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Improving novel motor learning through prior high contextual interference training

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ABSTRACT

The primary objective of the present experiment was to examine the influence of recent practice in a random and blocked format for future motor learning. First, individuals practiced three unique discrete sequence production tasks in either a blocked or random schedule. One day later, all individuals practiced a new motor sequence not previously practiced. On day three, mean total time for the test performance of the original three motor sequences was lower for individuals that practiced in a random format. This emerged as a significant reduction in mean total time from the completion of practice and the test trials implicating offline consolidation as a key contributor to the random practice performance advantage. A novel finding from the present work was that the acquisition of the novel discrete sequence production task practiced on Day 2 was better for individuals that had prior random rather than blocked practice experience. This benefit was robust appearing early during acquisition as significantly lower mean total time. This benefit from random practice experience remained during the delayed test trials administered on Day 3 for the novel motor sequence.

1. Introduction

The scheduling of practice that is most suited to facilitate the acquisition of multiple motor skills has been the subject of considerable experimental examination. One practice phenomenon focused on the best practice for learning multiple related skills is examined under the general rubric of the contextual interference (CI) effect (Brady, 2004; Magill & Hall, 1990; Shea & Morgan, 1979; Wright et al., 2016). This practice effect typically involves the comparison of the learning gains from random (RP) and blocked (BP) scheduling formats. On the one hand, RP is a relatively high interference practice environment because multiple motor skills are practiced concurrently thus demanding the learner to navigate constantly changing task demands across practice. In contrast, BP induces less interference throughout training because it involves the repeated performance of the same motor task for a predetermined number of trials before practice of other motor tasks. It turns out that RP, while characterized by relatively slow initial performance during training, is more effective for supporting long-term retention of the practiced skills. This finding, while frequently reported in the laboratory environment (Wright et al., 2016), has also emerged in various applied (Goode & Magill, 1986; Ollis, Button, & Fairweather, 2005; Schneider, Healy, & Bourne, 1998; Smith & Davies, 1995) and rehabilitative settings (Adams & Page, 2000; Hanlon, 1996; Knock, Ballard, Robin, & Schmidt, 2000).

An important consequence of extensive physical practice is the emergence of transient functional connectivity and structural adaptation between and within neural networks to support skilled motor behavior (Dayan & Cohen, 2011). Interestingly, it is now clear that the practice schedule to which the learner is exposed, as well as extent, plays a role in promoting inter-regional functional connectivity. For example, Lin et al. (2013) examined fMRI data collected during RP and BP and noted that RP, but not BP, led to a temporary coupling between dorsolateral prefrontal cortex (DLPFC) and premotor (PM) areas with key sensorimotor sites for up to 72-h after the completion of practice. Furthermore, as this connectivity developed there was a concomitant reduction in blood oxygenated level dependent signal at the neural sites involved which was interpreted as an increased efficiency and/or economy for planning learned behaviors via RP. Lin et al. (2013) claimed that a critical consequence of experiencing greater CI during practice was improvement in the communication between a frontal "strategic" network and the sensorimotor network to facilitate successful delayed retrieval of newly learned motor tasks (see also, Yang, Li, & Chiang, 2014). The notion that RP leads to the development of an extensive retrieval network is not new, first being noted in behavioral accounts, and is central to most descriptions of savings or retention benefits observed following high interference training (Lin et al., 2013;

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Shea & Zimny, 1983, 1988; Wright et al., 2016).

To date, enhanced learning from RP is manifest as superior execution of the specific skills that are included in the original bout of BP or RP during a delayed test often administered in a random schedule format. Fewer studies have adopted a blocked test format and revealed RP benefits (Wright, Brueckner, Black, Magnuson, & Immink, 2004). Recently, a couple of studies broadened the scope of investigation of this practice phenomenon by considering the impact of recent high-CI practice on subsequent motor learning (Hodges, Lohse, Wilson, Lim, & Mulligan, 2014; Kim, Rhee, & Wright, 2016). The specific objective of these studies was to assess the importance of the learner's practice history, particularly BP or RP, for acquisition of novel motor skills. The basic premise of these efforts was that if RP results in the establishment of an extensive memory network from recent practice experience, future learning of related skills would benefit. This might emerge as faster initial encoding of new knowledge, reflected in improved performance in acquisition, and/or superior retention of a novel skill compared to BP counterparts.

An initial assessment of this issue by Hodges et al. (2014) evaluated the influence of BP or RP on the learning of three new motor skills practiced 24-hrs later in (a) either a blocked or random format, or (b) a self-selected practice schedule. While prior RP enhanced the acquisition of novel skills on Day 2, which meant the typical performance deficit associated with a high CI practice environment was eliminated, delayed retention for the new skills was not dependent on a learner's previous training history. Kim et al. (2016), using a similar design to Hodges et al., addressed this same question but simplified the new learning environment to the acquisition of just a single rather than multiple skills, following BP or RP. Again, experience with RP accelerated the encoding of the new skill but failed to offer any further benefit across the retention interval beyond that observed from BP. These data then verified those of Hodges et al. (2014) suggesting some limited utility of a recent history with high CI training for later periods of skill acquisition.

