of the opponent's court (Da Matta et al., 2013). Specifically, the participant should stand comfortably with the non-dominant foot forward and the weight on the back foot, the ball in the non-serving hand out and in front of the serving shoulder. Next, the hand of the serving arm touches the back part of the ball with the feet, hips, shoulders, and elbows squared to the other side of the court. Then, the participant should toss (lift) the ball approximately 1 m high in front of the serving arm, and simultaneously the serving arm moves back elbow of the serving arm bent about 90 degrees and above shoulder height. Then, the body weight should change to the front foot, the serving arm and hand accelerate forward to hit the ball in front of the serving shoulder with the arm extended above the head with the hand open, palm facing out with a firm wrist.

The serves were performed from a serve position (P1) on the side A of the volleyball court, 4 m from the net and 4.5 m from both lateral lines on the side A, with the aim of reaching the center of a target on the floor of the opposite court (side B) (Figure 1). The serve was performed closer to the net because younger participants do not have enough strength to perform the serve outside the volleyball court, which could compromise the results. Therefore, performance demanded parametric adjustments of force or direction in relation to the target.

A circular target with 4 m of diameter was on the floor of the opposite court and with the center 4.5 m away from the centerline. The central area with a diameter of 1 m was the target bull's eye and any ball that reached it received 28 points. There were three more concentric areas with diameters increased by 1 m each, and the ball in these areas received 26, 24 and 22 points, respectively. Other areas were delimitated by two lines positioned on the floor from the serve position (side A), touching the edges of the target and continuing outside the court (side B), resulting in other areas with scores ranging from 20 to 2 points. The lowest score (2 points) was noted when the ball did not pass the net and was not in the direction of the target, and 4 points when the ball did not pass the net but was in the direction of the target. Following the same way of thinking, the ball that passed the net but reached the floor before or after the target received a higher score than a ball that touched the floor on the right or left. Based on these parameters, the highest score reflected participants' superior parameterization capability, that is, to perform adjustments. The net was 2 meters high.

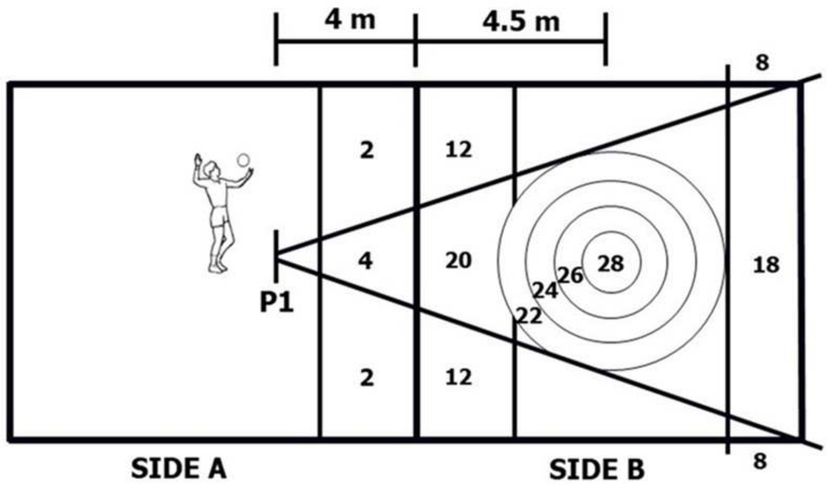

Figure 1. Instrument for assessing the performance of the volleyball overhand serve.

Before the experiment, two researchers were trained to note the scores, and the concordance between them was higher than 98%, and only one researcher participated in the data collection. The researcher stood close to the net on the right of side B of the court. This instrument was previously used in Matos et al. (2021) study.

