Distribution of Practice has Time Dependent Effects on Motor Skill Acquisition

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Abstract

Studies investigating the benefits of a distributed practice schedule on motor skill acquisition typically find that distribution of practice results in better learning (Lee et al., 2013; Shea et al., 2000). With that said, considerably less research has focused on how the benefits of distributed practice are impacted by stage of skill acquisition. To examine how stage of skill acquisition interacts with distribution of practice we had two groups of participants complete an extensive massed or distributed training schedule to learn a speed stacking sequence. Within each training session, participants in the massed practice group practiced the speed stacking sequence for 20 minutes continuously. In the distributed practice group participants also practiced the speed stacking sequence for 20 minutes each training session, however, the distributed practice group performed 10 two-minute practice sub-sessions with two minutes of rest between each sub-session. An analysis of speed stacking time revealed an overall benefit for distribution of practice as participants in the distributed practice group had faster performance times on a retention test relative to participants in the massed practice group. Interestingly, our analysis of the benefits of distribution of practice during training only showed performance benefits in the early (session one) and later (sessions eight, nine, and ten) stages of skill acquisition but not the mid-stages (sessions two through seven). Our results support previous work highlighting the benefits of a distributed practice schedule with regard to motor skill acquisition but they also suggest that these benefits may only occur differentially throughout acquisition.

Introduction

The structure of practice environments has considerable influence on motor skill acquisition. For instance, distributing practice over multiple sessions, as opposed to compacting practice time into few sessions results in enhanced retention of learned skills (Baddeley & Longman, 1978; Ebbinghaus, 1885). For example, in a recent study Kwon, Kwon, and Lee (2015) had two groups of participants learn a simple motor task with either a distributed or massed practice schedule. Participants in the distributed practice group had two 12-hour inter-trial intervals between practice sessions whereas participants in the massed practice group had two 10-min inter-trial intervals between practice sessions. Participants were then tested three separate times after the practice sessions to assess skill retention. Kwon and colleagues (2015) found that participants in the distributed practice group were faster and more accurate than participants in the massed practice group during these retention tests – a finding supporting the benefits of distribution of practice. Indeed, there are a multitude of studies that highlight the benefits of a distributed practice schedule (e.g., Shea, Lai, Black, and Pork, 2000; Simmons, 2012; Mackay, Morgan, Datta, Chang and Darzi, 2002; Bloom & Shuell, 2014; Spruit, Band and Hamming, 2014; Kwon, Kwon and Lee, 2015).

Distributing a practice session into smaller "chunks" appears to be beneficial even if practice is spread out over time as long as the same amount of time is spent on practice overall. For instance, Bloom and Shuell (1981) had two groups of high school students study a second language one time for 30 minutes (massed group) or three times over three days for 10 minutes (distributed) group. The results of a retention test given four days later revealed that students in the distributed group remembered more vocabulary words than students in the massed group. Similarly, Spruit, Band, and Hamming (2014) investigated the effects of distributed versus massed practice on skill acquisition and retention in the context of laparoscopic motor skill training. Spruit et al. had two groups of trainees learn a series of physical box trainer tasks in three 75 minute sessions either in one day (massed group) or spread out over three weeks (distributed group). A retention test revealed that participants in the distributed practice group exhibited better performance than those in the massed practice group suggesting that greater learning had occurred under a distributed practice schedule. No matter the time course, the aforementioned studies and a multitude of others support the benefits of distributed practice schedules.

While there is clearly a benefit to utilizing a distributed practice schedule during skill acquisition, learning is not a static process. For example, Fitts and Posner (1967) proposed that learning typically occurs in three sequential stages: cognitive, associative and autonomous (also see Fitts, 1964). During the initial cognitive stage of learning the learner determines the appropriate set of motor actions and is reliant upon explicit knowledge. In the second stage of learning, the associative stage, the learner focuses their attention on the specific motor actions that comprise the movement and works to improve movement coordination. Finally, in the third stage of learning the skill is now well established and is essence is “automatic”, hence the name. Typically, as learners acquire a motor skill they progress through these three stages of learning with measurable performance changes following a power law function (i.e., the power law of practice: Snoddy, 1926). Interestingly, little work has been done to examine how stage of learning impacts the effectiveness of distributed practice. Further, the few studies that have been conducted did not examine the impacted of distributed practice over an extended period of skill acquisition (e.g., Aghdasi & Jourkesh, 2011; Underwood, 1951).

