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Practice variability promotes an external focus of attention and enhances motor skill learning

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ABSTRACT

Variability in practice has been shown to enhance motor skill learning. Benefits of practice variability have been attributed to motor schema formation (variable versus constant practice), or more effortful information processing (random versus blocked practice). We hypothesized that, among other mechanisms, greater practice variability might promote an external focus of attention on the intended movement effect, while less variability would be more conducive to a less effective internal focus on body movements. In Experiment 1, the learning of a throwing task was enhanced by variable versus constant practice, and variable group participants reported focusing more on the distance to the target (external focus), while constant group participants focused more on their posture (internal focus). In Experiment 2, golf putting was learned more effectively with a random compared with a blocked practice schedule. Furthermore, random group learners reported using a more effective distal external focus (i.e., distance to the target) to a greater extent, whereas blocked group participants used a less effective proximal focus (i.e., putter) more often. While attentional focus was assessed through questionnaires in the first two experiments, learners in Experiment 3 were asked to report their current attentional focus at any time during practice. Again, the learning of a throwing task was more effective after random relative to blocked practice. Also, random practice learners reported using more external focus cues, while in blocked practice participants used more internal focus cues. The findings suggest that the attentional foci induced by different practice schedules might be at least partially responsible for the learning differences.

The learning benefits resulting from practice schedules that vary or intersperse different motor tasks have long been of interest to researchers (see Schmidt, Lee, Winstein, Wulf, & Zelaznik, 2019). When practicing various motor tasks in the same sessions – be it parameter variations of the same skill in the tradition of schema theory (Schmidt, 1975) or skills with different spatio-temporal characteristics (e.g., Shea & Morgan, 1979) – greater variability generally results in enhanced skill learning. Even though the literatures related to schema learning (for a review, see Shea & Wulf, 2005) and contextual interference (for a review, see Lee, 2012) are relatively distinct, they have in common that added variability aids learning.

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Variable practice of different movement parameters, such as absolute force or absolute movement time, typically leads to more effective learning than constant practice of a single task version (e.g., Kelso & Norman, 1978; Kerr & Booth, 1978; Shea & Kohl, 1990). A (recall) schema has been conceived of as the relationship between the movement outcome (e.g., distance an object was thrown) and the parameter selected (e.g., amount of force) under a given set of initial conditions (e.g., object weight). Variable practice involving multiple task versions, compared with constant practice of one task version, is assumed to enhance the learning of the schema rule governing parameter selection. A well-defined schema, in turn, facilitates the selection of parameters for practiced or novel task variations in the future. Furthermore, even though not directly predicted by schema theory, a random relative to a blocked order of parameter variations seems to further enhance learning (e.g., Lee, Wulf, & Schmidt, 1992; Shea, Lai, Wright, Immink, & Black, 2001). Recent findings show that memory consolidation relies on different neural substrates as a function of variable versus constant practice (Kantak, Sullivan, Fisher, Knowlton, & Winstein, 2010), supporting the idea of the engagement of different structures during or after practice.

Contextual interference studies typically compare learning under practice conditions that involve the same tasks, but a different order of tasks. A random order, which creates high interference due to the constant task changes, generally leads to enhanced retention or transfer performance (i.e., learning) relative to a blocked practice order with low contextual interference (e.g., Hall, Domingues, & Cavazos, 1994; Simon & Bjork, 2001). The pioneering study by Shea and Morgan (1979) provided the first demonstration of random practice benefits for learning. A group that practiced three different versions of a barrier-knock-down task in a random order showed more effective learning on retention and transfer tests than a blocked practice group that completed all trials on one task before moving to the next task. The learning advantages of random compared to blocked practice have been replicated in numerous studies. The contextual interference effect has been observed not only for typical laboratory tasks – such as tracking, aiming, anticipation-timing, or sequential-timing tasks – but also for sport skills, including kayak rolls, badminton serves, and tennis ground strokes (for reviews, see Brady, 1998; Magill & Hall, 1990; Wulf & Shea, 2002). The main explanations for the contextual interference effect, the elaboration hypothesis (Shea & Morgan, 1979; Shea & Zimny, 1983) and the reconstruction hypothesis (Lee & Magill, 1983, 1985), are information-processing accounts of the random-practice learning advantages. That is, the processing of task-related information is assumed to be more effortful under random relative to blocked practice conditions due to increased inter-task comparisons, or due to forgetting and subsequent memory retrieval processes, respectively. Greater challenges experienced in variable or random practice indeed seem to promote neural activity and connectivity that collectively reflect greater movement planning and more elaborate processing of sensory information (Cross, Schmitt, & Grafton, 2007; Lin et al., 2012; Lin, Winstein, Fisher, & Wu, 2010; Pauwels et al., 2018; for a review, see Wright et al., 2016). Aside from the learning benefits resulting from greater challenges associated with variable versus constant or random versus blocked practice, there may be other factors contributing to those benefits.

The present set of experiments explored the role of possible differences in attentional focus promoted by different practice schedules, in particular, an external versus internal focus of attention (e.g., Wulf, Höß, & Prinz, 1998). An external focus, or concentration, on the intended movement effect or outcome has consistently been found to enhance motor learning relative to an internal focus on body movements (for reviews, see Wulf, 2013; Wulf & Lewthwaite, 2016). Adopting an external focus during movement planning has been shown to improve motor learning as measured by movement effectiveness (e.g., hitting a target accurately, generating a precise force magnitude, maintaining a balanced position, producing a particular movement form) and efficiency (e.g., reduced muscular activity, higher physical working capacity, lower heart rate, better muscular coordination for producing greater maximum force). Moreover, an external focus has been demonstrated to facilitate functional variability – or compensatory adjustments among effectors, with the results that variability in the movement outcome is decreased – in tasks that involve hitting a target, such as dart throwing (Lohse, Jones, Healy, & Sherwood, 2014; Wulf & Prinz, 2001). Finally, a more distal external focus (e.g., golf hole, bullseye, piano sound) rather than one that is more proximal (e.g., clubhead, dart, piano keys) has been found to be more beneficial for motor performance and learning (e.g., Bell & Hardy, 2009; Duke, Cash, & Allen, 2011; Kearney, 2015; McKay & Wulf, 2012; McNevin, Shea, & Wulf, 2003). Overall, these findings, which are in line with Guthrie's (1952) description of learning according to which high levels of movement effectiveness and efficiency are hallmarks of skilled performance, suggest that the motor learning process can be accelerated by directing one's attention externally to the intended movement effect. An external focus facilitates automatic control processes (Wulf, McNevin, & Shea, 2001; Wulf, Shea, & Park, 2001) and frees up that system to engage flexible, reflexive movement control processes, and likely enhances functional connectivity of task-relevant brain areas ("goal-action coupling"; Wulf & Lewthwaite, 2016). An internal focus encourages self-related thoughts and increases micromanagement of the intended movement (e.g., "keep the elbow against the trunk") such that learners are more likely to engage in conscious control of their motor system and disrupt automaticity (Wulf & Lewthwaite, 2010, 2016).

