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Allowing time to consolidate knowledge gained through random practice facilitates later novel motor sequence acquisition

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ABSTRACT

Two experiments were conducted to examine the efficacy of random (RP) and blocked practice (BP) for enhancing later motor learning. Each experiment involved practicing three unique seven key serial reaction time (SRT) tasks in either a blocked or random format followed by practice of a novel SRT task either 2-min (Experiment 1) or 24-h (Experiment 2) later. While the expected benefit of RP for retention was present in both experiments, in Experiment 1 there was no advantage from prior RP for new learning. Experiment 2 explored the possibility that increasing the interval, from 2-min to 24-h, between BP or RP and practice of the novel motor task might allow consolidation of sequence knowledge acquired during BP or RP which in turn might facilitate new learning. As a result of the additional time between training bouts RP facilitated the rate at which the novel motor task was acquired. Interestingly, when this additional time was provided, both BP and RP supported (a) a performance saving for the first trial with the novel task, and (b) an offline improvement in performance across a 24-h interval not present when only the novel motor task was practiced. The latter benefits for new learning may have resulted from exposure to prior physical practice per se. or practice variability. These data are discussed with respect to (a) future learning benefits from prior experience training with greater CI, and (b) the importance of memory consolidation for motor learning.

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1. Introduction

Being able to effectively execute motor skills is central to our everyday lives illustrated by the range of skills that we perform on a regular basis such as driving a motor vehicle, typing on a computer keyboard, or playing a musical instrument. While the importance of extensive practice has been highlighted in recent years (Karni et al., 1995; Steele & Penhune, 2010), it has also been revealed that the manner in which practice is organized influences motor skill learning. This is illustrated in work addressing a practice phenomenon, referred to as the contextual interference (CI) effect, which focuses on best practice for improving the acquisition of multiple, related skills (Brady, 1998, 2004; Magill & Hall, 1990; Shea & Morgan, 1979; Wright et al., in press).

Random practice (RP), as it is called, is assumed to create relatively high interference during the acquisition of multiple motor skills because of the constantly changing task demands across practice trials. Alternatively, relatively less CI is created when using *blocked* practice (BP) because it involves the repeated performance of the same motor task for a predetermined number of trials prior to any practice with another task. Random practice has been reported to slow initial performance improvement but support superior retention efforts compared to BP. This finding is quite robust having been demonstrated in the laboratory (Immink & Wright, 2001; Li & Wright, 2000) and in applied contexts (Goode & Magill, 1986; Ollis, Button, & Fairweather, 2005; Schneider, Healy, & Bourne, 1998; Smith & Davies, 1995). Experiencing greater CI during practice also enhances motor skill learning for a variety of subject populations (Porretta & Obrien, 1991), and has been used successfully in clinical settings (Adams & Page, 2000; Knock, Ballard, Robin, & Schmidt, 2000).

Contemporary accounts of how greater CI during practice enhances motor learning have focused on differential motor preparatory processes encouraged by BP and RP (Lee & Magill, 1983, 1985; Shea & Zimny, 1983, 1988; Wright, 1991; Wright et al., in press). Shea and Zimny (1983, 1988) placed significant emphasis on the importance of planning processes crucial for extracting relationships between the practiced motor tasks during RP which they claim facilitates the development of a more intricate memory network. As a result individuals that experience RP have easier access to the newly acquired task-specific knowledge for use during later test situations (Lin et al., 2011, 2012).

It is becoming increasing apparent that the establishment of functional and structural neural networks, resulting from extensive practice, is associated with improved memory retrieval and is a hallmark of skilled motor behavior (Dayan & Cohen, 2011). Recently it was reported that increasing CI during practice promoted inter-regional functional connectivity. Lin et al. (2013) examined fMRI data collected during RP and BP and described the development of connectivity between two specific neural regions previously identified as crucial to motor task

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acquisition - contralateral dorsolateral prefrontal cortex (DLPFC) and premotor (PM) regions (Lin et al., 2013). Exposure to RP enhanced inter-regional coupling between DLPFC and PM areas with key sensorimotor sites for up to 72-h post-practice. As connectivity developed there was a concomitant reduction in blood oxygenated level dependent signal at the neural sites connected which was interpreted as greater efficiency and/or economy for planning upcoming motor performance following RP. This type of temporary connectivity did not occur for individuals in BP. Lin et al.'s (2013) claimed that practice involving greater CI results in a resilient adaptation in the connectivity between a frontal "strategic" network and the sensorimotor network to facilitate successful retrieval of well-practiced motor tasks (also see, Yang, Lin, & Chiang, 2014).

1.1. Experiment 1

While not extensive, the aforementioned neurophysiologic data associated with BP and RP are consistent with the general claim of Shea and Zimny (1983, 1988) that RP contributes to a more developed memory network that is conducive to successful access to motor memories across a broader timeframe. The present work considers the possibility that the described changes in neural connectivity, associated with RP, may provide a behavioral advantage that, to date, has not been considered. Specifically, having access to a more expansive memory architecture should support more effective encoding and retrieval of information about a related but novel motor task practiced at a later date. The primary focus of the present experiments then was to determine if prior exposure to a high CI practice environment provides an advantage for subsequent motor learning.