In sum, in spite of all the research highlighting the benefits of a distributed practice schedule little attention has been paid to how the effectiveness of distributed practice is impacted by stage of learning. To address this, in the present study, we had two groups of participants learn a speed stacking sequence with either a distributed or massed practice schedule over five weeks of practice. In line with previous work, be hypothesized that participants in the distributed practice group would outperform those in the massed practice group on a retention test following skill acquisition. However, here we also focused on practice session to practice session differences to examine whether or not a distributed practice schedule would be impacted by stage of learning. While we were uncertain what differences we would observe, if any, we hypothesized that participants in the distributed practice group would outperform those in the massed practice group during the later stages of skill acquisition paralleling the expected differences in retention scores.

Methods

Participants

Ninety-three participants, aged 19 to 27 (47 females), were recruited from the local undergraduate population. Three participants were removed from the study at the outset due to previous speed stacking experience. The remaining recruited participants were randomly divided into two groups – one group that practiced under a massed schedule (n = 45) and the other group that practiced under a distributed practice schedule (n = 45). Participants provided informed consent as approved by the University of Victoria Office of Research Services and in accordance with the Declaration of Helsinki (1964).

Task and Apparatus

Participants used standard speed stacking equipment that included plastic cups, a stacking mat and a timer (Speed Stack Inc., Englewood, CO). The mats were set up on waist high tables, with the timers placed in the center bottom edge of the mat. The cups began evenly spaced on the mat, in stacks of 3 cups on the left hand side, 6 on the center, and 3 on the right hand side, such that the cups formed a row in front of each participant, henceforth coined a 3-6-3 stack (in line with standard speed stacking naming convention). Participants began with both hands on the timing pads. The timer activated upon movement initiation beginning the stacking sequence. The participants task was to complete the stacking sequence, known as a "cycle stack," correctly and as quickly as possible. The cycle stack is a stacking pattern requiring each participant to follow a prescribed movement order sequentially achieving a 3-6-3 stack, followed by a 6-6 stack, and finally a 1-10-1 stack (see https://www.thewssa.com/docs/rules_rules.pdf for details).

Participants assigned to the massed practice group completed two 20 minute practice sessions per week. Within each 20 minute practice session, participants in the massed practice group completely as many speed stack cycles as possible without rest breaks. Participants assigned to the distributed practice group also completed two practice sessions per week. However, each distributed practice session was divided into a series of two-minute "mini" practice sessions with two-minute rest breaks between each two-minute mini practice session. In other words, participants completed 10 two-minute mini practice sessions interleaved with 10 two-minute rest breaks each practice session. As such, the total practice time in the distributed practice group was 40 minutes but this yielded 20 minutes of actual practice to match the amount of practice time for participants in the massed group. As with the massed practice group, participants in the distributed practice group were instructed to complete as many speed stacking cycles as possible within each practice session.

Task instructions required participants to complete each stacking sequence with proper technique. Upon completion of a sequence the stack was reset by a research assistant and practice began again. Accuracy was expressly emphasized over speed to participants at the start and throughout each practice session. Stacking errors invalidated a trial and participants had to reset and restart the stacking sequence. Errors were defined as a mistake in the speed stacking sequence or a "slip" – instances when speed stacking cups were knocked over. Overall practice time was monitored via a stopwatch to ensure each participant did not exceed their practice time limit. When participants reached the practice time allotment, the participant was required to immediately cease practice.

Data Collection and Analysis

Speed stacking completion time was recorded for each trial in seconds (+/- 0.1 s). A mean completion time was computed for each participant for each practice session. Only times for completed, error free stack cycles were included in subsequent analyses. It is worth nothing that given the aforementioned emphasis on accuracy, errors were minimal and were not analyzed[1]. Speed stacking completion time and error data for the massed and distributed practice groups were submitted to separate mixed analyses of variance (ANOVA), with one between factor (practice schedule (2): massed, distributed) and one repeated factor (practice session (10): 1 to 10). The assumption of sphericity was met for both ANOVAs and thus no correction was applied. Trend analyses were used to gauge learning effects across the ten practice sessions and post-hoc Tukey HSD t-tests were used to ascertain between group differences for each practice session. Further, we used an independent samples t-test to compare between group differences

[1] It is worth noting that a preliminary analysis of the error data revealed no effects across time or between conditions – a result driven by the lack of stacking errors for the majority of experimental trials.

for the retention tests. All descriptive statistics are reported with 95% confidence intervals (Cumming, 2013). An alpha level of 0.05 was assumed for all statistical tests.

