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Magnifying visual target information and the role of eye movements in motor sequence learning

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ABSTRACT

An experiment investigated the influence of eye movements on learning a simple motor sequence task when the visual display was magnified. The task was to reproduce a 1300 ms spatial–temporal pattern of elbow flexions and extensions. The spatial–temporal pattern was displayed in front of the participants. Participants were randomly assigned to four groups differing on eye movements (free to use their eyes/instructed to fixate) and the visual display (small/magnified). All participants had to perform a pre-test, an acquisition phase, a delayed retention test, and a transfer test. The results indicated that participants in each practice condition increased their performance during acquisition. The participants who were permitted to use their eyes in the magnified visual display outperformed those who were instructed to fixate on the magnified visual display. When a small visual display was used, the instruction to fixate induced no performance decrements compared to participants who were permitted to use their eyes during acquisition. The findings demonstrated that a spatial–temporal pattern can be learned without eye movements, but being permitting to use eye movements facilitates the response production when the visual angle is increased.

1. Introduction

The question of how eye movements are involved in motor sequence learning has intrigued theorists for a number of years and has stimulated empirical research especially in the last two decades (Albouy et al., 2006; Coomans, Deroost, Vandenbossche, van den Bussche, & Soetens, 2012; Kinder, Rolfs, & Kliegl, 2008; Marcus, Karatekin, & Markiewicz, 2006; Mayr, 1996; Miyashita, Rand, Miyachi, & Hikosaka, 1996; Press & Kilner, 2013; Remillard, 2003; Vieluf, Massing, Blandin, Leinen, & Panzer, 2015; Willingham, Nissen, & Bullemer, 1989; Willingham, 1999). However, how eye movements are involved in sequence learning is still an unanswered question because the empirical findings in the sequence learning literature provide contradictory results (Marcus et al., 2006).

Coomans et al. (2012) instructed performers to fixate on a cross in the middle of a screen and presented the target information very briefly to minimize eye movements while the performers reacted to a pair of stimuli by manually pressing keys as fast as possible. Their results indicated that performers learned the sequence even though they were instructed to fixate. One conclusion was that sequence learning can occur without overt oculomotor movements. In a series of four experiments, Remillard (2003) investigated the role of eye movements by varying the distance (from 3.9° to 14°) between the stimuli during sequence learning. The rationale was that eye movements were not required in the 3.9° condition, but they became essential for higher visual angles (e.g., 14°). The results from his experiments documented that participants learned the sequences regardless of the distances between the stimuli; thus, Remillard concluded that ‘eye movements were not necessary for learning’ (Remillard, 2003, p. 592).

Marcus et al. (2006) examined the role of eye movements on a serial reaction time task (SRT). In this type of task, participants initially react to the visual stimuli by depressing the corresponding keys as quickly as possible. When the stimuli are presented in a repeated sequence, participants with additional practice begin to anticipate the upcoming stimuli, resulting in a reduction in the time required to complete the entire sequence. Their findings demonstrated that, with practice, the eye movements reached the stimulus location prior to stimulus onset (anticipatory eye movements). This suggested that anticipatory eye movements reflected sequence learning, and participants shifted their visual–spatial attention to the attended stimulus (see also Sailer, Flanagan, & Johansson, 2005). Recently, Vieluf et al. (2015) addressed the question of the role of eye movements in motor sequence learning by using a more dynamic task in which participants had to perform a sequence of elbow flexion/extension movements with or without eye movements. Eye movements were recorded by an eye tracking system. The leftmost and rightmost targets were presented at a visual angle of approximately 24°. One group of participants was permitted to use eye movements, while the other group was instructed to fixate. The results

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provided empirical evidence that a movement sequence can be learned when participants are instructed to fixate, although permitting participants to use eye movements enhanced motor sequence learning. However, the instruction to fixate resulted in longer movement times, and authors suggested that fixation involves an active inhibition of eye movements that impaired the velocity of the manual response. One conclusion was that the instruction to fixate and perform the sequence simultaneously was a dual-task situation, which induced additional cognitive load that resulted in performance decrements (see also Hoffman & Subramaniam, 1995).

In brief, recent research indicates that sequence learning could occur without eye movements, but if the distance between the leftmost and rightmost targets is large enough, moving the eyes could be very useful for sequence learning. By using different methods to determine the role of eye movements in sequence learning, one can pose the question of whether the instruction to fixate, or the increased visual angle, or both affect sequence learning. Therefore, another approach investigating the role of eye movements in sequence learning would be to demonstrate that sequence learning still occurs in spite of the instruction to fixate and when the visual angle increases.

