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The effect of consistent and varied follow-through practice schedules on learning a table tennis backhand

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**Abstract**

In table tennis the follow-through action after a shot is an important part of skill execution. In this experiment, we aimed to extend literature around the contextual interference effect by investigating whether the way the follow-through is organised in practice affects learning of the backhand shot in table tennis. Thirty unskilled participants were allocated to blocked-variable practice, random-variable practice or a control-constant group and aimed backhand shots towards a target following ball projection from a machine. Each group completed these shots in a pre-test, a training phase with follow-through manipulations, a post-test, and a retention test. The random-variable group improved their shot accuracy from pre-test to post-test and from pre-test to retention test (both *P* < 0.01, *d* = 1.03), whereas neither the blocked-variable nor the control-constant group displayed any change in shot accuracy. Practising the follow-through in a random-variable fashion enhanced learning of the preceding shot compared with blocked-variable practice or no follow-through instructions. The benefits of learning motor skills under conditions of high contextual interference also apply to how follow-through actions are organised. The findings are of value to coaches and suggest that instructions related to the follow-through action should be considered as well as the primary skill itself.

Keywords: Contextual interference, motor skill learning, practice structure

**Introduction**

In table tennis, players must vary their shot selection and tactical play to cope with complex, ever-changing, and relatively unpredictable performance constraints. However, training these shots often occurs in a blocked and predictable fashion. The degree of consistency or unpredictability with which skills are practised and how this affects motor learning has received considerable attention in the broad field of human performance (see Goode & Magill, 1986; Hall, Domingues, & Cavazos, 1994; Pyle, 1919; Rendell, Masters, Farrow, & Morris, 2010; Shea & Kohl, 1990; Shea, Kohl, & Indermill, 1990; Shea & Morgan, 1979; Shoenfelt, Snyder, Maue, McDowell, & Woolard, 2002; Wright et al., 2016). Although researchers initially concluded that practising different skills in a blocked or consistent fashion resulted in superior motor learning relative to performing these skills in a more varied and unpredictable fashion (see Pyle, 1919), these early studies failed to include retention tests and so were unable to distinguish between short-term performance effects and more permanent long-term changes that would indicate learning.

 The way in which practice is organised, namely whether it is in a blocked and consistent fashion or in a varied and unpredictable manner, is thought to promote differing levels of contextual interference which refers to the degree of interference between the performance of one task or skill and the next in the context of practice (Battig, 1979). Skills which are practised in a blocked and consistent fashion result in low levels of contextual interference, whilst skills practised in a varied and unpredictable fashion produce high levels of contextual interference. The common pattern of findings, referred to as the contextual interference effect, is that blocked and consistent practice conditions promote rapid improvements in performance but retard learning, as evidenced by performance at delayed retention tests, whereas the opposite is true for practice conditions that produce high levels of contextual interference (see Broadbent, Causer, Ford, & Williams, 2015; Ollis, Button, & Fairweather, 2005; Pauwels, Swinnen, & Beets, 2014; Shea & Kohl, 1990; Shea & Morgan, 1979; Shea et al., 1990; Wright, Magnuson, & Black, 2005).

 To date, studies which have investigated the structure and organisation of practice have almost exclusively focused on the primary skill itself. In many sports, however, the follow-through after the primary skill is an important feature of technique and is frequently included in biomechanical analyses (e.g., Bezodis, Trewartha, Wilson, & Irwin, 2007; Cerrah et al., 2011; Elliott, Marsh, & Overheu, 1989; Fleisig et al., 1996), yet how this follow-through action is instructed or organised in practice and how this influences the motor learning process has received very little attention. The importance of the follow-through is evident in table tennis where it can noticeably vary depending on the direction, spin or speed imparted on the ball. The high ball speed and the small court size in table tennis mean the spatial-temporal demands placed on performers are extreme as they must quickly and accurately switch between different technical skills and combinations of these skills which exhibit different follow-through actions. These perceptual-motor skills and the ability to combine shot and spin variations are key characteristics of successful performance in table tennis (Limoochi, 2006; Munivrana, Furjan-Mandic, & Kondric, 2015; Toriola, Toriola, & Igbokwe, 2004).