Results

Our analysis of speed stacking completion time across practice sessions revealed a main effect for practice session ($F_{9,792} = 162.31$, $p < 0.001$) and an interaction between practice type and practice session ($F_{9,792} = 3.12$, $p < 0.001$). Trend analysis confirmed what can be clearly seen in Figure 1, practice times decreased as a function of practice (quadratic trend: $F_{1,88} = 82.36$, $p < 0.001$). Post-hoc analyses revealed that practice times were faster for distributed practice participants during practice session one ($t_{88} = 3.30$, $p < 0.001$; massed: 41.1s [38.8s 43.5s], distributed: 36.1s [34.2s 38.1s]), practice session eight ($t_{88} = 1.99$, $p = 0.049$; massed: 24.9s [22.9s 25.5s], distributed: 23.2s [22.3s 24.1 s]), practice session nine ($t_{88} = 3.11$, $p = 0.002$; massed: 24.2s [22.9s 25.5s], distributed: 21.8s [21.0s 22.6s]), and practice session ten ($t_{88} = 3.23$, $p < 0.001$; massed: 23.9s [22.7s 25.0s], distributed: 21.4s [20.4s 22.4s]). An independent samples t-test confirmed a distributed practice advantage during the retention test – distributed practice times (17.8s [17.2s 18.7s]) were faster than massed practice times (19.5s [18.8s 20.1s])($t_{88} = 3.07$, $p = 0.002$). No differences were observed in terms of speed stacking errors between groups or as a function of practice session (all p's > 0.05).

Discussion

The present study examined the impact of stage of learning on the benefits of a distributed practice schedule. Overall, we replicated previous findings as we found that participants who practiced with a distributed practice schedule performed better in a retention test after training than participants who practiced with a massed practice schedule (i.e., Baddeley & Longman, 1978; Mackay et al., 2002; Schmidt & Genovese, 1988). When we specifically examined session effects of distributed versus massed practice we found that early in acquisition (session one) participants who practiced with a distributed practice schedule were faster than participants who practiced with a massed practice schedule. Surprisingly, the benefits of a distributed practice schedule disappeared after the initial practice session – we did not observe a distributed practice advantage over massed practice in sessions two through seven. Interestingly, the benefits of a distributed practice schedule re-emerged during later stages of skill acquisition (sessions eight, nine, and ten).

During the first practice session (session one; see Figure 1), the distributed practice group demonstrated faster performance when compared to the massed practice group. Our results highlighting an initial distributed practice benefit are similar to Cook and Hilgard (1949) who found that distributed practice was decidedly advantageous on the first day of trials. Specifically, in their experiment Cook and Hilgard found that participants learning a pursuit rotor task that had longer rest breaks outperformed those with shorter rest breaks during the first of several days of skill acquisition. Why would this be? Recently it has been proposed that motor skill acquisition has both a fast time course that occurs within a practice session and a slower time course that occurs between practice sessions (Luft and Buitrago, 2005). In terms of the fast time course of motor skill learning, Bonstrup et al., 2019 have recently demonstrated that skill consolidation begins to occur during even extremely short rest breaks within a practice session. In terms of the present experiment, the rest breaks that were afforded the distributed practice group between each two-minute practice sub-session might have been sufficient for early skill consolidation to occur – an effect that presumably was blocked to some extent for participants in the massed practice group.

Another explanation for the early distributed practice advantage that we observed relates to observational learning. Given the design of our paradigm, participants in the distributed practice group were able to watch other participants perform the task during their rest break as we tested multiple participants at the same time. Indeed, there is a large body of work that shows that observing a skill engages cognitive learning processes similar to those that are engaged when movements are physically performed. For instance, work by Bellebaum and Colisio (2014) demonstrated similar neural processing of performance feedback when participants observed another person making errors during performance of a task. As such, participants in the present study may have used their rest breaks between practice sessions to observe other participants performing the task and benefited from this.