We hypothesized that variable or random practice conditions, in which the task goal changes from trial to trial, would promote more of an external focus than would constant or blocked practice. Particularly for motor tasks that involve different target distances, such as putting or chipping golf balls, shooting basketballs from different court locations, hitting tennis balls, or throwing baseballs, changing environmental conditions necessitate adjustments in motor planning, and might therefore induce an external focus of attention (e.g., on hitting the target). In contrast, stable conditions in constant or blocked practice, which do not require changes in movement planning, might be more conducive to a focus on the details of the movements. While most trials, independent of the practice schedule, typically result in less-than-perfect movement outcomes, under constant or blocked conditions performers might be more likely to attempt to change their movement coordination and adopt a more conscious mode of controlling their motions to correct deviations from the target (Pascua, Wulf, & Lewthwaite, 2015). In contrast, variable or random practice might act to override those tendencies due to the necessity of adapting to changing environmental demands (e.g., target distance) that help the performer maintain an external focus.

Thus, the purpose of the present study was to examine the hypothesis that greater variability in practice (i.e., variable or random practice) would promote an external focus while reduced variability (i.e., constant or blocked practice) would facilitate an internal focus of attention. In a series of experiments, we compared motor learning under constant versus variable (Experiment 1) or blocked versus random (Experiments 2 and 3) conditions. In each experiment, we asked learners to report their attentional focus while practicing. We predicted that variable or random practice would result in enhanced retention and/or transfer performance, relative to constant or blocked practice, respectively. In addition, we hypothesized that participants performing under variable or random conditions would report using more external foci, whereas those practicing under constant or blocked conditions would report greater usage of internal foci. If this were the case, the greater use of external focus of attention under more variable conditions could contribute to the learning advantages typically seen under those conditions.

1. Experiment 1

Previous studies, including many that used throwing tasks (e.g., Kerr & Booth, 1978; Wulf, 1991), have shown that conditions that provide learners with variable practice experience result in more effective retention or transfer performance. In the present experiment, we used an overhand throwing task, with different groups of participants throwing at a target from multiple distances (variable practice) or the same distance (constant practice). Learning was assessed by delayed retention and transfer tests. Several times during the practice phase, participants filled out rating scales to indicate the extent to which they focused on various aspects of performance.

1.1. Method

1.1.1. Participants

Twenty-four university students (18 females, 6 males), with a mean age of 23.7 years (SD = 5.04 years), participated in the experiment. To determine hand dominance, participants were asked which hand they usually used for throwing activities. Two participants were left-hand dominant (one in the constant group, one in the variable group) and no participant was ambidextrous. None of the participants were informed about the purpose of the study. The university's institutional review board approved the study. Participants signed an informed consent form prior to the start of the experiment.

1.1.2. Apparatus and task

The task involved throwing foam golf balls (4.3 cm in diameter) overhand with the non-dominant arm. The target consisted of a bullseye, with its center located at a height of 1 m above the ground. The target was hung in a catching net supported by a metal frame (2.1 × 2.1 × 1.4 m). The center circle of the bullseye had a diameter of 7.5 cm and was surrounded by seven concentric circles with radii of 15, 22.5, 30, 37.5, 45, 52.5, and 60 cm. If a ball hit the center, eight points were recorded. Seven to one point(s) were given for balls hitting the progressively larger circles, respectively, and zero points were given for complete misses. Participants threw from a distance of 4 m, 5 m, or 6 m during the practice phase, and from 5 m and 4.5 m on the retention and transfer tests, respectively. A video camera was used to record the target area and the recordings were later referenced for resolving any score uncertainty.

1.1.3. Procedure

Participants were randomly assigned to one of two groups, the constant or variable practice group. Variable group participants threw from all three distances (4, 5, and 6 m) during practice. The order of distances was pre-determined and quasi-random, with the constraint that each distance occurred 20 times. Constant group participants were divided into three subgroups, and each subgroup threw from one of the distances (4 m, 5 m, or 6 m) for a total of 60 practice trials. The task was described to the participants at the beginning of the experiment. They were asked to perform an overhand throw, similar to a baseball-throwing motion. The experimenter demonstrated the throw with the non-dominant arm and gave the participants basic instructions about the technique. Each trial started with the participant standing at the designated distance marked by a line on the floor. The experiment included two days. On Day 1, participants performed a pre-test from the 5-m line (five trials) and the practice phase (60 trials). There was a two-minute rest period after each 10-trial block. Two days later, retention (5 m) and transfer (4.5 m) tests, each consisting of two blocks of 10 trials, were conducted. Two experimenters recorded the participants' throwing scores on both days of the experiment.

To assess participants' attentional focus (i.e., what they focused on and to what degree), they were asked to fill out a questionnaire after the 20th, 40th, and 60th practice trials. The questionnaire consisted of a six-item rating scale. Participants were asked to indicate to what extent, on a scale from 1 ("not at all") to 10 ("very much"), they concentrated on each of the following cues: arm, shoulders, and posture as internal foci, and ball, target, and distance to target as external foci. Questionnaire items were arranged in the following order: arm, ball, target, shoulders, posture, distance to target.

1.1.4. Dependent variables and data analysis

Inter-rater reliability in recording the throwing accuracy scores was assessed using intra-class correlation (ICC) analysis (Shrout & Fleiss, 1979). Based on a two-way mixed-effects, absolute-agreement model, the ICC (2, 2) for 288 (20%) randomly selected trials was $r = 0.917$, 95% CI [.895, .934], $p < .001$, representing excellent inter-rater reliability in scoring the throwing performance of the participants. Accuracy scores were averaged across blocks of 10 trials. A univariate analysis of variance (ANOVA) was used to analyze the pre-test data. A 2 (groups: constant, variable) × 6 (blocks of 10 trials) ANOVA with repeated measures on the last factor was used to analyze the throwing accuracy data for the practice phase. The retention and transfer tests were analyzed in 2 (groups: constant,