 Howard, Wolpert, and Franklin (2015) provided a rare example of research which has investigated how follow-through actions contribute to learning motor skills. Using a laboratory-based lever-positioning task, they reported, contrary to the contextual interference effect, that more consistent follow-through actions enhanced motor learning whilst varied follow-through actions impaired the learning process. When interpreting their findings, Howard et al. (2015) argued that a consistent follow-through action activates a single motor memory and results in superior learning, whereas a varied follow-through results in interference and prevents consolidation of the motor memory. However, when explaining the contextual interference effect, it is precisely this interference which results from unpredictable learning conditions that is considered responsible for the superior long-term motor learning. Although this contextual interference makes learning conditions more difficult and has been shown to slow the rate of performance change, increasing the degree of cognitive challenge by being required to continually reconstruct (Lee & Magill, 1983, 1985) or contrast between movement patterns in working memory so that each are made elaborate and distinct (Shea, Hunt, & Zimny, 1985; Shea & Morgan, 1979; Shea & Zimny, 1983) is thought to promote stronger memory representations which ultimately enhances long-term learning. Critically in this regard, Howard et al. (2015) did not include a retention test in their design. Given that learning is recognised as a *relatively permanent* change in performance, including delayed retention tests after the initial training period is fundamental when looking to draw conclusions about motor learning. Indeed, the pattern of findings that Howard et al. (2015) present replicates what is seen during training periods in much research investigating contextual interference (e.g., Broadbent, Causer, Williams, & Ford, 2017; Gane & Catrombone, 2011; Shea & Kohl, 1990; Shea & Morgan, 1979; Shea et al., 1990). It is therefore important to further investigate how a consistent or varied follow-through action affects motor learning through a research design including a delayed retention test.

 It is also important to examine if the conclusions drawn by Howard et al. (2015) using a simple and artificial laboratory task also apply to learning more complex and sport-specific skills. In table tennis, players are forced to play shots in response to an opponent and operate under strict spatial and temporal constraints. These dynamic interactions are likely to necessitate that table tennis players will be required to make quick perceptual-cognitive decisions; different follow-through actions will, therefore, likely be exhibited as they adapt to the technical demands of the situation. Given the different performance constraints which operate in table tennis relative to the simple, closed, and self-paced task that was used by Howard et al. (2015), along with their failure to include a retention test, we argue that their results must be treated with caution when considering how follow-through actions might affect motor learning for complex sport skills.

 The aim in this experiment was therefore to examine how the organisation of follow-through actions affected motor learning of a backhand shot in table tennis. Participants learned to play a backhand shot with the aim always being to play the ball to a designated target on the table which remained the same throughout. Participants were therefore always presented with the same to-be-learned primary skill, however we manipulated the instructions that we provided to participants regarding their follow-through action; some participants were instructed to follow-through in a blocked fashion (i.e., consistent and predictable from one trial to the next), whilst others were instructed to follow-through in a varied fashion (i.e., inconsistent and unpredictable from one trial to the next). We also used a control group who were given no instructions related to the follow-through action. Given the strong theoretical underpinnings and extensive body of literature which has demonstrated the contextual interference effect when investigating how the primary skill is organised, along with our critiques of the methods employed by Howard et al. (2015), we only expected to see changes in performance in certain groups between specific time points and so made a series of a priori hypotheses in relation to these. We predicted that the group practising with a blocked follow-through would significantly improve their shot accuracy from pre-test to post-test. In the absence of any instructions related to the follow-through action, we expected the control group to follow-through in a consistent manner and so we also hypothesised that they would show a significant improvement in accuracy from pre- to post-test. However, from pre-test to retention test we predicted that the contextual interference and cognitive challenge caused by organising the follow-through in a varied fashion during the training period would result in the development of enhanced memory representations and so we predicted that the varied follow-through group would be the only group to show a significant improvement in shot accuracy from pre- to retention test.

**Method**

*Participants*

Thirty unskilled individuals (18 males, 12 females; mean ± SD age = 27.63 ± 5.58 years) volunteered to participate in the study and were assigned to one of three groups; blocked-variable practice group (n = 10), control-constant group (n = 10), or random-variable practice group (n = 10). Participants were classed as unskilled if they reported not currently playing table tennis recreationally or having ever played for a competitive table tennis club. Three of the participants were left hand dominant and were evenly assigned across the three groups; the remaining 27 participants were right hand dominant. To ensure the appropriateness of sample size, we conducted a power analysis using G\* power (Faul, Erdfelder, Lang, & Buchner, 2007). The calculation was based on the effect size reported for a Group × Test Type interaction in a study investigating blocked and random practice for learning golf chip shots (Aiken & Genter, 2018; *ηp2*= 0.25). We set a moderate correlation (*r* = 0.3), power at 0.8, and alpha level at 0.05. The total sample size required for the 6 testing phases by 3 groups ANOVA used in the current study was n = 9.

 Ethical approval was obtained from, and research was conducted within the guidelines of, the lead author’s University’s research ethics committee (ethics approval reference: SMEC\_2016-17\_11). The research was conducted following the principles of the Declaration of Helsinki. All participants provided written informed consent.