To date, we know of only one study that examined future learning benefits following prior RP or BP (Hodges, Lohse, Wilson, Lim, & Mulligan, 2014). Hodges et al. had individuals train in either a RP or BP format which was then followed by additional practice with a novel set of motor skills again in either a random or blocked schedule. Thus the study involved four independent experimental conditions namely: RP-BP, RP-RP, BP-RP, and BP-BP. In a second experiment, the same issue was addressed but following RP or BP each participant self-selected the subsequent practice schedule when learning the second sets of skills. The general hypothesis forwarded by Hodges et al. was that initial experience with RP would be especially useful for individuals that later faced BP. The thinking was that prior exposure to RP would encourage the use of movement planning operations that had previously led to some recall success when faced with BP.

While evidence emerged that the initial practice format (i.e., RP or BP) played a part in the general strategy implemented by the learner during future periods of practice, the most striking finding of Hodges et al. (2014) was that the most recent practice format was the critical determinant of test performance. That is, if the learner's most recent practice was RP rather than BP, their test performance benefitted. One other finding worth noting was that prior experience with RP improved acquisition during subsequent BP but failed to influence retention. These data suggest that earlier exposure to RP influences the learner's capacity to more effectively encode information about a new motor task. As a whole, these data do no provide overwhelming support for a broad-based future learning advantage from recent RP experience. This conclusion is further supported by the equivocal findings regarding successful transfer following RP and BP (Lin et al., 2011, 2012; Shea & Morgan, 1979). Unfortunately Hodges et al. (2014) focused on the influence of RP or BP on the performance of a new "set" of motor skills. A more parsimonious approach to evaluating the influence of an earlier practice schedule for new learning would be to evaluate the acquisition of a single rather than multiple novel tasks after the original practice experience (i.e., either RP or BP). This approach removes potential interactions between the processing strategies that are adopted during each acquisition phase involving different sets of motor tasks.

To address this issue participants in Experiment 1 practiced three unique motor tasks in either BP or RP after which they were immediately provided additional training with a novel motor task. Twenty-four hr. later, performance for all practiced motor tasks, three from RP or BP as well as the novel motor task, was again assessed. It was expected that for the motor tasks originally practiced in either BP or RP, the typical CI effect would emerge. Individuals exposed to BP would exhibit superior performance during acquisition but those experiencing RP would reveal superior retention. With respect to performance of the novel task, if prior exposure to RP rather than BP is beneficial, one would expect (a) greater savings as evidenced by superior performance on the initial trial of acquisition for the novel task, (b) a faster rate of acquisition of the novel task, and/or (c) greater delayed retention of the novel task. In the case of (c) it is possible that a delayed benefit might be manifest as offline gain for the new task knowledge as a result of RP and/or evidence of forgetting following BP.

2. Methods

2.1. Participants

All right-handed undergraduate students ($N = 45$)[1] participated in the experiment for course credit. The participants had no prior experience with the experimental tasks. All subjects completed an informed consent, approved by Texas A&M University's Institutional Review Board, before participation in the experiment.

2.1.1. Apparatus and task

The motor tasks used in the proposed work have been characterized as a serial reaction time task and has been used extensively to examine motor sequence learning (Rhodes, Bullock, Verwey, Averbeck, & Page, 2004). This task involved typing a predetermined set of seven key presses repeatedly as quickly and accurately as possible for 30 s using different orders of the "V", "B", "N", and "M" keys on a standard PC keyboard (see, Walker, Brakefield, Hobson, & Stickgold, 2003). The order in which these keys were depressed for each separate motor task was determined by the sequential illumination of four boxes, displayed on a computer screen in a spatially compatible manner with the fingers. For example, participants were instructed to associate the leftmost box with the "V" and depress this key when this box was illuminated. Alternatively, if the rightmost box was illuminated, the participant was instructed to press the rightmost key which was the "M" key. The target tasks were executed with the participant's non-dominant hand throughout all acquisition and test phases.

Four distinct 7-key motor tasks were used, three of which were trained using random (RP) or blocked (BP) practice with the fourth novel task being encountered by all participants after BP or RP was completed. The target motor tasks each consisting of seven-keys, were 4–1-3-2-4-2-3, 3–2-4-1-2-4-3, and 1–4-2-3-1-3-2 where "1" represented the leftmost key (i.e., "V") and "4" was associated with the rightmost key (i.e., "M"). The novel task also consisted of seven-keys, namely, 2–3-1-4-3-1-2. All features of this experiment was programmed using E-Prime® 2.0 (Psychology Software Tools, Inc., Sharpsburg, PA).

2.1.2. Procedure

Prior to any participation participants read and signed an informed consent. Individuals were then randomly assigned to one of three different practice schedule conditions, BP, RP, or a no practice (NP) control condition depicted in Fig. 1. RP involved a pseudo-random presentation of the three 7-key motor tasks during the initial acquisition phase on Day 1. Individuals assigned to BP completed practice with one motor

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[1] Fifteen participants were included in a control condition referred to as the NP (no practice) condition. The data from these individuals was used as a control condition for both Experiment 1 and 2. These individuals only practiced the novel motor sequence on Day 1 and returned twenty-four later to complete test trials for all motor tasks.