



Extensive practice improves adaptation to unpredictable perturbations in a sequential coincident timing task[☆]

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ABSTRACT

Extensive practice is associated with a higher level of learning than practice until performance stabilization. This is partially attributable to the changes in the variability of the structure that control the motor skill that occur during practice. However, because both conditions result in performance stabilization, the error in the task performance does not decrease further, and it is necessary to introduce higher demands (e.g., unpredictable perturbations) into the task for differences between the two conditions to arise. This study aimed to investigate whether extensive practice contributes to adaptation to unpredictable perturbations in a sequential motor skill task as compared to practice until performance stabilization. Thirty-four self-reported right handed young adults performed a sequential coincident timing task and were assigned to two groups during the first phase of experiment: the stabilization group (SG) or the extensive practice group (EG), which differs with respect to the quantity of practice. In the second phase, both groups performed under equal conditions and the subjects practiced the same task performed in the first phase, but unpredictable changes in the velocity of the visual stimulus were occasionally introduced. The results suggest that extensive practice improves adaptation to unpredictable perturbations better than practice until performance stabilization and indicates that the motor learning process continues after performance stabilization.

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1. Introduction

The learning processes underlying the acquisition of a motor skill continue during practice to the point of performance stabilization at which high accuracy and low variability are achieved [6,19] and may even continue beyond that point with extensive practice [7,22,23,25,27]. In extensive practice, practice continues even after reaching performance stabilization. Because extensive practice may lead to further changes in the structure that controls motor skill, certain differences in performance may be seen after extensive practice as compared to practice until stabilization, thereby highlighting the different levels of learning achieved between the two conditions [17]. These differences cannot be detected when the constraints imposed on practice conditions are small, and subjects

with different levels of learning can solve the task without difficulty [5]. However, if the amount of practice modifies the strategy used to solve motor problems [16], it is possible that by changing the task constraints, differences in performance between the two conditions may emerge.

Specifically, detectable differences in performance are expected because the structure that controls motor skill is consistent. To detect differences in performance between the two conditions, the components of the motor skill must first be identified. The components have been considered to be the sub-movements of the motor skill, and the consistency of a structure has been measured by the variability of the components [10,12], which change as the level of learning increases [11]. When, during practice (i.e., even after a motor skill is learned), conditions are changed that demand changes in performance, subjects' must adapt by changing the structure that controls the motor skill. The more unpredictable and challenging the perturbations are during practice, the more profound the learning changes will be in those structures [18,21].

This study aimed to investigate whether extensive practice contributes to adaptation to unpredictable perturbations in a sequential motor skill task by comparing extensive practice to practice until performance stabilization. First, we expected that under

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normal situations (without perturbations), both conditions would not show any differences due to the weak constraints imposed upon them. Second, we hypothesized that under the same unpredictable perturbations, extensive practice would improve performance as compared to practice until performance stabilization and that the variability would decrease for extensive practice relative to practice until stabilization. Finally, we expected that extensive practice would improve performance after removal of the perturbations because its structure is more stable and quickly returns to the level of performance reached before the introduction of perturbations.

2. Methods

Thirty-four self-reported right-handed young (ranging in age from 18 to 35 years; mean of 25.2 ± 3.7 ; 16 men and 18 women) adults participated in the study. The subjects performed a coincident complex timing task using their right hands. The apparatus is shown in Fig. 1 and consisted of a stimulus array with 1.83 m in length and contained 97 LEDs (the first of which was yellow, and the other 96 LEDs were red). The stimulus array was placed on a table in front of the subject with 30° of inclination from the horizontal plane, and a response box ($1.50 \text{ m} \times 1.00 \text{ m} \times 0.20 \text{ m}$) that was composed of six optic sensors ($0.11 \text{ m} \times 0.11 \text{ m}$) was provided.

To begin the task, the topmost, yellow LED on the stimulus array was turned on as a warning signal and the subject positioned with the hand in sensor 0. After this LED was turned off, the red LEDs were flashed sequentially, such that the displacement of the light stimulus simulated an object moving down the array toward the table. While the red LEDs were flashed, the subject performed a pre-established sequence of touches (sensors 1–2–3–4–5) at any velocity with the constraint of touching the last sensor simultaneously as the last red LED flashed within a target time of 2250 ms.

After each trial, the subjects were informed of their performance (the difference between the target time and the response time) in the following way: if the response occurred between 0 and 25 ms of the target time, the subject was informed, “Well done, you were correct!”; a subject with an error between 26 and 50 ms was told, “You were a little slow/fast!”; a subject with an error between 51 and 100 ms was informed, “You were slow/fast!”; and, if the subject’s error was greater than 100 ms, the subject was told, “You were very slow/fast!”. “Slow” was used to describe the subject’s

response when the subject touched the last sensor after the last red diode fired, and “fast” was used when the subject touched the last sensor before the last red diode fired.