*Apparatus*

The study was performed on a standard size (2.7 × 1.5 m) table tennis table (Butterfly, Krefeld, Germany). The scoring system was adapted from Poolton, Masters, and Maxwell (2006) as follows. Six 50 cm wide squares were marked on the opposing side of the table and a 25 cm wide square was marked within the middle square furthest from the participant; three points were awarded for hitting into this area, two points for the large square surrounding it, and one point for the other five squares (see Figure 1). No points were awarded if the ball was not hit to any of the six squares. Dunlop Club training balls (40 mm diameter) were delivered to the participants from a ball projection machine (Table Tennis Buddy V200, Joola, Germany) which was positioned behind the right-hand corner of the table opposite the participant (Figure 1). The ball projection machine was set at a frequency of 30 balls/minute and balls were projected at a speed of 6.5 m/s. All participants completed the study using the same Dunlop Max All Round table tennis bat. A high definition camera (Panasonic HC-V720 HD Camcorder, Berkshire, UK) sampling at 50 Hz was mounted above the participants’ end of the table to record the follow-through of the bat.

FIGURE 1 NEAR HERE

*Procedure and Manipulations*

The experiment was divided into two sessions; the first comprised a pre-test and training period and was followed by a retention test in the second session. Prior to the pre-test, participants were informed that table tennis balls would be delivered from a ball projection machine and that they were required to play a backhand shot. The ball had to bounce once before being struck and the subsequent bounce should be on the other side of the net and aimed for the central three-point target. No further instruction was given on how to play the shot. Following a familiarisation period (10 shots), participants completed a pre-test of 50 shots aimed at the central three-point target with no further instruction.

 Following the pre-test, participants were allocated to groups based on their pre-test score to ensure there were no differences in performance levels between groups prior to the intervention. After this, participants completed a training period consisting of three blocks of 50 trials in which backhand shots continued to be aimed at the central three-point square. The control-constant group received no further instruction. The blocked-variable and random-variable groups were instructed to aim the ball at the centre square but to guide the follow-through of the shot to the right, left or middle. To follow-through to the right, participants were instructed to complete their shot in such a way that the bat finished pointing towards the far right-hand corner of the table. The same instruction was given regarding the left-hand corner for the left follow-through. For the middle follow-through, participants were instructed that the bat should follow the central line of the table. No further instructions were provided. The blocked-variable group completed blocks of 50 trials with the same follow-through (50 left, 50 middle, and 50 right) and the order was counter-balanced between participants. The random-variable group performed shots with the same number of follow-throughs to the left, middle, and right as the blocked-variable group. However, for the random-variable group, instructions as to which follow-through to perform were provided verbally by the investigator prior to ball projection on each shot. Follow-throughs were performed in a random order with no two consecutive trials the same. Following the training period, all groups completed a post-test following the same procedure as the pre-test with no follow-through instruction. A retention test was completed 24 to 48 hours later, in the same fashion as the pre- and post-tests.

*Measures and Data Analysis*

The maximum score available was 150 points. Two observers live recorded shot accuracy with agreement on 90% of the trials. Video images from the camera directly above the participants were viewed frame-by-frame in Windows Media Player 12 to quantify the follow-through execution by the blocked-variable and random-variable groups during the training period. For shot numbers 20-30 in each block, the location of the centre of the bat was marked at the point of contact with the ball and again at the end of the follow-through (i.e., cessation of forwards movement of the bat). The average follow-through angle of the bat relative to the centre line of the table was then identified for each participant in each of the follow-through conditions (see Figure 2 for an example). The average follow-through angle for each participant in the control-constant group for shot numbers 20-30 in the second block of the training period was also identified.

FIGURE 2 NEAR HERE

A repeated measures ANOVA was conducted to verify that there were differences in follow-through angles depending on whether participants were instructed to follow-through to the left, middle, or right. A further one-way between participants ANOVA was run on pre-test accuracy scores to ensure there was no initial difference in task performance prior to the follow-through manipulation. A 3 (Group [blocked-variable, random-variable, control-constant]) × 6 (Phase [pre-test, training 1, training 2, training 3, post-test, retention test]) mixed-design ANOVA with repeated measures on the last factor was conducted with performance score acting as the dependent variable. To test our a-priori hypotheses that only the blocked-variable and control-constant groups would increase their performance accuracy from pre- to post-test and that only the random-variable group would improve their performance accuracy from pre-test to retention test, paired samples *t*-tests were conducted to compare mean accuracy scores in the pre-test with mean accuracy scores in the post and retention test for each group.