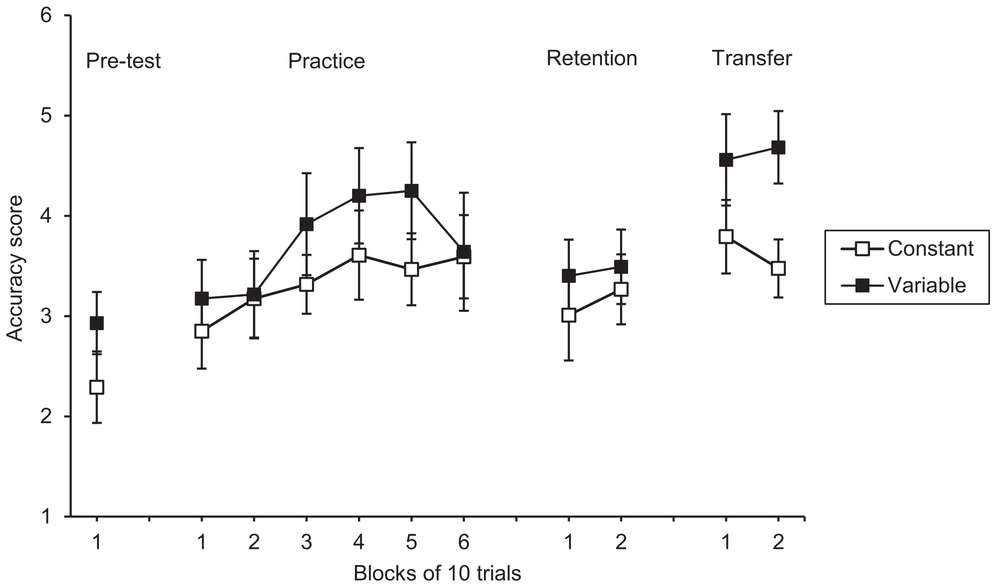

Fig. 1. Throwing accuracy of the constant and variable groups on the pretest, during practice, and on the retention and transfer tests in Experiment 1. Error bars represent standard errors.

variable) × 2 (blocks of 10 trials) repeated-measures ANOVAs. Attentional focus ratings for each of the six items were averaged across the questionnaires from the three timepoints and analyzed using univariate ANOVAs. In an additional analysis we determined the relative use of external versus internal foci by subtracting the average rating of all internal foci from the average rating of all external foci. The alpha level was set to a value of 0.05, and the partial eta squared (η_p^2) measure was used to determine effect size. Greenhouse-Geisser adjustments were used in instances where sphericity was violated.

1.2. Results

1.2.1. Throwing accuracy

Throwing accuracy results are shown in Fig. 1. There was no significant difference between groups on the pre-test, F (1, 22) = 1.76, p = .199, η_p^2 = 0.077. During practice, there was a general increase in accuracy across blocks, F (5, 110) = 4.23, p = .001, η_p^2 = 0.161, but no main effect of group, F (1, 22) = 0.57, p = .459, η_p^2 = 0.025, nor interaction of group and block, F (5, 110) = 0.79, p = .559, η_p^2 = 0.035.

On the retention test (5 m distance) two days later, both groups showed similar accuracy scores, and there was no change across blocks. [The average accuracy score for the variable group was 3.45, and 2.56 (4 m), 3.14 (5 m), and 3.71 (6 m) for the three constant sub-groups.] The main effects of group, F (1, 22) = 0.44, p = .516, η_p^2 = .019, and block, F (1, 22) = 0.39, p = .541, η_p^2 = .017, as well as the interaction of group and block, F (1, 22) = 0.09, p = .771, η_p^2 = .004, were not significant. However, on the transfer test from a novel throwing distance (4.5 m), the variable group (M = 4.62, SD = 1.14) had higher accuracy scores than the constant group (M = 3.63, SD = 1.42). [Average accuracy scores were 4.62 for the variable group, and 3.19 (4 m), 3.91 (5 m), and 3.8 (6 m) for the constant sub-groups.] The main effect of group was significant, F (1, 22) = 4.64, p = .042, η_p^2 = .174. The main effect of block, F (1, 22) = 0.14, p = .717, η_p^2 = .006, and the interaction of block and group, F (1, 22) = 0.72, p = .406, η_p^2 = .032, were not significant.

1.2.2. Attentional focus

Overall, the relative usage of external versus internal foci (i.e., external minus internal focus ratings) was greater for the variable group (M = 7.25, SD = 6.53) compared with the constant group (M = 2.67, SD = 2.35). The Group effect was significant, F (1, 22) = 5.23, p = .032, η_p^2 = .589. Fig. 2 shows the groups' average ratings for each attentional focus item. Significant group differences were seen for items pertaining to posture and distance to the target. The constant group focused more on posture (i.e., internally) than did the variable group, F (1, 22) = 4.61, p = .043, η_p^2 = .173. In contrast, the variable group focused more on the distance to the target (i.e., externally) than did the constant group, F (1, 22) = 6.46, p = .019, η_p^2 = .227. There were no group differences for arm, F (1, 22) = 0.16, p = .696, η_p^2 = .007, shoulders, F (1, 22) = 1.62, p = .216, η_p^2 = .069, ball, F (1, 22) = 0.21, p = .653, η_p^2 = .009, and target, F (1, 22) = 0.15, p = .705, η_p^2 = .007.

1.3. Discussion

Consistent with previous findings (e.g., Kerr & Booth, 1978; Shea & Kohl, 1990), the present results demonstrated more effective

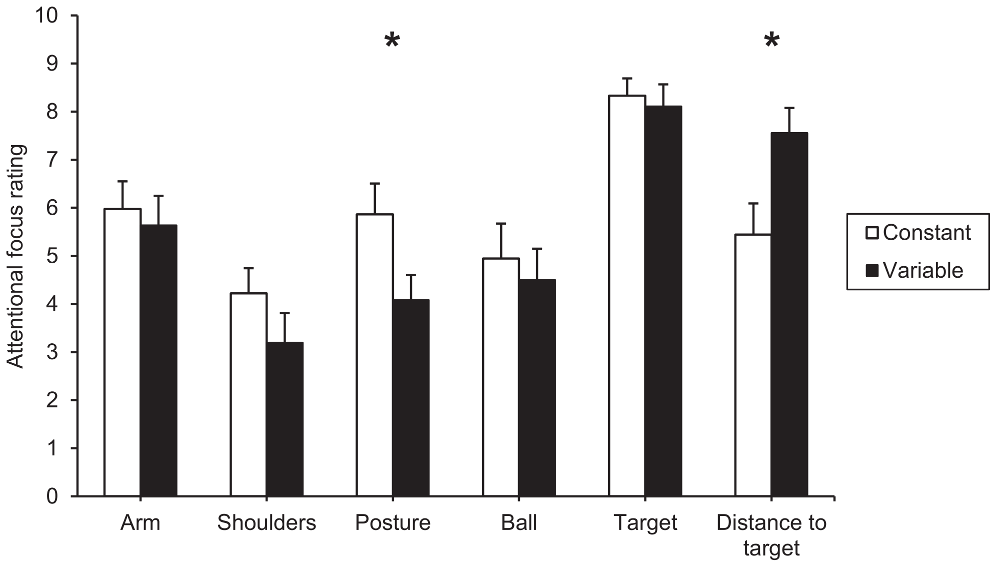

Fig. 2. Attentional focus ratings of the constant and variable groups during the practice phase in Experiment 1. Error bars represent standard errors.