As noted above, we also found a distributed practice advantage in the later practice sessions – our results demonstrated a distributed practice benefit in practice session eight, nine, and ten. With that said, it is difficult to state why the distributed practice advantage re-emerged in the later stages of practice in the present experiment. One potential explanation is that during the middle stages of learning in our study (sessions two to seven) the benefits of observational learning were masked by benefits brought about by mass repetition. Indeed, previous work has shown that massed practice does help with skill learning in some instances and it could be that is the case here (CITATION). Another possible explanation for the re-emergence of a distributed practice advantage relates to feedback frequency. Given our experimental design, the distributed practice group experienced a reduction, or at least a spacing, of feedback frequency given the two-minute rest breaks between each two-minute mini practice session. In line with this supposition, Lam and colleagues (2011) found that performance during the later stages of skill acquisition was reduced as a result of a high relative to a low feedback frequency schedule. Lam et al.'s results, and are own, are in line with a large body of work demonstrating that reduced feedback frequency enhances learning and future performance (Lee et al., 1990; Sparrow & Summers, 1992, Weeks & Kordus, 1998; Weeks, Zelaznik & Beyak, 1993). As such, it is possible that our results are explained by a reduction in the frequency of feedback participants experienced under a distributed practice schedule.

Conclusions

The results of the present study replicate previous work and show that distribution of practice leads to enhanced learning as observed by performance during a retention test. However, our work also suggests that distributed practice benefits may only occur in the early and late stages of learning. We propose that the effects of distributed practice in combination with unrestricted observational learning shaped the learning process we observed here. We also speculate that the later re-emergence of a distributed practice advantage may be due to concomitant changes in feedback frequency brought about by distributed practice schedules.

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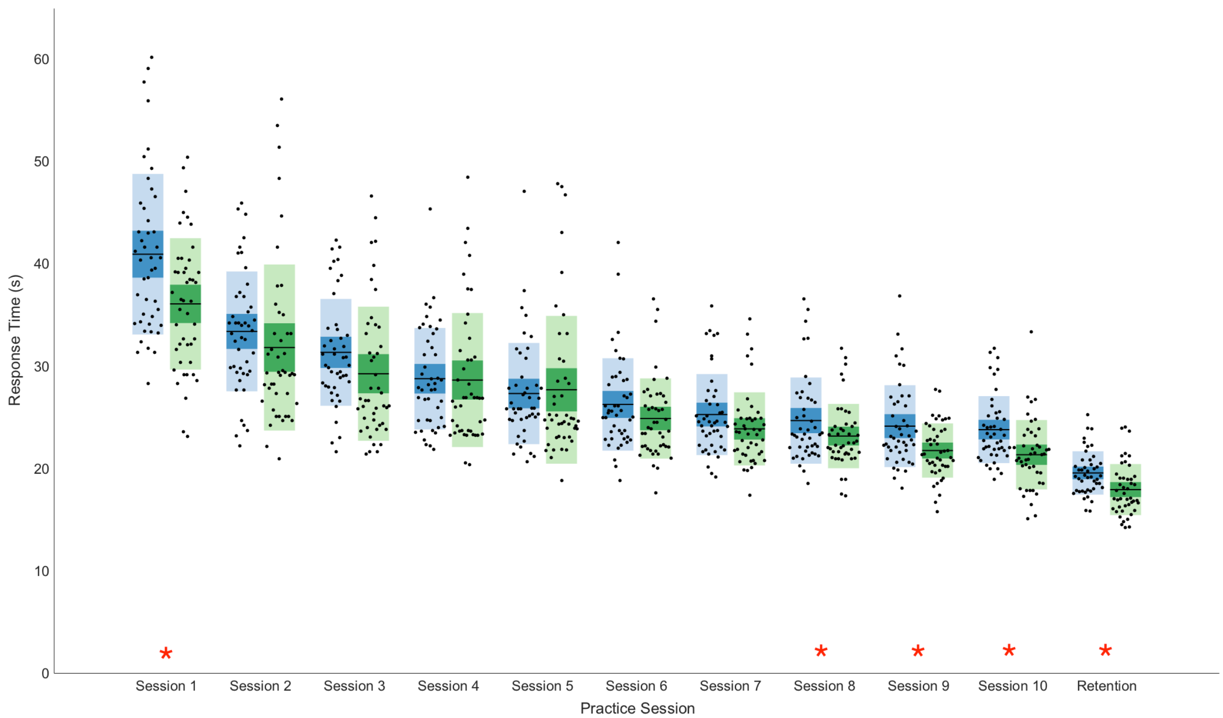
Figure Captions

Figure 1. Mean times (s) for all massed and distributed participants for every practice session and the retention test. Error bars reflect 95% confidence intervals. Asterisks indicate time points at which there is a significant different.



Response Time (s)
60
50
40
30
20
10
0
Session 1
Session 2
Session 3
Session 4
Session 5
Session 6
Session 7
Session 8
Session 9
Session 10
Retention
Practice Session