Although our primary interest was to examine shot accuracy at retention- and transfer-tests relative to pre-test as a function of follow-through instruction, we also analysed data to check if follow-through instruction affected the direction of errors made during acquisition. To do this, we analysed a sample of 900 acquisition trials (300 with the follow-through movement to the right, 300 to the left, and 300 to the middle). We ran three separate 1-way repeated measures ANOVAs to test if errors to the left, errors to the right, and errors down the middle were affected by follow-instruction.

All data was checked to ensure it satisfied parametric assumption of normality and homogeneity of variance. Violations of sphericity were corrected using Greenhouse-Geisser procedures. Effect sizes are reported using partial eta squared (*ηp2*) in all instances and Cohen’s *d* for comparisons between two means. In the case of significant main effects or interactions, Bonferroni-corrected pairwise comparisons were used as post-hoc tests. The alpha level was set at 0.05, but in the case of multiple *t*-tests, the sequential Bonferroni correction was applied to control for family-wise error.

**Results**

First, the repeated measures ANOVA revealed a significant main effect of follow-through instruction on the follow-through angle exhibited by the participants, *F* (1.33, 25.26) = 40.789, *P* < 0.001, *ηp2*= 0.68. Post-hoc tests revealed that when instructed to follow-through to the left (*M* = -19.3, *SE* = 4.3°), the follow-through was directed significantly further to the left than when instructed to follow-through to the middle (*M* = -1.5, *SE* = 3.0°, *P* = 0.001) which was in turn significantly further to the left than when instructed to follow-through to the right (*M* = 26.4, *SE* = 4.0°, *P* = 0.001). The instructions for participants to adopt different follow-through actions were therefore successful. The control-constant group exhibited a mean follow through angle of 6.4 ± 4.5° (*M* ± *SE*).

Mean and standard error values of performance scores for the blocked-variable, random-variable, and control-constant group are presented in Figure 3. A one-way ANOVA revealed no significant differences in performance levels in the pre-test between blocked-variable (*M* = 72.30, *SE* = 4.85), random-variable (*M* = 72.50, *SE* = 5.42) and control-constant (*M* = 72.70, *SE* = 9.71) groups, *F* (2, 27) = 0.001. *P* = 0.999, *ηp2*= 0.00, meaning all groups showed the same level of performance outcome in playing the backhand shot prior to any experimental manipulation.

The 3 (Group [blocked-variable, random-variable, control-constant]) × 6 (Phase [pre-test, training 1, training 2, training 3, post-test, retention test]) mixed-design ANOVA revealed a significant Group × Phase interaction, *F* (10, 135) = 3.55, *P* < 0.001, *ηp2* = 0.21. A main effect of Phase was also observed, *F* (10, 135) = 14.38, *P* < 0.001, *ηp2*= 0.35. Bonferroni-corrected pairwise comparisons revealed that participants’ performance levels were significantly higher in the post-test (*M* = 83.60, *SE* = 3.78, *P* = 0.009, *d* = 0.53) and retention test (*M* = 82.80, *SE* = 3.51, *P* = 0.031, *d* = 0.51) than in the pre-test (*M* = 72.50, *SE* = 3.90).

To test our a priori predictions, we conducted planned comparisons between performance scores from pre- to post-test and pre- to retention test for each of the three groups. From pre- to post-test, a significant increase in performance level was observed for the random-variable group (*Mdiff* = 17.70, SE = 5.03, *P* = 0.007, *d* = 1.03) but not for the blocked-variable (*Mdiff* = 7.60, SE = 5.52, *P* = 0.202, *d* = 0.42) or control-constant group (*Mdiff* = 13.23, SE = 4.18, *P* = 0.088, *d* = 0.29). From the pre-test to the retention test, a significant increase in performance level was observed for the random-variable group (*Mdiff* = 13.70, SE = 3.87, *P* = 0.006, *d* = 0.89) but not for the blocked-variable (*Mdiff* = 7.40, SE = 5.84, *P* = 0.237, *d* = 0.37) or control-constant group (*Mdiff* = 9.80, SE = 5.77, *P* = 0.124, *d* = 0.38). Finally, the main effect of Group was not significant, *F* (2, 27) = 0.65, *P* = 0.529, *ηp2*= 0.05.

FIGURE 3 NEAR HERE

 The follow-through condition had no effect on the number of misses to the left (*F* = 2.086, *p* = 0.175, *ηp2* = 0.294) or to the right (*F* = 2.389, *p* = 0.142, *ηp2* = 0.323). ANOVA showed misses in the middle third were affected by follow-through instruction (*F* =4.520, *p* = 0.040, *ηp2* = 0.475), however no significant pairwise effects were evident when post-hoc Bonferroni corrections were applied. Being instructed to follow-through to the right or left did not bias errors to these directions.