learning for the variable practice group relative to the constant practice group. Even though group differences were not significant on the retention test, transfer performance at a novel distance, two days after the practice phase, was enhanced by variable practice. Furthermore, in support of our hypothesis, variable group participants reported an overall greater use of external relative to internal foci than did constant group participants. Specifically, the variable group adopted a distal external focus (i.e., on the distance to the target) to a greater extent than did the constant group. We also hypothesized that constant group participants would focus more internally than those undergoing variable practice. Constant group participants indeed focused more on their posture than did variable group participants.

Because of the frequent change in target distance, variable practice necessitated constant readjustments in motor planning. Consequently, under variable practice conditions, learners were required to concentrate more (externally) on the target distance than those practicing under constant conditions in which the target distance remained the same. In contrast to variable practice, constant practice promoted an internal focus of attention. In particular, constant group participants indicated that they focused on their posture to a greater extent than did variable group participants. Posture seems to represent a more general focus on movement form than arms or shoulders for which no significant group differences were seen (similar to ball and target). A previous study also showed that, when throwing from the same distance to the target, performers tended to focus on movement form (control condition in Pascua et al., 2015). Given that most trials constitute misses of the target, performers likely attribute errors, implicitly or explicitly, to faulty body mechanics. Attempts at correcting those errors presumably involve a greater concentration on body movements (i.e., internal focus). In variable practice, the constant need to focus on the target distance presumably leaves little room, or attentional capacity, for a focus on movement form. An external focus on the target has previously been shown to enhance learning to throw with the non-dominant arm relative to no attentional focus instructions (Pascua et al., 2015; Wulf, Chiviacowsky, & Drews, 2015).

Constant versus variable practice, while typical for studies testing schema theory (Schmidt, 1975) predictions, involves distinctly different conditions (e.g., one versus three task variations). We therefore wanted to examine whether less extreme differences in practice schedules, namely, blocked versus random practice (e.g., Shea & Morgan, 1979) as more typically examined in the contextual interference literature, would yield differences in learners' focus of attention as well. We assessed possible blocked-random practice effects on learning and attentional focus in Experiment 2.

2. Experiment 2

Studies examining contextual interference effects typically involve the same tasks, and the same number of trials per task, for all participants (e.g., Hall et al., 1994; Shea et al., 2001). The only difference between groups is the organization of practice, whereby the order of tasks is blocked (e.g., AAA…, BBB…, CCC…) for one group and random (e.g., A, C, B, A, B, …) for another. A random practice order has consistently been found to result in more effective retention or transfer performance than a blocked practice order (see Lee, 2012). This includes situations in which parameter variations of the same task are practiced (Lee et al., 1992). We asked whether blocked versus random practice would also promote differences in learners' focus of attention that could potentially contribute to the differential effectiveness of these types of practice. In the present experiment, participants practiced a golf-putting task under blocked or random conditions. As in Experiment 1, the tasks differed with respect to the distance from the target. During the practice phase, participants filled out questionnaires in which they indicated the extent to which they adopted specific internal or external foci.

2.1. Method

2.1.1. Participants

Thirty-six university students (19 females, 17 males), with a mean age of 26.1 years (*SD* = 8.45 years), participated in the experiment. Participants had little or no prior golf putting experience and were naïve as to the purpose of the study. The university's institutional review board approved the study. Prior to participating in the experiment, all participants provided informed consent.

2.1.2. Apparatus and task

Participants putted standard white golf balls to a target (2.5 × 2.5 cm) on a level artificial-turf indoor green (1.2 × 4.0 m). Three putting distances were marked by red, green, and blue lines on the putting green at 1.2, 1.5, and 1.8 m, respectively, from the center of the target. To begin each putting trial, participants retrieved a golf ball from a basket placed next to the putting lane. For each trial, the experimenter measured the distance between the center of the target and the edge of the ball. If the ball came in contact with the rear border (located 0.4 m away from the target center) of the putting green, a deviation of 0.4 m was recorded.

2.1.3. Procedure

Participants were randomly assigned to either the blocked or random practice group. Before the beginning of the practice phase, each participant observed two demonstrations of the putting task by the experimenter. The practice phase consisted of three blocks of 20 trials. Participants in the blocked group performed 20 trials from one of the three putting distances before proceeding to the next putting distance. Distance order was counterbalanced within the group using all six possible ways of arranging the three putting distances. Participants in the random group were assigned a different putting distance for each trial, in a pre-determined order. Participants received a 2-minute rest period upon completion of each 20-trial block. All participants returned to the lab two days later to perform a 12-trial retention test (1.5 m) and a 12-trial transfer test (2.1 m).

During each rest period and at the end of the practice phase, participants were asked to complete a questionnaire designed to assess their attentional focus (i.e., what they focused on and to what degree). The questionnaire consisted of a six-item rating scale ranging from 1 ("not at all") to 10 ("very much"), on which participants indicated the degree to which they focused on the following cues: arms, shoulders, and hands as internal foci, and putter, target, and distance to target as external foci. The questionnaire items were arranged in the following order: arms, putter, hands, target, shoulders, distance to target.

2.1.4. Dependent variables and data analysis

Deviations from the target were averaged across three blocks of 20 trials for the practice phase, and across all 12 trials for each of the retention and transfer tests. A 2 (groups: blocked, random) × 3 (blocks of 20 trials) analysis of variance (ANOVA) with repeated measures on the second factor was used to analyze the putting accuracy data for the practice phase. Retention and transfer performance were examined using univariate ANOVAs. To analyze differences in attentional focus, we averaged ratings across the three measurement times and used univariate ANOVAs for the various questionnaire items. A value of 0.05 was used as the alpha level, and the effect size was determined using the partial eta squared (η_p^2) measure. Any violation of the assumption of sphericity was corrected with the Greenhouse-Geisser procedure.