Kim et al. (2016) noted that one feature of their study that may have restricted the effectiveness of RP for new motor learning was the use of a serial reaction time (RT) task for which the learner completed a series of seven key-presses as frequently as possible during a 30-s trial (see, Walker, Brakefield, Hobson, & Stickgold, 2003). In hindsight, the use of the serial RT task by Kim et al. may have inadvertently compromised the magnitude of CI created during RP because each 30-s trial involved the execution of 5-15 repetitions of the <u>same</u> motor sequence (i.e., essentially a form of BP). Thus, it is likely that the RP condition used by Kim et al. (2016) induced significantly lower CI than typically created in previous studies (Brady, 2004; Magill & Hall, 1990; Wright et al., 2016). A primary goal of the present work then was to address this shortcoming and re-evaluate the potential robustness of prior high CI training for new motor learning. To accomplish this, the present work involved the practice of a number of discrete sequence production (DSP) tasks in either a RP or BP format. The use of DSP tasks, rather than the serial-RT task, allowed RP scheduling to maximize the extent of CI by ensuring frequent changes in the motor skill executed across trials (Abrahamse, Ruitenberg, de Kleine, & Verwey, 2013). Based on the aforementioned evidence, acquisition of a novel motor sequence is expected to be facilitated following RP but not BP. It is also possible that by maximizing CI during the initial bout of RP, retention benefits for the new sequence will emerge.

An additional advantage of using the DSP task in the present work was the opportunity to probe the locus of any facilitation in novel skill acquisition and/or retention following training under different practice formats. Abrahamse et al. (2013) proposed that the execution of a DSP task involves three distinct planning processes. The first process, referred to as sequence initiation is reflected in the time to complete the first key-press of a DSP task. This process involves selection and preparation of the DSP task including readying its initial motor chunk. A relatively slow key-press typically observed in the middle of a DSP task, the concatenation point, indexes a cost of transitioning between motor chunks that comprise the DSP task. Finally, all other key-presses are usually executed considerably faster, often with an RT lower than 100 ms, than those associated with the initiation and concatenation processes. This latency reflects the cost of executing the most primitive element (i.e., key-press) contained in a motor chunk. Assuming experience with prior RP contributes to improvement in a memory retrieval processes for newly learned skills, it seems reasonable to assume that any retention benefits that emerge would most likely to be observed for the sequence production processes most dependent on retrieval, that is, initiation and maybe concatenation (but see Verwey, Abrahamse, & Eikelboom, 2010) rather than execution.

2. Methods

2.1. Participants

Participants were right-handed undergraduate students (N = 36) that received course credit for their participation. They had no prior experience with the experimental tasks and were unaware of the specific purpose of the study. All participants completed an informed consent approved by an Institutional Review Board before any involvement in the experiment.

2.2. Apparatus and task

The motor skills used in the present work are characterized as discrete sequence production (DSP) tasks (Abrahamse et al., 2013). These tasks are used extensively to study motor sequence learning (Doyon et al., 2009). Each DSP task used in the present work was performed on a standard PC keyboard and involved typing a predetermined set of six key-presses in response to a visual signal that indicated the key to press. The keys used in the present experiment were the “D”, “F”, and “G” on which the ring, middle, and index finger of the left-hand were placed respectively and the “J”, “K”, and “L” keys which were associated with the index, middle, or ring fingers of the right-hand. The order of key-presses for each DSP task was dictated by the presentation of a black dot within one of the six boxes displayed horizontally across the lower third of the computer screen in a spatially compatible manner with the placement of the fingers on the keyboard (see Fig. 1A). Participants were instructed to associate the leftmost box of the display with the “D” key and press this key when a black dot appeared in this box. Alternatively, individuals were told that a black dot in the rightmost box required a press of the rightmost “L” key with the right ring finger. The black dot remained in the same location of the display until the correct key was pressed. Four unique 6-key DSP tasks were used throughout the experiment. Three of these tasks were used during random or blocked practice on Day 1 and the fourth was used as the novel task on Day 2 (see Fig. 1B).

There was a 300-2000 ms response-to-stimulus interval (RSI) after the third key press for all DSP tasks during every practice trial to encourage participants to execute each unique DSP task as two motor chunks, each containing 3 key-presses (Abrahamse et al., 2013; Verwey & Eikelboom, 2003). Abrahamse et al. propose that the latency associated with the first key press captures the costs of organizing the sequence as a whole and initiating the first chunk whereas the time for key press four, following the longer RSI, reflects the costs related to concatenating the two motor chunks as well as initiating chunk 2 of a DSP task. The remaining key presses (2, 3, 5 and 6 in the present case) involved an execution process. All features of this experiment were programmed using E-Prime® 2.0 (Psychology Software Tools, Inc., Sharpsburg, PA).

2.3. Procedure

Participants first read and signed an informed consent. Individuals