Experimental Design

All participants completed the three-phase experiment, which involved the pre-test, acquisition phase, and retention test. The experiment was carried out over three weeks for each participant. In the pre-test, the participants performed 12 trials in the P1 area with a 10-second inter-trial interval. Based on the performance from the pre-test, the 36 participants were counterbalanced into three experimental groups (n = 12): G1, group of massed practice with one second of an inter-trial interval (1-second); G15, group of distributed practice with fifteen seconds of an inter-trial interval (15-second); and, G40, group of distributed practice with forty seconds of an inter-trial interval (40-second). This procedure was adopted to ensure that all groups started the experiment with a similar level of performance in the volleyball serve. The acquisition phase started twenty-four hours after the pre-test, with 200 trials divided into three practice sessions that occurred every other day (session 1 = 80 trials, session 2 = 60 trials, and session 3 = 60 trials). Finally, the retention test was performed one week after the last session of the acquisition phase and used a 10-second inter-trial interval, being the same procedure as the pre-test, to infer the improvement in the sports motor skill practiced.

Procedures

The instructions were standardized on the first day of the pre-test. Participants watched a video with an experienced subject performing two executions of the volleyball serve on a 14-inch screen laptop (Lenovo Yoga520®) before the pre-test. Soon after, the participants were positioned in the P1 region to start the pre-test. In the pre-test, the participants performed 12 trials in the P1 area with a 10-second inter-trial interval. An experimenter controlled the inter-trial intervals by providing a ball before every trial according to the experimental group. Another researcher positioned on side B, close to the net and the marking line, noted the serve performance score throughout the experiment to obtain the same reliability criterion of the measures. Finally, all participants executed the serves individually.

In the acquisition phase, the participants watched the same video used in the pre-test twice before every session. The amount of practice in the acquisition phase was divided into blocks of 10 trials with 60 s intervals, independently of the session (i.e., with 80 or 60 trials). The G1 participants performed the serves individually, and in the G15 and G40, three participants alternately performed one block of trials. However, they could not see each other while performing the serve. This procedure was adopted as a function of the inter-trial interval. The researchers controlled the inter-trial interval and noting the score were the same during the whole experiment.

The retention test was performed one week after the last block of the acquisition phase, with the same procedure as the pre-test. During the whole experiment, feedback about the serve score was not provided, but the participants could see the region where the ball touched the floor.

Data analysis

Performance was analyzed in terms of accuracy and consistency as basic characteristics of motor skills. For this purpose, the dependent variable was the scores derived from the serve concerning the target, ranging from 2 (lowest score) to 28 points (highest score). Data analysis was organized in blocks of 12 trials from pre-test, three acquisition sessions, i.e., the last 12 trials of each session, and a retention test.

The performance accuracy (PA) was calculated by PA = (ΣPS/ΣPP), where PA is the ratio of accuracy, PS refers to the points scored in the blocks of 12 trials, and PP is the possible points that could be achieved in such blocks. Therefore, the higher the accuracy ratio, (i.e., closer to 1) the better the performance accuracy. Performance consistency was calculated by coefficient of variation (CV) CV = σ/μ, where CV was the ratio of variability, σ referred to the standard deviation, and μ was the arithmetic mean. Therefore, the lower the consistency ratio, i.e., close to zero, the better the performance consistency. These calculations also involved the same blocks of 12 trials.

Statistical analysis considered data from five blocks of 12 trials: pre-test, the last blocks of each practice day, and the retention test. A 3 x 5 mixed-model ANOVA was run for accuracy and consistency data by considering the blocks of trials as the repeated measure. Observed significant effects were followed up using univariate analysis and the TukeyHSD test. The effect size (η_p^2) was defined as small for $\eta_p^2 > .01$, medium for $\eta_p^2 > .09$ and large for $\eta_p^2 > .25$ (Cohen, 1988). These analyses were preceded by Shapiro-Wilk's W and Bartlett's tests of normality and homogeneity of variance. The significance level was set at $p < .05$ using Statistica® 13.0 software (Stat Soft Inc., Tulsa, USA).

