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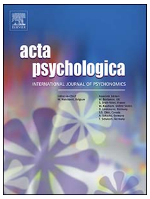

# The influence of eye-movements on the development of a movement sequence representation during observational and physical practice

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## ABSTRACT

An experiment was conducted to examine the development of a movement sequence representation and the role of eye-movements during observational and physical practice. The task was to reproduce a 1300 ms spatial-temporal pattern of a sequence of elbow flexions and extensions. An inter-manual transfer design with a retention and two effector transfer tests (contralateral limb) was used. The mirror transfer test required the same pattern of homologous muscle activation and a sequence of joint angles as experienced during the acquisition phase, and the non-mirror transfer test required the same visual-spatial pattern as performed or observed during acquisition. Participants were randomly assigned to one of four groups differing in eye-movements (free to use their eyes vs. instruction to fixate) and the practice type (observational practice vs. physical practice). The results indicated that permitting to use eye-movements facilitates sequence learning. This advantage was found on both practice types. The results of the transfer tests indicated that participants of the physical practice group who were permitted to use their eyes demonstrated superior transfer performance in the mirror transfer test, while participants in the observational practice group demonstrated better performance on the non-mirror transfer test. These findings indicated that eye-movements enhanced the development of a visual-spatial representation during observational practice as well as a motor representation during physical practice.

## 1. Introduction

The learning of movement sequences and the development of a sequence representation have received a good bit of experimental attention (Abrahamse, Ruitenberg, De Kleine, & Verwey, 2013; Clegg, DiGirolamo, & Keele, 1998; Shea, Panzer, & Kennedy, 2016; Verwey, Shea, & Wright, 2015, for reviews). By comparison little experimental attention has been directed to what extent eye-movements are involved in acquiring a movement sequence and in developing a sequence representation for later response production. The main purpose of the present experiment was to study the role of eye-movements on the development of a movement sequence representation.

In the sequence learning literature, theoretical schemes such as those proposed by Hikosaka et al. (1999) suggest that the processing of a movement sequence is distributed in the brain in independent spatial (e.g. spatial locations of end effectors and/or sequential target positions) and motor (e.g. sequence of activation patterns of the agonist/antagonist muscles and/or achieved joint angles) representations with distinct neural networks subserving each class of processing. According to this perspective, the learning of movement sequences involves both, a fast developing, effector-independent component represented in visual-spatial coordinates, and a more slowly developing effector-dependent component that is represented in motor coordinates. In addition, Hikosaka et al. (1999) proposed that early in sequence learning similar brain areas are responsible for the processing of visual and auditory input information and oculomotor output information to control eye-movements (Miyashita, Rand, Miyachi, & Hikosaka, 1996).

One way to test the assumptions of the Hikosaka model and to assess the type of a movement sequence representation acquired during practice, is to use two effector transfer tests (Shea, Kovacs, & Panzer, 2011 for a review). In one effector-transfer test the visual-spatial coordinates were reinstated but the unpracticed limb was used. In this transfer test, the participants moved to the same spatial locations (non-mirrored), but as the contralateral limb was used, a new unpracticed pattern of muscle activation and a new pattern of joint angles were required. The other transfer test involved a mirror presentation of the target positions. In the mirror effector-transfer test, the participants used the same pattern of muscle activation and achieved the same relative joint angles as during practice although the contralateral homologous muscles were used. Thus, this transfer test was referred to as the

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motor (mirror) test because motor coordinates (using the Hikosaka perspective) were reinstated and the visual-spatial coordinates were changed (Shea et al., 2011).

Recent empirical findings using the effector transfer tests with different tasks (multi-element movement sequence or simple spatial-temporal movement sequence with a duration of 1300 ms) showed that movement sequence performance following observational practice relies primarily on a visual-spatial representation (Boutin, Fries, Panzer, Shea, & Blandin, 2010; Gruetzmacher, Panzer, Blandin, & Shea, 2011). However, for physical practice, the motor representation guides the response production for the simple movement sequence (a spatial-temporal pattern of 1300 ms) after only one day of practice (Panzer, Krüger, Mühlbauer, Kovacs, & Shea, 2009).

There is also some research that has been conducted to directly address the role of eye-movements in acquiring a movement sequence by physical practice (e.g. Albouy et al., 2006; Coomans, Deroost, Vandenbossche, van den Bussche, & Soetens, 2012; Vieluf, Massing, Blandin, Leinen, & Panzer, 2015), and by observational practice (Kinder, Rolfs, & Kliegl, 2008; Marcus, Karatekin, & Markiewicz, 2006; Press & Kilner, 2013). However, the role of eye-movements in sequence learning is not unambiguous. Some experiments provided empirical evidence that eye-movements were not necessary to learn a movement sequence (Remillard, 2003) while other studies demonstrated that eye-movements enhanced sequence learning (Marcus et al., 2006; Massing, Blandin, & Panzer, 2016).