2.2. Results

2.2.1. Putting performance

During the practice phase, both groups performed similarly and reduced their deviations from the target across practice blocks (see Fig. 3). The main effect of block was significant, F (2, 68) = 7.20, p = .001, η_p^2 = .175. There was no significant main effect of group, F (1, 34) = 0.23, p = .100, η_p^2 = .010, and no significant interaction of group and block, F (2, 68) = 0.47, p = .628, η_p^2 = .014. On the retention test, both groups also produced similar performances, F (1, 34) = 0.02, p = .895, η_p^2 = .001. However, on the transfer test with a longer putting distance, the random group had significantly smaller errors than the blocked group, F (1, 34) = 8.86, p = .005, η_p^2 = .207.

2.2.2. Attentional focus

Ratings of the extent to which participants' attention was directed internally (arms, shoulders, hands) or externally (putter, target, distance to target) are shown in Fig. 4. There were no significant group differences for attentional focus on the arms, F (1, 34) = 0.04, p = .853, η_p^2 = .001, shoulders, F (1, 34) = 0.35, p = .561, η_p^2 = .010, hands, F (1, 34) = 0.02, p = .886, η_p^2 = .001, and target, F (1, 34) = 1.01, p = .322, η_p^2 = .029. However, significant group differences were seen for attentional focus on the putter, F (1, 34) = 4.16, p = .049, η_p^2 = .109, and the distance to the target, F (1, 34) = 4.61, p = .039, η_p^2 = .119. The blocked group (M = 6.96, SD = 1.66) had higher ratings relative to the random group (M = 5.37, SD = 2.86) for the putter focus, while the random group (M = 8.50, SD = 0.47) had higher ratings than the blocked group (M = 7.07, SD = 0.47) with respect to a focus on the distance to the target.

2.3. Discussion

The results showed that random practice enhanced learning. While there were no group differences on the retention test, the random group putted with significantly greater accuracy than the blocked group on the transfer test. Thus, learning advantages for

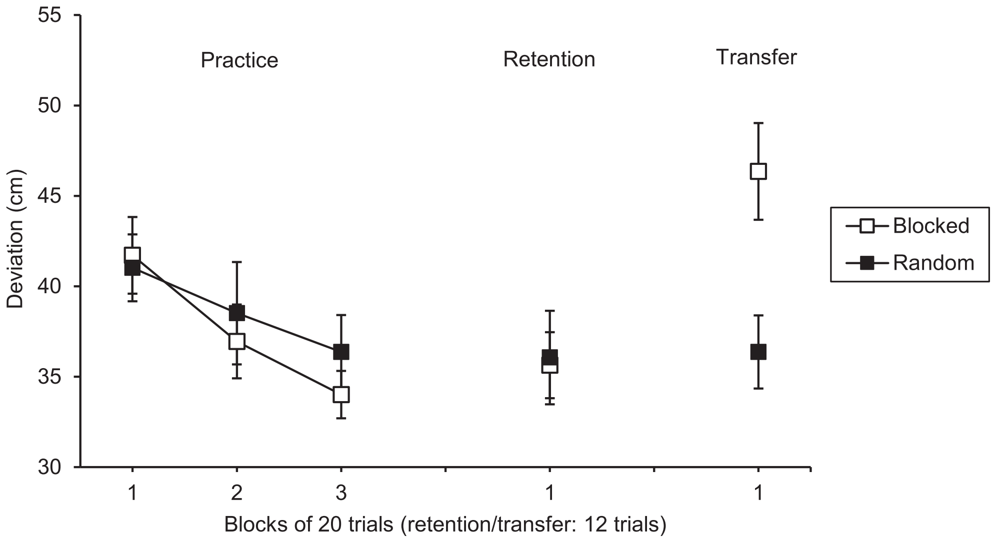

Fig. 3. Putting performance of the blocked and random groups during practice, and on the retention and transfer tests in Experiment 2. Error bars represent standard errors.

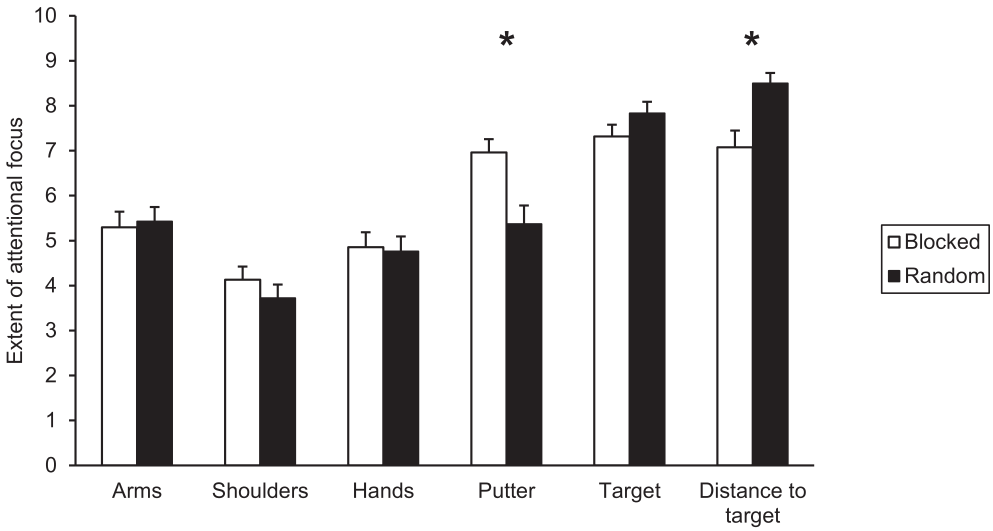

Fig. 4. Attentional focus ratings of the blocked and random groups during the practice phase in Experiment 2. Error bars represent standard errors.

the random group were seen on a novel variation of the task (involving a longer putting distance) two days after the practice phase. It is not unusual to see group differences on transfer tests, but not on retention tests (e.g., Chiviacowsky & Wulf, 2002; Lai & Shea, 1998; Wulf & Lee, 1993). The additional challenges associated with performance under novel conditions can reveal differences in learning that may not be seen on less demanding (retention) tests. Overall, these findings are in line with the often-found learning advantages resulting from random relative to blocked practice (for a review, see Lee, 2012).