**Discussion**

 We aimed to examine how different follow-through practice schedules affect learning of the backhand shot in table tennis. Given the extensive body of research which has reported the contextual interference effect when investigating how the primary skill is practised, we made two main predictions. First, we predicted that the blocked-variable and control-constant groups would significantly improve their shot accuracy from pre- to post-test as we expected participants in both of these groups to adopt a consistent follow-through within training phases, which would reduce interference and disruption from one shot to the next and enable them to acquire greater shot accuracy over the training period. Second, we predicted that participants in the random-variable follow-through group would be forced to contend with greater interference from one trial to the next, which would slow the initial rate of performance change, but lead to better long-term learning. Consequently, we hypothesised that only the random-variable group would improve their shot accuracy from pre- to retention test. Our findings partially supported these hypotheses. As we predicted, participants in the random-variable group significantly improved their shot accuracy from pre- to retention test. However, contrary to our hypotheses the random-variable group also significantly improved their shot accuracy from pre- to post-test whereas both the blocked-variable and control-constant groups did not.

 The finding that a more random and varied practice schedule results in superior motor skill learning (as inferred through performance at delayed retention tests) has been well reported (see Brady, 1998; Green & Sherwood, 2000; Hall, Domingues, & Cavazos, 1994; Lee & Simon, 2004; Shea & Morgan, 1979; Shea et al., 1990). However, this is the first study to demonstrate that the benefits of a random-varied practice schedule also apply to the organisation and structure of the follow-through action. Being forced to continually vary and adapt the follow-through is likely to have been challenging for participants and demanded high levels of concentration on the skill. In line with the forgetting-reconstruction (Lee & Magill, 1985) and elaboration-distinctiveness (Shea & Zimny, 1983) theories, we argue this heightened concentration and cognitive engagement will have resulted in the development of more robust memories and long-term learning that was evidenced through superior performance in the retention test. These theories, which have been used to interpret results related to how the primary skill is organised, can also explain why a random-variable follow-through results in superior motor skill learning relative to blocked-variable and control-constant conditions.

 In addition to performance at post- and retention-tests, it is important to consider performance curves (illustrated in Figure 3) to gain a more complete picture of the skill acquisition process. Both experimental groups show degradation in performance after pre-test, which contrasts the typical pattern of performance curves that show rapid rates of improvement in the early stages of skill learning (e.g., see Gane & Catrambone, 2011; Lohse, Sherwood, & Healy, 2010; McNevin, Shea, & Wulf, 2003; Menayo, Sabido, Fuentes, Moreno, & Garcia, 2010). However, in the acquisition phase of this study, participants completed the task in a different way than they had done in the pre-test (i.e., they were required to direct their follow through toward a particular location). This is likely to have made the task more difficult, explaining this initial degradation for both experimental groups. It could also explain the distinct trends of the two experimental groups over the course of acquisition. Whereas the blocked-variable group showed minimal improvement through training, the random-variable group improved shot accuracy over time. Having to follow through to a different location in each block appears to have prevented the blocked-variable group from improving performance over time as they were forced to “start from scratch” every fifty trials. Conversely, whilst the random-variable group faced greater variability from one trial to the next, the instructions and task for each training block remained the same, thus facilitating adaptation to the task demands and performance improvements over time. The constant-control group, in contrast, who were not constrained to satisfy any particular follow-through instruction, showed a performance curve that more closely resembles that typically associated with acquisition of motor skills.

 Although we did not measure constructs related to intrinsic motivation, recent theoretical accounts and empirical investigations highlight their importance in motor learning and offer a useful perspective to interpret the distinct between-group trends. The random-variable group - the only group to significantly improve shot accuracy from pre- to post- and retention-tests - was also the group which showed the largest improvements from each training block to the next. These improvements through the intervention period may enhance perceptions of competence (Saemi, Wulf, Varzaneh, & Zarghami, 2011), interest/engagement in the task (Sheldon & Filak, 2008), and result in greater effort being expended during practice (Abbas & North, 2018). These effects have also resulted in participants demonstrating superior motor learning relative to those who were exposed to conditions that led to lower perceptions of competence, interest or effort ratings. Perceived competence, which is conceptually similar to self-efficacy (Bandura, 1997), is considered a basic psychological need (cognitive evaluation theory; Deci, 1975; Deci & Ryan, 1985) and so any variables positively impacting such measures are likely to improve intrinsic motivation, which itself is now identified as a key theoretical construct in aiding motor learning (OPTIMAL theory of motor learning; Wulf & Lewthwaite, 2016). Whilst caution must be applied to this interpretation, as measures of intrinsic motivation were not recorded in the current study, it appears worthwhile for future research to investigate whether these findings from investigations into feedback and motor learning (e.g., Abbas & North, 2018) and attentional focus and motor learning (e.g., Wulf & Lewthwaite, 2016) from a motivational perspective also transfer to contextual interference.