In a previous experiment Marcus et al. (2006) investigated the role of eye-movements in movement sequence learning by using a serial reaction time (SRT) task. In this type of task, participants react to horizontally presented visual stimuli by depressing the corresponding key as quickly as possible (Nissen & Bullemer, 1987). When the stimuli are presented in a repeated order, participants begin to anticipate the next stimulus, and consequently the time to complete the sequence decreased. In the Marcus et al. (2006) experiment participants had to acquire a 10-element sequence by observational practice or by physical practice and they were instructed to visually follow the stimuli. Reaction times and eye-movements were measured. Their findings showed that with increasing practice participants of the physical practice group decreased their reaction times. However, more interesting was the fact that with increasing observational and physical practice participants moved their eyes to the stimulus location prior to stimulus onset. This finding suggested that anticipatory eye-movements accompany sequence learning in both physical and observational practice (Press & Kilner, 2013 for similar findings; see also Flanagan & Johansson, 2003).

In another experiment, Massing et al. (2016) investigated whether eye-movements facilitate movement sequence learning. Participants were instructed to move a cursor by a sequence of elbow extension/flexion movements to reproduce a 1300 ms spatial-temporal pattern presented on a computer screen. One group of participants was not permitted to use eye-movements – they were instructed to fixate – while another group of participants was free to move their eyes. The main finding was that performance increased irrespective of whether participants were instructed to fixate or not. However, participants who were permitted to use their eyes performed superiorly compared to those who were instructed to fixate. This led the authors to suggest that eye-movements facilitate movement sequence learning (Massing et al., 2016).

Although there is an increasing interest in the role of eye-movements and movement sequence learning following observational and physical practice it still remains an open question to what extent eye-movements are involved in the development of an efficient movement sequence representation. The primary purpose of the present experiment was to assess the role of eye-movements during acquisition of a movement sequence in the development of a movement sequence representation following physical or observational practice. If eye-movements are involved in the development of a sequence representation then permitting to use eye-movements during observational practice will result in the development of a visual-spatial representation (Boutin et al., 2010; Ellenbuerger, Boutin, Blandin, Shea, & Panzer, 2012) whereas eye-movements during physical practice will enhance the development of a motor representation for sequence production (Kovacs, Boyle, Gruetzmacher, & Shea, 2010; Panzer et al., 2009, Experiment 1). In contrast, the instruction to fixate the eyes during observational or physical practice will impair sequence learning and the development of an efficient sequence representation for later sequence production. This prediction is also based on an aspect of the Hikosaka model which proposed that early in sequence learning the association corticies are responsible to process visual input information and to control eye-movements (Hikosaka et al., 1999). While visual-spatial processing early in learning is supported by the association corticies the instruction to fixate minimizes eye-movements and may inhibit the development of an efficient sequence representation which is primarily responsible for sequence production.

## 2. Method

### *2.1. Participants*

Undergraduate students ($n = 50$) participated in this experiment. The participants were randomly assigned to one of four experimental groups: an observational practice group in which participants were permitted to use eye-movements during acquisition (OP-FREE), an observational practice group in which participants were instructed to fixate a fixation point (OP-FIX), a physical practice group in which participants practiced the task physically and eye-movements were permitted (PP-FREE), and a physical practice group in which participants physically practiced the task and were instructed to fixate a fixation point during acquisition (PP-FIX). The demographic data and the ‘n’ of each group are presented at Table 1.

The participants had no prior experience with the experimental task and were not aware of the specific goals of the study. All participants were right-hand dominant as determined by the Edinburgh-Handedness Inventory (Oldfield, 1971) and had normal or corrected-to-normal vision. They received class credit for participation in the experiment. 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 and material*

The apparatus consisted of two horizontal levers supported at their proximal ends by a vertical axle that turned almost without friction in a ball-bearing support. The supports were fixed on the left and right sides of a table, allowing the lever to move in the horizontal plane over the table. At the distal end of each lever, a vertical handle was fixed. The handles' position could be adjusted so that, when grasping the handle, the participants' 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). For the observational practice groups a

**Table 1**
Mean age, the standard deviation (SD), and gender for each group.

| Group | Age | | Gender | |
|---|---|---|---|---|
| | Mean (years) | SD (years) | Male (n) | Female (n) |
| OP-FREE ($n = 13$) | 23.31 | 5.40 | 5 | 8 |
| OP-FIX (n = 13) | 20.46 | 1.81 | 7 | 6 |
| PP-FREE ($n = 12$) | 21.42 | 1.93 | 4 | 8 |
| PP-FIX (n = 12) | 21.67 | 2.98 | 6 | 6 |