The experiment was divided into two phases: pre-exposure and exposure. During the pre-exposition phase, one group practiced until they reached performance stabilization, and the other group practiced beyond this point. As such, the two groups represented two different levels of learning. Operationally, the stabilization group (SG) was characterized by practicing the task until a performance criterion of three trials in a row with an error smaller than or equal to 25 ms in 120 trials was reached. The extensive practice group (EG) was characterized by practicing the task until six blocks of the same performance criterion were reached within 320 trials. All subjects reached the specific criterion in this amount of practice. This performance criterion was established to decrease the effects of inter-individual variability. If the rhythm of learning was different among the subjects, the same quantity of practice represents different levels of learning among the subjects of the same group [15]. With this procedure, all of the subjects in the same group have the minimum degree of competence necessary to respond to the perturbations, and the two groups have different levels of skill.

After a break of 3 min, the second phase of the experiment started. It consisted of 126 additional trials, and the subjects continued to practice the same task as in the pre-exposition phase (i.e., these trials were used as control trials); however, on occasion, they were exposed to 18 trials of two different perturbations: nine trials in the first perturbation (P1) during which the speed of the light stimulus started slower than in the control trials in the initial two-thirds ($2/3$) of the narrow bar and proceeded faster in the last third of the narrow bar and nine trials in the second perturbation (P2) during which the light stimulus was initially faster in the first two-thirds ($2/3$) of the bar than in the control trials and slower in the last third of the narrow bar. The sequences and target times remained constant during the pre-exposition phase and during the control trials in the exposition phase. The first perturbation was inserted into the fourth trial; subsequently, one perturbation was inserted every seven trials. The unpredictability of the perturbation was guaranteed by the pseudo-random order of the types of perturbations presented. Moreover, during the pilot study, the subjects were not able to identify “when” or “which” perturbation would occur. Both phases of the experiment lasted approximately 22 min for the SG and e 34 min for the EG.

To assess the initial development of the subjects’ skill, the absolute error (AE), which states about accuracy (the difference between the intended and the performed goal) and the variable error (VE), which states about consistency (the dispersion of the performed goal), were analyzed by an ANOVA (two groups $\times$ two blocks) during the first and last blocks of three trials in the pre-exposure phase. These two measures, i.e., absolute and variable error, represent the performance proximity to a specific goal and the variation of the performance in relation to the goal, respectively. Another ANOVA (two groups $\times$ three blocks) was used in the exposure phase. Both of the ANOVAs applied repeated measures in the last factor and in blocks of nine trials. Follow-up procedures were conducted using Tukey’s test ($p < 0.05$). To assess the skill structure that control motor skill, the task was analyzed in five components: component 1 (C1) the relative time spent from sensor 0 to sensor 1; component 2 (C2) the relative time from sensor 1 to sensor 2 and so on. The variability (standard deviation) of the five components of the skill was analyzed by a MANOVA (two groups $\times$ three blocks) followed by a univariate test of significance. For the pre-exposure phase, the analysis was performed at the beginning of the phase (FIRST block) and at the end of the phase (LAST block) because the subjects required different amount of practice to reach the performance criterion. In the exposure phase, the analysis was performed on three blocks of trials: those immediately prior to the

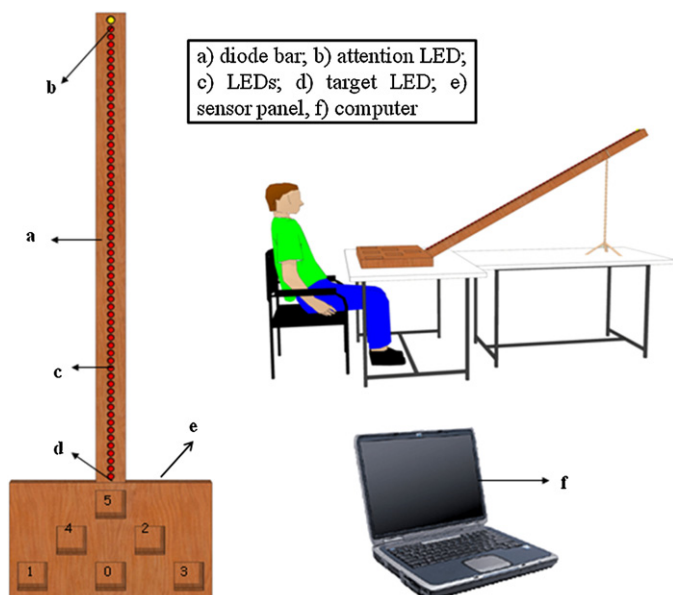


Fig. 1. The complex coincident timing task used in the experiment.

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