 To date, only one other study has investigated how organisation of the follow-through action affects learning of the preceding skill (see Howard et al., 2015). Our finding that a random-variable follow-through action results in superior motor learning of the primary skill directly contrasts with the conclusions of Howard et al. (2015). The failure of Howard et al. (2015) to include a retention test, which makes it difficult to distinguish between transient performance effects and more permanent learning, is one potential explanation for this. Another important variable which could explain the contrasting findings concerns the nature of the task. In contrast to the self-paced lever moving task employed by Howard et al. (2015), which has little transferability to sport-specific or other ‘real-world’ tasks, the table tennis backhand shot we used is a complex task that represents a skill that is used in game situations. Such a skill necessitates controlling multiple degrees of freedom, is externally paced, and requires participants to intercept a fast-moving projectile that must be struck in to a narrow target area. In table tennis, where performers operate under strict temporal pressures and may play shots to the same location but impart different spins on the ball which may require different follow-through actions, we have presented evidence that practising with a more varied follow-through action leads to superior learning. A particular advantage in practising with a random-variable follow-through action is likely to be in the ability to adapt to different task constraints and show variation in the shots played. Although we employed a retention test to distinguish between performance and learning effects, we did not include transfer tests. This is something that researchers should look to investigate in future studies. Given the need to adapt to different types and speed of shots from table tennis opponents, as well as being required to direct shots to various locations on the table, it would be reasonable to expect that the advantages of being forced to continually adapt the follow-through action during acquisition would lead to even greater learning advantages being evident in transfer tests.

 A surprising finding, and one that is contrary to the pattern of results observed in the contextual interference effect and our hypotheses, was that the random-variable group also made significant improvements in shot accuracy from pre- to post-test, outperforming both blocked-variable and control-constant groups. However, most studies investigating the effects of blocked and varied practice schedules have used a relatively small number of trials during training periods (18 acquisition trials per task, Shea & Morgan, 1979; 30 trials per task, Green & Sherwood, 2000), yet when more extended training periods are employed it is not unusual by the end of practice for varied practice groups to progress to the same performance levels as blocked groups (see Helsdingen, van Gog, & van Merrienboer, 2011; Pauwels et al., 2014) or even exceed them (see Maslovat, Chua, Lee, & Franks, 2004). It is possible the relatively high number of trials we employed in the training period meant that the learning benefits of practising in cognitively challenging conditions were realised by the end of training and thus our retention test reflected persistence of learning rather than indicating learning in the first instance. Inspection of performance after the first training block (where the number of trials is more in line with that typically employed throughout entire acquisition periods) shows a pattern of results which more closely matches the contextual interference effect. This pattern of findings matches those reported by Maslovat et al. (2004) and Pauwels et al. (2014) who also employed longer training periods and suggests the initial detrimental effects of practising in difficult conditions can be overcome if the training period is extended. However, it is worth highlighting the findings of Shea et al. (1990) who reported that, regardless of whether participants practised for 50, 200, or 400 acquisition trials, the random group always showed inferior performance through the acquisition period when compared to the blocked group.

**Conclusions**

 In conclusion, we have presented evidence that practising a skill with a random-varied follow-through action results in superior motor learning of that skill compared with blocked-variable practice of different follow-through actions or no specific follow-through action instructions. We have demonstrated that contextual interference effects related to practice organisation of the primary skill also transfer to the practice structure and organisation of the follow-through action. However, this is the first study to demonstrate the contextual interference effect in follow-through movements and so it is important for future researchers to replicate these findings before they can be confidently applied to practice. The temporal and spatial constraints of table tennis, along with the importance of the follow-through in table tennis when varying shot type, mean that practising the follow-through in a varied and unpredictable fashion enhances learning and the ability to adapt externally-paced skills. The findings are potentially of practical value to table tennis coaches and suggest that when trying to learn a backhand shot, their athletes should follow-through after the shot in a varied fashion. These novel findings have important implications for practice design in table tennis, and future research should ascertain their generalisability to different table tennis shots and other racquet sports, as well as to other sporting movements where a follow-through is employed.

**References**

Aiken, C. A., & Genter, A. M. (2018). The effects of blocked and random practice on the learning of three variations of the golf chip shit. *International Journal of Performance Analysis in Sport*, *18*(2), 339-349. DOI: 10.1080/24748668.2018.1475199.