Results

Concerning the performance accuracy (Figure 2a), a 3 x 5 mixed-model ANOVA revealed main effects of interaction [$F(8, 132) = 3.96$, $p = .0003$, $\eta_p^2 = .19$, observed power = .99]. For the G1 group, the TukeyHSD test showed higher accuracy of G1 than G15 in the BL3 ($p < .05$). Moreover, the G1 had higher accuracy than G15 and G40 groups in the retention test ($p < .05$). The post hoc test showed a G1 increment in performance accuracy from pre-test to all other blocks of trials ($p < .01$). Similar results were revealed for G15 and G40 groups, except for BL1 and BL3's ($p < .01$), respectively. These results allow inferring that: (i) all groups increased performance accuracy from the pre-test; (ii) such increment was maintained in the retention test; (iii) in this latter, G1 obtained superior accuracy to G15 and G40 groups.

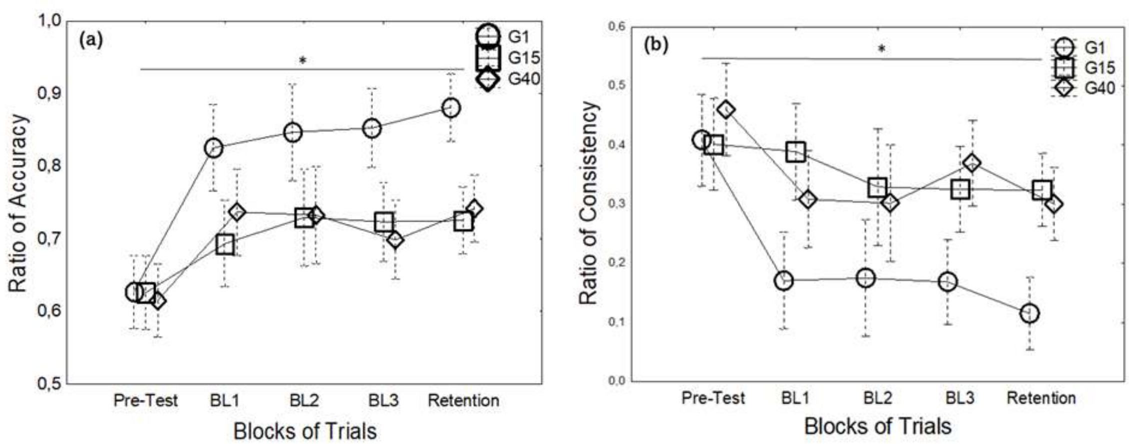

Figure 2. (a) Ratio of accuracy and (b) Ratio of consistency. Vertical dashed line bars represent 95% of the confidence interval, *interaction effect $p < .0003$.

Regarding the performance consistency (Figure 2b), a 3 x 5 mixed-model ANOVA also revealed main effects of interaction [$F(8, 132) = 3.57$, $p = .00008$, $\eta_p^2 = .18$, observed power = .98]. For the G1 group, the TukeyHSD test showed a higher consistency of the G1 than the G15 and G40 groups in the BL3. Moreover, G1 had higher consistency than G15 and G40 groups in the retention test ($p < .05$). The post hoc test showed a G1 increment in performance consistency from the pre-test to all other blocks of trials ($p < .01$). Similar results were revealed for the G40 group, excepting BL3's ratio of accuracy ($p < .01$). These results allow inferring that: (i) G1 and G40 groups increased performance consistency from the pre-test; (ii) such increment was maintained in the retention test; (iii) G1 was more consistent in the retention test than G15 and G40 groups.

Discussion

Considerable discussion about the effects of massed and distributed practices has taken place concerning whether the motor skill is continuous or discrete (e.g., Magill & Anderson, 2017). Continuous motor skills have been the main common kind of tasks used in spacing of practice studies, showing that distributed practice led to better learning than the massed one. Despite this, continuous skills have been seen as difficult to manipulate inter-trial intervals. On the other hand, studies using discrete motor skills have pointed out that massed practice implies better motor learning than distributed practice. Clearly, this is not the case here. Differently from the studies with simple lab tasks, most studies using sportive motor skills have used discrete tasks (Aghdasi & Jourkesh, 2011; Dail & Christina, 2004; Panchuk et al., 2013; Swandewi, Mintarto, & Nurkholis, 2017; Fuentes-García et al., 2022), and the results showed no differences between massed and distributed practices.