Importantly, participants in the random group reported focusing on the distance to the target to a greater extent than did blocked group participants. In contrast, the blocked group focused significantly more on the putter compared with the random group. Even though both foci of attention would be described as external in nature, a putter focus represents a more *proximal* external focus than the more *distal* focus on the distance of the target. Numerous studies (e.g., Bell & Hardy, 2009; McKay & Wulf, 2012; McNevin et al., 2003) have shown that a distal external focus – that is, concentration on a movement effect that occurs at a relatively greater distance from the body – is generally more effective than a proximal external focus (for a review of the "distance" effect, see Wulf, 2013). In fact, a study by Kearney (2015) demonstrated that the learning of a golf-putting task benefited more from a distal (ball path to the target) than a proximal (putter) external focus. Thus, random practice participants in the present study adopted to a greater extent an external focus that has been shown to result in more effective learning, whereas the blocked practice participants reported more frequently using a less effective focus.

The present findings align with the idea that random compared with blocked practice might promote a more effective attentional focus – which could have contributed to the learning differences associated with these practice schedules. However, the two groups did not differ with respect to internal foci (arms, shoulders, hands), as originally hypothesized. Therefore, we wanted to follow up on these findings with another experiment, using a different task and a more sensitive method of determining participants' attentional foci.

3. Experiment 3

In Experiment 3, we used a throwing task, similar to Experiment 1. An overhand throw involves a relatively large number of degrees of freedom and uses no (external) implement aside from the ball to be thrown at the target. We therefore suspected that, in the absence of specific external focus instructions (see control group in Pascua et al.'s study, 2015), participants would adopt an internal focus on body movements under blocked practice conditions. Rather than giving participants a limited number of options to choose from at the end of trial blocks, as we had done in the previous two experiments, we asked them throughout the practice phase for open-ended reports of what they were currently focusing on. More specifically, participants were able to report their specific attentional focus, including changes in focus, and were free to do so at any time during practice. We hypothesized that random practice would lead to more effective learning than blocked practice, and to more reports of external foci, given the constantly changing distance to the target. We also hypothesized that blocked practice would result in more reports of internal foci than random practice.

3.1. Method

3.1.1. Participants

Thirty-two university students (19 females, 13 males), with a mean age of 23.2 years (SD = 3.47 years), participated in the study. To determine hand dominance, participants were asked which hand they usually used for throwing activities. Five participants were left-hand dominant (two in the blocked group, three in the random group) and none of them were ambidextrous. All participants were naïve as to the purpose of the study. The university's institutional review board approved the study. Prior to participating in the experiment, all participants provided informed consent.

3.1.2. Apparatus and task

Participants used their non-dominant arm to perform overhand throws at a target, using foam golf balls (4.3 cm in diameter). The target and scoring procedure were identical to the ones used in Experiment 1. Four throwing distances were marked by lines in red, green, blue, and yellow colors on the ground located 2, 2.8, 3.6, and 4.4 m from the target, respectively. A video camera was used to record the target area and the recordings were later referenced for resolving any score uncertainty.

3.1.3. Procedure

Participants were randomly assigned to one of two groups, the blocked or random practice group. Before the beginning of the practice trials, two demonstrations of the overhand throwing technique were provided by the experimenter. Participants also received instructions to orally report what they were concentrating on. Participants completed two warm-up trials, after which they were also asked to report what they focused on. The practice phase consisted of three blocks of 20 trials on Day 1. The blocked group completed all 20 trials for each of the 2, 2.8, and 3.6 m distances before proceeding to the next throwing distance; each participant in the group was randomly assigned one of the six possible ways of arranging the three throwing distances. The random group was assigned a different throwing distance on each trial, in a pre-determined order. Random group participants also completed a total of 20 trials from each distance. There was a two-minute rest interval between 20-trial blocks.

To avoid a controlling or intrusive environment that may have affected participants' performance, they were only requested to make an initial verbal report anytime within the first trial of each block (i.e., the first, 21st, and 41st trials) and were told that they were not required to make a verbal report for every single trial, except when they changed their object of concentration. Participants who did not make a verbal report by the end of the first trial of each block or were quiet for any five consecutive trials within a block were asked to report what they were concentrating on. Verbal reports were recorded with a digital audio recorder for post-experiment reference in resolving any classification uncertainty. Two days after the practice phase, participants performed retention and transfer tests, each consisting of 12 trials, from the blue (farthest practiced throwing distance of 3.6 m) and yellow (novel throwing distance of 4.4 m) lines, respectively. They were not asked to report their attentional foci on Day 2. Two experimenters recorded the participants' throwing scores on both days of the experiment as well as their verbal reports on Day 1.

3.1.4. Dependent variables and data analysis

Intra-class correlation (ICC) analysis was employed to determine inter-rater reliability in recording the throwing accuracy scores (Shrout & Fleiss, 1979). Based on a two-way mixed-effects, absolute-agreement model, the ICC (2, 2) for 384 (20%) randomly selected trials was $r = 0.964$, 95% CI [.956, .971], $p < .001$, representing excellent inter-rater reliability in scoring the throwing performance of the participants. Accuracy scores during practice were averaged across 20 trials and analyzed in a 2 (groups: blocked, random) × 3 (blocks of 20 trials) ANOVA with repeated measures on the second factor. For the retention and transfer tests on Day 2, accuracy scores were averaged across all 12 trials per test and analyzed using univariate ANOVAs.

To analyze participants' reports of attentional focus, a coding scheme with three categories was devised. Each word or phrase representing an object of concentration or mental state was classified as an external focus (e.g., "ball trajectory", "bullseye", "target"),

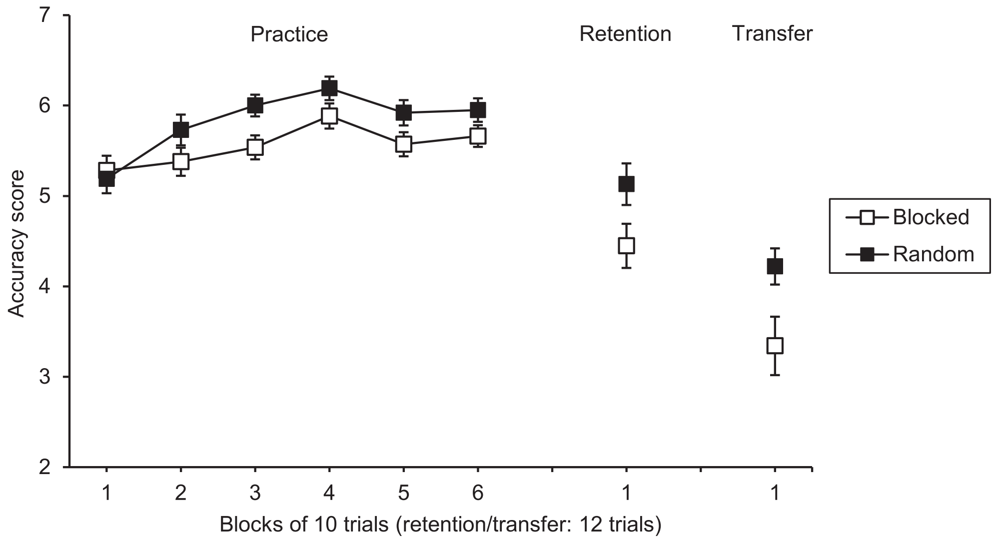

Fig. 5. Throwing accuracy of the blocked and random groups during practice, and on the retention and transfer tests in Experiment 3. Error bars represent standard errors.

