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Impacts of visuomotor sequence learning methods on speed and accuracy: Starting over from the beginning or from the point of error

Kanji Tanaka [a,b,c,*], Katsumi Watanabe [a,b]

[a] Faculty of Science and Engineering, Waseda University, Tokyo, Japan
[b] Research Center for Advanced Science and Technology, The University of Tokyo, Tokyo, Japan
[c] Japan Society for the Promotion of Science, Tokyo, Japan

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ABSTRACT

The present study examined whether sequence learning led to more accurate and shorter performance time if people who are learning a sequence start over from the beginning when they make an error (i.e., practice the whole sequence) or only from the point of error (i.e., practice a part of the sequence). We used a visuomotor sequence learning paradigm with a trial-and-error procedure. In Experiment 1, we found fewer errors, and shorter performance time for those who restarted their performance from the beginning of the sequence as compared to those who restarted from the point at which an error occurred, indicating better learning of spatial and motor representations of the sequence. This might be because the learned elements were repeated when the next performance started over from the beginning. In subsequent experiments, we increased the occasions for the repetitions of learned elements by modulating the number of fresh start points in the sequence after errors. The results showed that fewer fresh start points were likely to lead to fewer errors and shorter performance time, indicating that the repetitions of learned elements enabled participants to develop stronger spatial and motor representations of the sequence. Thus, a single or two fresh start points in the sequence (i.e., starting over only from the beginning or from the beginning or midpoint of the sequence after errors) is likely to lead to more accurate and faster performance.

1. Introduction

Learning of complex behavioral sequences such as playing a musical instrument is never easy. According to a proposed theory, behavioral sequences are initially composed of relatively independent elements, but are gradually concatenated and consolidated through practice (e.g., Hikosaka, Rand, Miyachi, & Miyashita, 1995; Verwey, 1999, 2001). Sequence learning methods play a crucial role in leading to more accurate or faster performance of the sequences.

Two contrasting representative practice methods have been purported: practicing parts separately, and practicing the whole sequence (e.g., Naylor & Briggs, 1963). In the part practice condition, participants learn separate components of a sequence (i.e., one part at a time), combining all components later. In the whole practice condition, participants learn all components of the sequence at once. It has been shown that the superiority of practice methods depends on the nature of the types of required skill (e.g., Gopher, Weil, & Siegel, 1989), the types of task (e.g., memorization or play of musical scores; Brown, 1928; Rubin-Rabson, 1940; O'Brien, 1943), the difficulty of task (different levels of musical scores; Brown, 1928), or individual differences (different ages in juggling practice; Chan, Luo, Yan, Cai, & Peng, 2015). One of the benefits of whole practice could be that participants can integrate the knowledge or sequence component and coordinate it in a whole sequence (e.g., Lim, Reiser, & Olina, 2009; McGuigan & MacCaslin, 1955). However, it can be a cost to separate the sequence into some units (e.g., Park, Wilde, & Shea, 2004). In contrast, a benefit of part practice is that participants are allowed to repeatedly train a divided component of sequence (e.g., Newell, Carlton, Fisher, & Rutter, 1989; So, Proctor, Dunston, & Wang, 2013), but, it might cost to integrate the components into a whole sequence.

Most people make errors during learning, particularly in a complex sequence. Many decades ago, Brown (1928) investigated effects of three types of piano practice: whole, part, and combination. In the whole practice condition, participants played a score from the beginning to end without error corrections. In the part practice condition, the score was divided into several units and participants played each unit. In the combination practice method, participants played the score from the beginning to end, but, they were allowed to repeat the point at which error occurred. The results of the test indicate that the practice methods likely modulate practice effects (i.e., shorter performance time), but the superiority of the methods was different by the difficulty of the played score. The combination practice showed the

* Corresponding author at: Waseda University, 3-4-1 Ohkubo, Shinjuku, Tokyo 169-8555, Japan.
E-mail address: kanji.t9@gmail.com (K. Tanaka).

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shortest performance time when the easiest score was assigned, indicating that error corrections during learning contribute to improvement of the sequence learning (i.e., learning the score). The error corrections in the sequence learning mainly have two methods: starting over from the beginning of a sequence or restarting from the point at which the error occurred. However, it was still unclear which method leads to better learning of a sequence after people make an error. If people restart from the beginning of a sequence, it may take them many trials to reach the place at which they previously made the error. Contrary to this, if people restart from the point at which the error occurred, they might be able to amend their performance immediately after making the error.