Abbas, Z. A., & North, J. S. (2018). Good- vs. poor-trial feedback in motor learning: The role of self-efficacy and intrinsic motivation across levels of task difficulty. *Learning and Instruction*, *55*, 105-112 <https://doi.org/10.1016/j.learninstruc.2017.09.009>

Battig, W. F. (1979). The flexibility of human memory. In L. S. Cermak & F. I. M. Craik (Eds.), *Levels of processing in human memory* (pp. 23-44). Erlbaum, NJ: Hillsdale.

Bandura, A. (1997). *Self-efficacy: The exercise of control.*New York: W. H. Freeman and Company.

Bezodis, N., Trewartha, G., Wilson, C., & Irwin, G. (2007). Contributions of the non-kicking-side arm to rugby place-kicking technique. *Sports Biomechanics*, *6*, 171-186.

Brady, F. (1998). A theoretical and empirical review of the contextual interference effect and the learning of motor skills. *Quest*, *50*, 266-293.

Broadbent, D. P., Causer, J., Ford, P. R., & Williams, A. M. (2015). Contextual interference effect in perceptual-cognitive skills training. *Medicine & Science in Sports & Exercise*, *47*, 1243-1250.

Broadbent, D. P., Causer, J., Williams, A. M., & Ford, P. (2017). The role of error processing in the contextual interference effect during the training of perceptual-cognitive skills. *Journal of Experimental Psychology: Human Perception and Performance*. http://dx.doi.org/10.1037/xhp0000375

Cerrah, A. O., Gungor, E. O., Soylu, A. R., Ertan, H., Lees, A., & Bayrak, C. (2011). Muscular activation patterns during the soccer in-step kick. *Isokinetics and Exercise Science*, *19*, 181-190.

Deci, E. L. (1975). *Intrinsic motivation.* New York: Plenum.

Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior.* New York: Plenum.

Elliott, B., Marsh, T., & Overheu, P. (1989). A biomechanical comparison of the multisegment and single unit topspin forehand drives in tennis. *International Journal of Sport Biomechanics*, *5*, 350-364.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G\*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*, 175–191. http://dx.doi.org/10.3758/BF03193146.

Fleisig, G. S., Barrentine, S. W., Zheng, N., Escamilla, R. F., & Andrews, J. R. (1999). Kinematic and kinetic comparison of baseball pitching among various levels of development. *Journal of Biomechanics*, *32*, 1371-1375.

Gane, B. D., & Catrambone, R. (2011). Extended practice in motor learning under varied practice schedules: Effects of blocked, blocked-repeated, and random schedules. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *55*, 2143-2147.

Goode, S., & Magill, R. A. (1986). Contextual interference effects in learning three badminton serves. *Research Quarterly for Exercise and Sport*, *57*, 308-314.

Green, S., & Sherwood, D. E. (2000). The benefits of random variable practice for accuracy and temporal error detection in a rapid aiming task. *Research Quarterly for Exercise and Sport*, *71*, 398-402.

Hall, K. G., Domingues, D. A., & Cavazos, R. (1994). Contextual interference effects with skilled baseball players. *Perceptual Motor Skills*, *78*, 835-841.

Helsdingen, A. S., van Gog, T., & van Merrienboer, J. J. G. (2011). The effects of practice schedule on learning a complex judgment task. *Learning and Instruction*, *21*, 126-136.

Howard, I. S., Wolpert, D. M., & Franklin, D. W. (2015). The value of the follow-through derives from motor learning depending on future actions. *Current Biology*, *25*, 397-401.

Lee, T. D., & Magill, R. A. (1983). The locus of contextual interference in motor-skill acquisition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *9*, 730-746.

Lee, T. D., & Magill, R. A. (1985). Can forgetting facilitate skill acquisition In D. Goodman, R. B. Wilberg, & I. M. Franks (Eds.), *Differing perspectives in motor learning and control* (pp. 3-22). Amsterdam, North Holland: Elsevier.

Lee, T. D., & Simon, D. A. (2004). Contextual interference. In A. M. Williams & N. J. Hodges (Eds.), *Skill acquisition in sport: Research, theory, and practice* (pp. 29-44). London: Routledge.

Limoochi, S. (2006). A survey of table tennis coaches’ opinions of some criteria in talent identification. *International Journal of Table Tennis Sciences*, *6*, 280-287.

Lohse, K. R., Sherwood, D. E., & Healy, A. F. (2010). How changing the focus of attention affects performance, kinematics, and electromyography in dart throwing. *Human Movement Science*, *29*, 542-555.

Maslovat, D., Chua, R., Lee, T. D., & Franks, I. M. (2004). Contextual interference: Single task versus multi-task learning. *Motor Control*, *8*, 213-233.