an internal focus (e.g., "arm", "body movement", "flick of wrist"), or other focus (e.g., "distracted", "mind wandered," "not thinking"). For ambiguous terms such as "force" and "power", participants were encouraged by the experimenter to elaborate on them further until the relevant category(s) could be identified. Each participant's average number of foci per category was calculated for each block of 20 practice trials and used as the dependent variable. Inter-coder agreement was assessed using Krippendorff's alpha to determine how reliably two coders categorized the content of the participants' verbal reports (Hayes & Krippendorff, 2007). Krippendorff's alpha for 1386 (70%) randomly selected trials was $\alpha = .858$, indicating good inter-coder agreement in interpreting the reported foci. Verbal reports for each of the three attentional foci were averaged across the three blocks and analyzed using univariate ANOVAs. The alpha level was set a-priori at 0.05, and the partial eta squared (η_p^2) value was calculated to determine the effect size. Any violation of the assumption of sphericity was corrected with the Greenhouse-Geisser procedure.

3.2. Results

3.2.1. Throwing accuracy

The blocked and random groups increased their accuracy scores across the practice phase, with both groups showing similar performances (see Fig. 5). The main effect of block was significant, F (2, 60) = 4.08, $p = .022$, $\eta_p^2 = .120$. There was no significant main effect of group, F (1, 30) = 1.59, $p = .217$, $\eta_p^2 = .050$, nor interaction of group and block, F (2, 60) = 0.26, $p = .775$, $\eta_p^2 = .008$. On the retention test, the random group (M = 5.13, SD = 0.91) produced significantly higher throwing accuracy scores than the blocked group (M = 4.45, SD = 0.98), F (1, 30) = 4.17, $p = .050$, $\eta_p^2 = .122$. Transfer test performance was also significantly more effective for the random group (M = 4.22, SD = 0.82) compared with the blocked group (M = 3.34, SD = 1.29), F (1, 30) = 5.23, $p = .029$, $\eta_p^2 = .148$.

3.2.2. Attentional focus

As can be seen in Fig. 6, random group participants reported more external than internal foci, whereas participants in the blocked group used more internal than external foci. Few reported foci were classified as others, and those numbers were similar for both groups. The frequency of reported external foci was significantly higher in the random group than in the blocked group, F (1, 30) = 4.83, $p = .036$, $\eta_p^2 = .139$. The incidence of reported internal foci was significantly higher for the blocked group than for the random group, F (1, 30) = 5.53, $p = .025$, $\eta_p^2 = .156$. The groups did not differ with respect to other foci, F (1, 30) = 0.83, $p = .369$, $\eta_p^2 = .027$. The difference between the frequency of reported external versus internal foci was not significant, F (1, 62) = 1.79, $p = .186$, $\eta_p^2 = .028$, but each of them was reported more frequently than other foci, F (1, 62) $>$ 159.25, $p < .001$, $\eta_p^2 = .651$, and F (1, 62) $>$ 72.02, $p < .001$, $\eta_p^2 = .537$, respectively. Table 1 provides a list of the most frequently reported attentional foci.

3.3. Discussion

The purpose of this experiment was to further explore the role of attentional focus as a function of practice schedule. Rather than providing participants with predetermined focus options, as in Experiments 1 and 2, participants were free to report what they were focusing on, and when their focus changed. The results were clear in showing that a random practice schedule resulted in the use of a greater number of external focus cues (e.g., ball trajectory, distance to the target) than did a blocked practice schedule. In contrast, the blocked group reported a higher usage of internal focus cues (e.g., arm, wrist) than did the random group. Furthermore, the

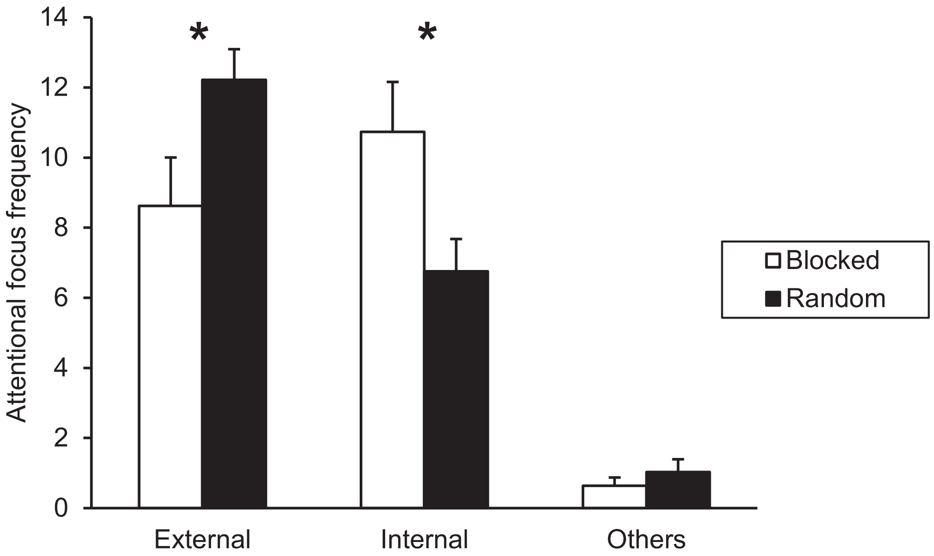

Fig. 6. Reported attentional foci of the blocked and random groups during the practice phase in Experiment 3. Error bars represent standard errors.

Table 1
Lists of the five most reported cues for each attentional focus type in Experiment 3.

	Blocked Group	Random Group
External Focus	Target/bullseye/number 8	Target/bullseye/number 8
	Ball trajectory	Distance
	Number seven	Ball trajectory
	Distance	Ball velocity
	Hold the ball	Ball force
Internal Focus	Wrist position	Fingers
	Arm position	Elbow position
	Arm power	Arm power
	Fingers	Wrist position
	Elbow position	Arm position
Other Focus	Mind wandered	Nothing
	No focus	Mind wandered
	Far distance	Refocus
	Spacing out	Distracted
	Distracted	Adjust vision

retention and transfer test results demonstrated that random practice enhanced learning over blocked practice. Overall, the present findings suggest that differences in attentional focus may be a factor that contributes to the typically seen learning differences resulting from practice conditions involving high versus low contextual interference.