In the present study, our aim was two-fold. First, we investigated whether the various learning methods (i.e., starting over from the beginning and from the point at which error occurred) led to different efficiency of memorization of a given sequence (i.e., accuracy). Second, after the memorization, we also investigated whether the methods led to different efficiency of the improvement of performance time of a sequence. We employed a visuomotor sequential learning task in which participants perform via trial-and error (i.e., inevitably make errors), known as the $m \times n$ task (e.g., Hikosaka et al., 1995, 1996; Hikosaka, Nakamura, Sakai, & Nakahara, 2002; Sakai et al., 1998; Sakai, Kitaguchi, & Hikosaka, 2003; Sakai, Hikosaka, & Nakamura, 2004; Tanaka & Watanabe, 2013, 2014a, 2014b, 2015; Watanabe, Ikeda, & Hikosaka, 2006; Watanabe, Ikeda, & Miyao, 2010; Fig. 1). By adopting a trial-and-error process, once participants complete a sequence without errors, we can assume that all participants obtain the same level of explicit knowledge of the sequence. The experimental device had 16 buttons on a 4×4 matrix on a touch panel monitor. Three buttons (i.e., a triad) turned red at the same time (m) and the other buttons remained gray against a white background. The complete sequence to be learned was composed of six triads (n; 3×6 task). As all triads had a predetermined correct order to be pressed, participants were required to learn the sequence via trial-and-error. We firstly prepared two methods, one in which participants started over from the beginning of the 3×6 sequence (here, the all-back sequence method) and the second in which they restarted from the triad of the 3×6 sequence in which they made the error (here, the zero-back sequence method). Participants in the all-back sequence method were required to start the next trial from the beginning of the sequence, even if an error occurred at the sixth triad in a 3×6 sequence, while those in the zero-back sequence method could start the next trial from the sixth triad of the sequence if they made an error at that point. In both all-back and zero-back sequence methods, participants were required to reveal the correct order of button presses in a given sequence by trial-and-error, and to successfully perform the sequence without errors (i.e., from the first triad to sixth triad), for a total of 20 trials. In previous studies examining the part and whole practice methods (e.g., Park et al., 2004), the next element of a given sequence to be learned was preliminarily scheduled, while in the present study, the same was based on where an error occurred.

In Experiment 1, we compared accuracy, performance time, and working time in the all-back and zero-back sequence methods. Here, we defined accuracy as the number of committed errors until the next successful trial, performance time as the performance time in successful trials (in which no errors occurred), and working time as the

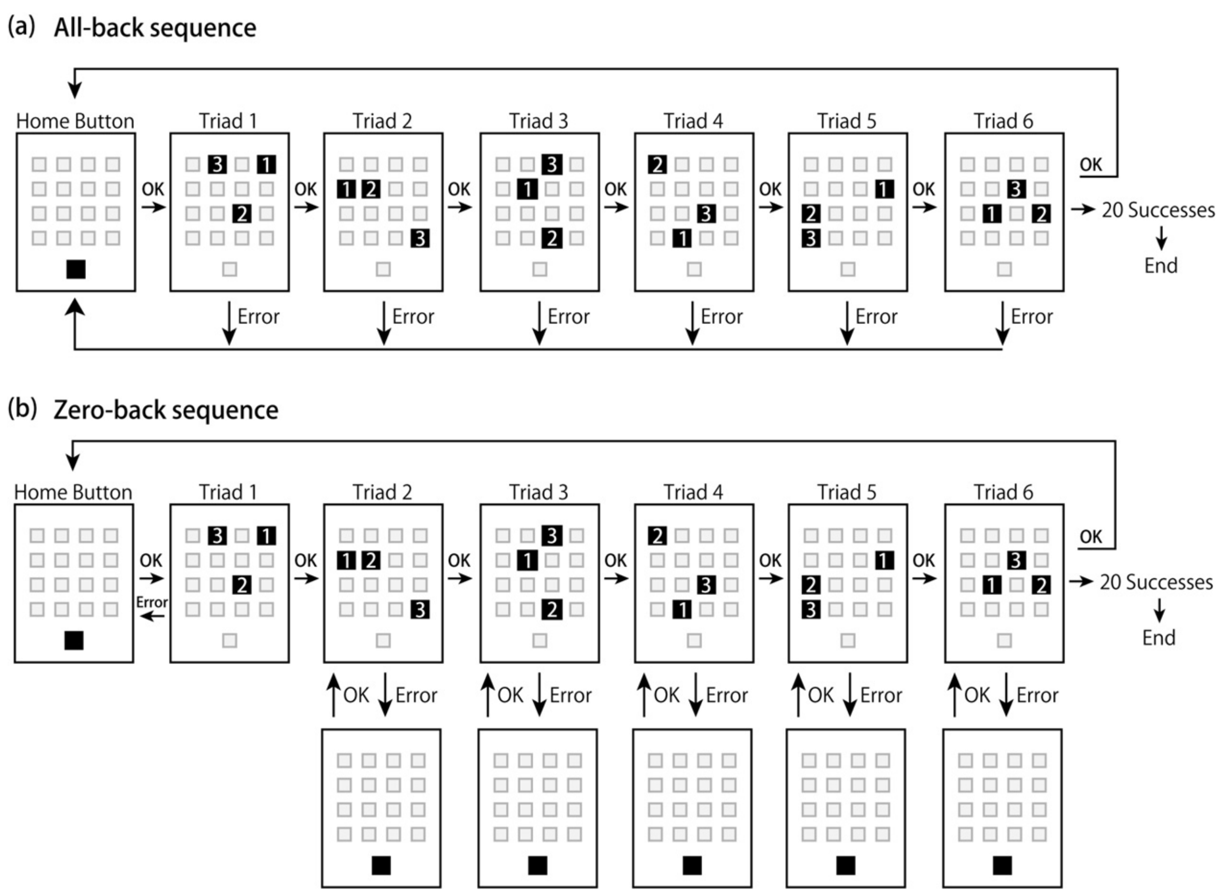

Fig. 1. Experimental paradigms in the present study. (a) Experimental flow of the all-back sequence method: If button presses were wrong in any triad, the next trial began from the home button. (b) Experimental flow of the zero-back sequence method: If button presses were wrong in a triad, the next trial began from the beginning of the triad in which the error occurred. Note that the numbers shown on the device did not appear during the experiments.