McNevin, N. H., Shea, C. H., & Wulf, G. (2003). Increasing the distance of an external focus of attention enhances learning. *Psychological Research*, *67*, 22-29.

Menayo, R., Sabido, R., Fuentes, J. P., Moreno, F. J., Garcia, J. A. (2010). Simultaneous treatment effects in learning four tennis shots in contextual interference conditions. *Perceptual and Motor Skills*, *110*, 661-673.

Munivrana, G., Furjan-Mandic, G., & Kondric, M. (2015). Determining the structure and evaluating the role of technical-tactical elements in basic table tennis playing systems. *International Journal of Sports Science and Coaching*, *10*, 111-132.

Ollis, S., Button, C., & Fairweather, M. (2005). The influence of professional expertise and task complexity upon the potency of the contextual interference effect. *Acta Psychologica*, *118*, 229-244.

Pauwels, L., Swinnen, S. P., & Beets, I. A. M. (2014). Contextual interference in complex bimanual skill learning leads to better skill persistence. *PlosOne, 9(6)*: e100906. doi: 10.1371/journal.pone.0100906.

Poolton, J. M., Masters, R. S. W., & Maxwell, J. P. (2006). The influence of analogy learning on decision-making in table tennis: Evidence from behavioural data. *Psychology of Sport and Exercise*, *7*, 677-688.

Pyle, W. H., (1919). Transfer and interference in card-distributing. *Journal of Educational Psychology*, *10*, 107-110.

Rendell, M. A., Masters, R. S., Farrow, D., & Morris, T. (2010). An implicit basis for the retention benefits of random practice. *Journal of Motor Behavior*, *43*, 1-13.

Saemi, E., Wulf, G., Varzaneh, A. G., & Zarghami, M. (2011). Feedback after good versus poor trials enhances motor learning in children. *Revista Brasileira de Educação Física e Esporte, 25,* 673-681.

Shea, C. H., & Kohl, R. M. (1990). Specificity and variability of practice. *Research Quarterly for Exercise and Sport*, 61, 169-177.

Shea, C. H., Kohl, R., & Indermill, C. (1990). Contextual interference: Contributions of practice. *Acta Psychologica*, *73*, 145-157.

Shea, J. B., Hunt, J. P., & Zimny, S. T. (1985). Representational structure and strategic processes for movement production. *Advances in Psychology*, *27*, 55-87.

Shea, J. B., & Morgan, R. (1979). Contextual interference effects on the acquisition, retention, and transfer of a motor skill. *Journal of Experimental Psychology: Human Perception and Performance*, *5*, 179-187.

Shea, J. B., & Zimny, S. T. (1983). Context effects in memory and learning information. In R. A. Magill (Ed.), *Memory and control of action* (pp. 345-366). Amsterdam: North Holland.

Sheldon, K. M., & Filak, V. (2008). Manipulating autonomy, competence, and relatedness in a game-learning context: New evidence that all three needs matter. *British Journal of Social Psychology, 47,* 267-283.

Shoenfelt, E. L., Snyder, L. A., Maue, A. E., McDowell, C. P., & Woolard, C. D. (2002). Comparison of constant and variable practice conditions on free-throw shooting. *Perceptual and Motor Skills*, *94*, 1113-1123.

Toriola, A. L., Toriola, O. M., & Igbokwe, N. U. (2004). Validity of specific motor skills in predicting table-tennis performance in novice players. *Perceptual and Motor Skills*, *98*, 584-586.

Wright, D. L., Magnuson, C. E., & Black, C. B. (2005). Programming and reprogramming sequence timing following high and low contextual interference practice. *Research Quarterly for Exercise and Sport*, *76*, 258-266.

Wright, D., Verwey, W., Buchanen, J., Chen, J., Rhee, J., & Immink, M. (2016). Consolidating behavioral and neurophysiologic findings to explain the influence of contextual interference during motor sequence learning. *Psychonomic Bulletin & Review*, *23*, 1-21.

Wulf, G., & Lewthwaite, R. (2016). Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. *Psychonomic Bulletin & Review, 23,* 1382-1414.

**Figure Captions**

Figure 1. Position of ball projection machine (top-right corner) and scoring system, adapted from Poolton et al. (2006), with numbers representing the point score awarded for a shot landing in that area.

Figure 2. Example of a participant executing a left follow-through and how angles were quantified. An angle of zero represented a follow-through (from ball contact to the most forward point of the follow-through) parallel to the line down the centre of the table, a negative angle represented a follow-through to the left and a positive angle represented a follow-through to the right.

Figure 3. Mean ± SE performance scores in pre-test, training blocks 1–3, post-test, and retention test for the control-constant, blocked-variable, and random-variable groups.

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