This study investigated the effects of practice spacing on the learning of volleyball overhand serve. The massed practice was expected to promote beneficial motor learning because of the inter-trial parameterization demand during acquisition. Results support this hypothesis since massed practice (G1) resulted in higher performance accuracy and consistency than distributed practice schedules (G15 and G40) during retention test. Interestingly, the results support our hypothesis but not those from the spacing of practice literature. Based on this, the massed practice would imply lower motor learning than distributed practice due to fatigue and reduced cognitive effort (Benjamin & Teullis, 2010; Edwards, 2011; Magill & Anderson, 2017; McMorris, 2014). So the question here is: why did this not happen?

The fact that the massed practice group has improved performance over the acquisition trials suggests that a one-second interval was enough for participants to deal with the feedback and reorganize the action plan for the subsequent trial. In fact, massed practice did not demonstrate fatigue and loss of performance over the 80 trials in the acquisition phase. On the contrary, it was revealed to be able to continue increasing performance (Fig 3). Therefore, these results are contrary to the hypothesis that massed practice leads to high levels of fatigue (Benjamin & Tullis, 2010; Magill & Anderson, 2017), and deteriorates performance.

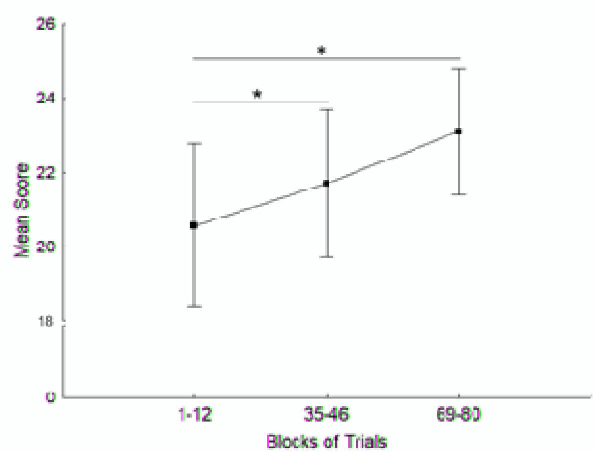

Figure 3. Mean performance score of the massed practice group (G1) through one-way ANOVA with repeated measures referring to the block of 80 trials. Performance accuracy increased throughout the 80 trials of practice (*significant difference, $p < .001$).

Massed practice allows less time to process feedback from visual information, which could have impaired learning. However, as previously described, the feedback was available to participants with visual access to the real experimental environment. Two points must be considered concerning visual information. First, the time for visual information processing vary from 80 to 200 msec, depending on the task specificity (Cordo & Flanders, 1989; Ruschel et al., 2011; Senel & Eroglu, 2006; Spittle, 2021). Second, the motor control system uses sensory information from previous trials to predict their actions (Salvesbergh, & van der Kamp, 2000; Gray 2002). So, shorter inter-trial intervals may be enough to compare the distance between the target and the actual performance for planning necessary adjustments.

Beyond feedback for planning adjustments, the inter-trial length also influences memory consolidation (Buch et al., 2021). During practice with short inter-trial intervals, the same structure of the skill is kept in the working memory, and parameter adjustments are made in every trial (Lage et al., 2015). This process can improve the parameterization learning of massed practice. However, the longer the inter-trial interval opposite results can happen because the same structure of the skill should be restored in working memory in every trial. This process of skill structure recovering in every trial improves the same structure of the skill learning (Lee & Magill, 1983), but not parameterization learning (Lai et al., 2000). So, the distributed practice deteriorates the ability to recover parameter information from trial to trial (Baddeley, 2000, 2012; Zhu et al., 2021), resulting in worse performance than massed practice. Moreover, the longer inter-trial interval may have diminished task engagement during practice, and may also result in poorer learning (Lelis-Torres et al., 2017), observed in the retention test. Together, these factors may cause the distributed to produce practice worse performance accuracy and consistency than massed practice.