The primary purpose of the present experiment was to continue the process of systematically studying the role of eye movements in motor sequence learning when the visual angle of the target information is systematically varied, and eye movements are minimized by the instruction to fixate. However, in contrast to the traditional SRT task where the stimuli are presented in one dimension on the computer screen, in the present experiment, the stimulus information is presented in two dimensions (see also Albouy et al., 2006; Kinder et al., 2008). Two dimensions presumably increased the necessity of using eye movements to process visual information about the target positions. The visual angle of the projected target information was 3.2° in width and 7.5° in height in the small condition and 6.1° in width and 16.4° in height in the magnified condition. Magnifying the dimensions of the target information was done to increase the likelihood that eye movements become obligatory. If eye movements are not necessary for sequence learning, as suggested by Remillard (2003), then sequence learning should occur regardless of whether the participants were instructed to fixate and the visual angle increased. Note that in the Remillard (2003) experiments, participants were not instructed to fixate. If, however, eye movements are an integral part of sequence learning, as proposed by Marcus et al. (2006), we expect that sequence learning is impaired when performers are instructed to fixate, especially when the visual angle is increased.

2. Method

2.1. Participants

Undergraduate students ($N = 43$) in sport sciences participated in the experiment for course credit (29 male, 14 female, mean age = 21.48 years; SD ± 1.82 years). The participants had no prior experience with the experimental task and were not aware of the specific purpose of the study. All participants were right-hand dominant as determined by the Edinburg-Handedness Inventory (Oldfield, 1971). Informed consent was obtained prior to participation in the experiment. The experiment was conducted in accordance with the revised version of the Declaration of Helsinki (2008).

2.2. Apparatus

The apparatus consisted of one horizontal lever affixed to one end of a near-frictionless vertical axle. The lever was fixed on the right side of a table. The axle, which rotated freely in a ball-bearing support, allowed the lever to move in the horizontal plane over the table surface. At the distal end of the lever, a vertical handle was fixed. The handle's position could be adjusted so that when grasping the handle, the participant's elbow could be aligned with the axis of rotation. A potentiometer was attached to the lower end of the axis to record the position of the lever, and its output was sampled at 1000 Hz (Agilent Technologies, Agilent U2300 series USB Multifunctional Data Acquisition Device, USA). A wooden cover was placed over the table during the experiment to prevent participants from seeing the lever and their arm.

A 22″ computer screen (with a spatial resolution of 1024 × 768 pixels and a temporal resolution of 120 Hz; 3 ms reaction time) was used to display the goal waveform (see Fig. 1) and feedback to the participant. The screen was placed at the vertical meridian so that the middle of the screen and the body midline were aligned. The participants were seated at approximately 80 cm from the screen.

Participants' eye movements were recorded with a Tobii glasses 1 eye-tracking system (Tobii Technology AB, Danderyd, parallax and slippage compensation, Sweden). The gaze position was determined by pupil tracking and recorded with a temporal resolution of 30 Hz and a spatial resolution of 0.5° over the range of the visual angle between the leftmost and rightmost target information. At the beginning of each experimental session, the eye-tracking system was calibrated for each participant using Tobii Studios 9 calibration dots.

2.3. Task, procedure, and experimental groups

Participants were instructed to sit in front of the computer screen on a height adjustable chair and to place their head on a chin rest. The chair and the chin rest were then adjusted so that the participant's lower right arm was positioned at approximately an 85° angle to his/her upper arm in the starting position and his/her eyes were at the height of the horizontal midline of the computer screen and in front of the fixation point. At the beginning of each trial, the goal waveform and a fixation point (diameter of 2 cm) positioned to the left of the goal waveform in the middle of the screen were displayed (Fig. 1, right), and participants were asked to move the lever to the starting position (1° × 1° area at the beginning of the goal waveform). The goal waveform was a spatial–temporal waveform pattern of 1300 ms duration created by summing two sine waves with different periods and amplitudes. The amplitudes in the goal waveform ranged from 0° to 45° from the start position. The goal waveform was the target information and was presented in two different sizes: small and magnified. The small target information was projected on the middle of the screen with 10.5 cm in the vertical and 4.5 cm in the horizontal line dimensions. The resulting visual angles were 3.2° in width and 7.5° in height. In the magnified version, the target information was presented in the middle of the screen, with 23.5 cm in the vertical and 8.5 cm in the horizontal line dimensions. The resulting visual angles were 6.1° in width and 16.4° in height. In both versions, the cursor could be moved in the horizontal direction by the participants moving the lever. One second after positioning the cursor in the start position, a tone told the participant to begin his/her response when he/she was ready. As soon as the participant started the movement, the goal movement pattern disappeared from the screen and a cursor representing the position of the lever was displayed. Note that the fixation point was still visible. The cursor had a diameter of 0.6 cm. Data collection was triggered by the movement of the lever. The participants were instructed to move the lever with their dominant right arm through a sequential pattern of extension–flexion movements (3 reversals; changing the movement direction from extension to flexion or vice versa). They were required to produce the criterion spatial–temporal pattern displayed in front of them as accurately as possible and then return the lever to the start position. Approximately 1 s following the completion of the participant's response, the criterion waveform and the movement pattern produced by the participant were overlaid on the display for 5 s, and the root mean square error was displayed as knowledge of results (KR). The time interval of 5 s was used to ensure that participants had enough time to process feedback information. During this time interval, participants were not allowed to move the lever from start position.