4. General discussion

Across three experiments, we found that greater variability in practice (i.e., a random order of different target distances) resulted in enhanced motor learning relative to constant practice from one distance (Experiment 1) or blocked practice from the same three distances (Experiments 2 and 3). In particular, transfer to a novel distance, as measured by delayed tests, was facilitated by increased practice variability in all three experiments. In addition, delayed retention test performance was more effective after random relative to blocked practice in Experiment 3. These learning advantages were independent of the type of task (overhand throwing in Experiments 1 and 3, golf putting in Experiment 2) and they are consistent with previous findings (e.g., Kim, Chen, Verwey, & Wright, 2018; Lee & Magill, 1983; Porter & Magill, 2010; Shea & Morgan, 1979; Simon & Bjork, 2001).

The findings are similar to those found for other types of learning. In a study by Metcalf and Xu (2016), inductive learning was enhanced by random ("spaced") practice relative to blocked ("massed") practice. Participants asked to attribute novel paintings to specific artists showed more effective learning when exemplars by different artists were presented in an interleaved or random fashion during practice, compared with exemplars by the same artist being shown together or in a blocked fashion. Moreover, Metcalf and Xu found that those learning differences were associated with differences in participants' attention. Specifically, there was a greater degree of mind wandering during blocked relative to random practice. In the present study, mind wandering – as demonstrated by small numbers of reported "other" foci – was low in either practice condition. This may be due to the more active, physical engagement of participants in the current study as opposed to the more passive viewing of pictures in Metcalf and Xu's experiment. Yet, both studies share the finding of differences in learners' attentional focus resulting from random versus blocked practice.

The important new insight provided by the present set of experiments is that variable or random practice also caused learners to adopt greater use of a distal external focus of attention (i.e., distance to the target); in contrast, constant or blocked practice resulted in greater use of internal (Experiments 1 and 3) or proximal external (Experiment 2) foci, which are generally comparatively less effective for motor learning. In fact, studies have demonstrated that the learning of throwing tasks benefited more from a distal external focus on the target compared with internal foci (Chiviacowsky, Wulf, & Ávila, 2012; Saemi, Porter, Wulf, Ghotbi-Varzaneh, & Bakhtiari, 2013). Similarly, golf putting performance has been shown to be more effective with a distal external relative to proximal external or internal focus of attention (Kearney, 2015).

The present findings suggest that the attentional foci induced by different practice schedules might be at least partially responsible for the differences in learning outcomes typically observed with these practice schedules. Particularly when it comes to practicing task variations that require parameter adjustments due to changing task goals (e.g., target distance) – such as hitting golf balls, performing basketball jump shots, or executing soccer passes – the external focus promoted by frequent (random) changes in the task goal might contribute to the learning advantages. In investigations of motor performance, external attentional focus invoked via task instructions has been linked to central and peripheral neural (Kuhn, Keller, Lauber, & Taube, 2018; Kuhn, Keller, Ruffieux, & Taube, 2016) and neuromuscular (Lohse, Sherwood, & Healy, 2010; 2011; Vance, Wulf, Töllner, McNevin, & Mercer, 2004) processes consistent with enhanced motor efficiency. Kuhn and colleagues demonstrated the typical superiority of external focus over internal attentional focus instructions in the same individuals in fatiguing and maximal force production tasks (Kuhn et al., 2016, 2018). These investigators used transcranial magnetic stimulation protocols to find evidence of "instant modulation" of the motor cortex with enhanced suppression of non-prime mover muscle activation and increased intracortical inhibitory activity under external compared with internal focus conditions.

An external focus has been found to enhance both motor performance and learning (Wulf & Lewthwaite, 2016; Wulf, 2013). However, the coordinated neural and neuromuscular activity associated with an external focus of attention to optimize movement efficiency in motor performance paradigms has not yet been linked empirically with the functional connectivity or distinct goal-action coupling (Wulf & Lewthwaite, 2016) indicative of skilled motor behavior or motor learning (Lin et al., 2018).

Whether framed as variable over constant practice (e.g., Kantak et al., 2010; Kerr & Booth, 1978), random over blocked practice (e. g., Shea & Morgan, 1979), interleaved over repetitive practice (e.g., Lin et al., 2018), or spaced over massed practice (Metcalf & Xu, 2016) the value of practice variability has been generally affirmed and variously explained. For example, schema theory considered that variable practice strengthened motor schemata (Schmidt, 1975). Discussions of the contextual interference effect have focused on the impact of random or interleaved practice on the creation of effortful processing or challenge. Challenging conditions may also provide optimal potentiation of dopaminergic or other neurochemical underpinnings of neurogenesis and learning (e.g., Chalavi et al., 2018; Shors, 2014; Wulf & Lewthwaite, 2016). Task performance alone may not be what provides rewarding value to learners. The opportunity to experience one's relative mastery of challenging conditions with multiple tasks, variations in tasks, or effective switching between tasks (e.g., Bukowski, de Lemus, Marzecová, Lupiáñez, & Gocłowska, 2019; Srna, Schrift, & Zauberman, 2018) may result in enhanced motivation and attention for learning. The relation of greater variability to an external attentional focus in the present experiments suggests that enhanced coordinative efficiency or goal-action coupling (Wulf & Lewthwaite, 2016), or more optimized automatic, or effortless (Wulf & Lewthwaite, 2010) processing, may, perhaps ironically, be involved in the practice variability effect. Other explanations that may align with the superiority of variable practice include the opportunity to allow newly generated dendritic spines reflecting synaptic plasticity to stabilize rather than be immediately overwritten by the same task or task version (Yang et al., 2014).

Future studies, with sufficient power to examine mediating processes, will be necessary to determine whether the use of external versus internal foci (or proximal external focus in Experiment 2) associated with variable or random versus constant or blocked practice, respectively, played a causal role in their differential effects on motor learning outcomes. The design of follow-up studies centered on investigating the potential congruence between contextual interference and attentional focus neuromechanisms may also delineate the combined role of the neural processes underlying these two effects in potentiating the learning of motor skills.

5. Authors' notes

1. The authors would like to acknowledge that the original suggestion for this study was provided by golf coach Markus Westerberg, BS.
2. Dr. Takehiro Iwatsuki is now at Pennsylvania State University, Altoona College, Altoona, USA.

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