On the other hand, the distributed practice has shown better results for the learning of older adults (Leite et al., 2013). Older adults have declined their capacity for information processing (Ebaid & Crewther, 2019; Rosano et al., 2012). The information processing (Marteniuk, 1976) during small inter-trial intervals can make the results analysis of the previous trial difficult, comparing them with the expected result, and organizing changes for the next trial difficult. Consequently, the slower information processing of older adults can deteriorate the skill structure or parameters learning under massed practice, differently than what is observed with younger adults.

The results of the present study are reliable. Many sports motor skill learning studies did not significantly control the inter-trial interval during the acquisition phase or retention test. Concerning the acquisition phase, some studies have no inter-trial interval citation (Dail & Christina, 2004; Swandewi, Mintarto, & Nurkholis, 2017) or control about the time spent to perform the motor skill (Aghdasi & Jourkesh, 2011). All these intervals influence the ability to access the working and long-term memory. Our study had three inter-trial intervals, one to access the working memory, i.e., one second, and two to access long-term memory, i.e., 15 and 40 seconds (Brown, 1958; Ricker, Vergauwe, & Cowan, 2016). Considering the inter-trial intervals during the retention test, some used inter-trials that could have favored the distributed practice, i.e., 20 seconds (Spittle, McNeil, & Mesagno, 2012), or the inter-trial interval time was not specified (Krishnan, 2019). The present study balanced the inter-trial interval in relation to the massed and distributed practice, i.e., 10 seconds, thus minimizing the influence of the learning condition in the retention test and extending the results from Panchuk et al. (2013).

The results from simple lab tasks with parameters learning indicate better results for the distributed practice (Andersen et al., 2015; Metalis, 1985) were not replicated with a complex sports motor skill (Spittle, McNeil, & Mesagno, 2012; Fuentes-García et al., 2022). This problem has been reported in the literature (Matos et al., 2021; Wulf & Shea, 2002). Complex sports motor skills require greater control of the degree of freedom and probably different efforts from working memory and long-term memory, which should be addressed in the future. Thus, the present study indicates the importance of testing the results from lab tasks with sports motor skills, providing different insights into the learning process.

Although our performance measures were enough to have statistical support, it does not provide information about changes in movement pattern, which is a limitation. Future work should include kinematic measures indicating the skill structure and parameters learning to understand better the spacing of practice effects on learning sports motor skills. Furthermore, investigating the interaction of spacing of practice with other variables manipulated during practice, such as practice schedule, would provide great information about the learning process of sports motor skills. These steps are already being done in our lab.

Practical applications

The results of this study have practical applications for interventions by teachers and coaches in the decision-making of drill design for sports motor skills (e.g., discrete and serial skills) (Dutra et al., 2021; Moon, 2022; Paulina, García-Tascon, & Guerrero, 2022; Izzo et al., 2023). For instance, teachers and coaches should consider the importance of using a maximum of two or three participants in a line to perform sports skills drills such as overhand serve in volleyball. In teaching sports motor skills, we suggest that working with fewer individuals in the line (i.e., short inter-trial interval) would allow for better learning through massed practice.

Conclusions

We used different inter-trial intervals to investigate the spacing of practice and used one massed group and two distributed groups. We demonstrated that the shorter inter-trial interval is greater for parameters learning of sports motor skills, but it is still necessary to investigate its effect on the skill structure learning. Massed practice did not promote fatigue and loss of performance, but it allowed information to be processed more efficiently in working memory. These findings can help teachers and coaches to optimize their training schedules through massed practice to learn sports motor skills.

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