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# Impact of hand orientation on bimanual finger coordination in an eight-finger tapping task

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ABSTRACT

In the present experiment we examined whether a symmetry tendency in bimanual finger coordination is observable in an experimental setting resembling a serial learning task and whether this tendency is defined in hand-based coordinates. Participants performed an eight-finger bimanual coordination task, in which they responded to sequences of visual stimuli by sequences of tapping movements. Visual stimuli triggered flexion of fingers, which were parallel or mirror symmetrical in respect to the body midline. Additionally, the orientation of the right hand relative to the left hand was varied. When both hands had the same orientation, the mirror symmetrical mode was more stable than the parallel mode. When both hands had different orientations, in contrast, the parallel mode was more stable. This result suggests that the tendency towards mirror symmetry was defined in hand-based coordinates. This outcome is relevant for the research of skill learning regarding the issue of whether acquired sequence knowledge is tied to specific effectors.



## 1. Introduction

In skill learning research participants repeatedly carry out structured movement sequences, and the improvement of performance compared to a random sequence is considered as sequential learning. To study whether this observation reflects effector-specific motor learning[1] or effector-unspecific

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[1] Learning on the level of effectors is usually considered to be "motor" in a narrower sense in that it is assumed to be related to sequential patterns of muscle activation or to the adjustments of control signals to the biomechanical properties of the effectors (e.g., Berner & Hoffmann, 2009a; Shea, Kovacs, & Panzer, 2011; Verwey & Clegg, 2005; Verwey & Wright, 2004).

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spatial learning a paradigm of intermanual transfer has frequently been used (e.g., Cohen, Pascual-Leone, Press, & Robertson, 2005; Deroost, Zeeuws, & Soetens, 2006; Grafton, Hazeltine, & Ivry, 2002; Kirsch & Hoffmann, 2010, 2011; Kovacs, Boyle, Grutmatcher, & Shea, 2010; Kovacs, Han, & Shea, 2009; Kovacs, Mühlbauer, & Shea, 2009; Panzer, Krueger, Muehlbauer, Kovacs, & Shea, 2009; Panzer et al., 2009; Romei, Thut, Ramos-Estebanez, & Pascual-Leone, 2009; Shea et al., 2011; Verwey & Clegg, 2005; Witt, Margraf, Bieber, Born, & Deuschl, 2010). In this paradigm participants typically perform a repeating sequence of movements with one hand and switch afterwards to the untrained hand. In one transfer condition, the original sequence of stimuli and/or response locations is maintained, which, however, now requires a new unpractised sequence of movements. In another transfer condition, the original sequence of stimuli and/or response locations is modified so that the response of the untrained hand now involves movements homologous to those used during previous training. Performance with transfer to homologous effectors is considered as indicator for effector-specific motor learning.

This conclusion is based on the assumption that the control of homologous muscles is more effective and more closely linked to each other than the control of non-homologous muscles (e.g., Verwey & Clegg, 2005; Witt et al., 2010; cf. also Criscimagna-Hemminger, Donchin, Gazzaniga, & Shadmehr, 2003). This assumption was initially prompted, however, by research with an entirely different type of paradigm, namely from bimanual coordination. These studies repeatedly showed that a mirror symmetrical coordination mode in which homologous muscle groups are activated simultaneously is more stable than a parallel mode, in which homologues muscles are activated in alternation (e.g., Kelso, 1984; Swinnen, 2002). For instance, in a classical index finger coordination task, in which cyclical adduction and abduction movements of fingers of both hands are performed, the mirror symmetrical (synchronous movements toward the sagittal midline and away from it) as well as the parallel modes (one finger moves towards the sagittal plane while the other moves away from it) can usually be produced with a high accuracy at low movement frequency. An increase in oscillatory frequency, however, results in a switch from the parallel towards the symmetrical mode, but not vice versa. This and similar results appear to suggest a possibility of transfer of motor knowledge from one effector system to another according to the mirror symmetry of joints as often assumed in sequence learning research.

There have been, however, doubts regarding the validity of the transfer from bimanual coordination to sequence learning (Grafton et al., 2002; Kirsch & Hoffmann, 2011; Verwey & Clegg, 2005). For example, Kirsch and Hoffmann (2011) did not find indications of a sequence representation in terms of finger movements that can be transferred between hands in motor coordinates in spite of task characteristics which stressed and explicitly required this form of learning and transfer. Such doubts seem justified in face of the many differences between sequence learning tasks and bimanual coordination tasks, which may impose different constraints on motor control as well. For example, in sequence learning tasks participants usually respond to complex sequences of visual stimuli as quickly as possible with sequences of key presses (e.g., Nissen & Bullemer, 1987). The critical dependent variable is response time (RT). In bimanual coordination tasks, in contrast, the movement sequences are simple, and they shall not be executed as quickly as possible in response to an imperative stimulus, but in phase with an external pacemaker. The dependent variables are based on parameters of movement execution such as error rates. To validate the transfer of the homology advantage from bimanual coordination to serial learning a kind of "missing link" which combines features of both tasks seems warranted. It would be reassuring to observe superiority of symmetrical effectors under conditions that resemble more the bimanual coordination task as well as those that resemble the serial learning task. To provide such evidence was the purpose of the present paper.

We tried to bridge bimanual coordination and sequence learning research by using a bimanual reaction time task that combines features of both, a serial reaction time task (SRT) and a bimanual coordination task. Participants responded to a repeating 8-element sequence of visual stimuli by sequential tapping with pairs of fingers, one on the left hand and one of the right hand each time. In order to increase the coordination speed we successively decreased either the response-stimulus interval (RSI) or the interstimulus interval (ISI) within one block of trials. RSI blocks represent a type of a serial learning task (cf. Berner & Hoffmann, 2008, 2009b) in which performance differences are expressed in response times (RTs) because participants were not forced by task context to make