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Research report

Motor sequence learning and intermanual transfer with a phantom limb

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ABSTRACT

Amputees with phantom limb sometimes report vivid experiences of moving their phantom. Is phantom movement only "imaginary", or, instead, it has physiological properties comparable to those pertaining to real movements? To answer this question, we took advantage of the intermanual transfer of sequence learning, occurring when one hand motor skills improve after training with the other hand. Ten healthy controls and two upper-limb amputees (with and without phantom-movement) were recruited. They were asked to perform with the right (intact) hand a fingers-thumb opposition sequence either in Naïve condition or after an active (Real condition) or a mental (Imagery condition) training with the left (phantom) hand. In healthy controls, the results showed different effects after active training (i.e., faster movement duration (MD) with stable accuracy) and after mental training (i.e., increased accuracy with stable MD). Opposite results between moving-phantom case and static-phantom case were found. In the Real condition, after an "active" training with her phantom hand, the moving-phantom case showed a faster performance of the intact hand. This transfer effect was not different from that found in healthy controls, actually performing the active training with an existing hand (Real condition), but, crucially, it was significantly different from both Imagery and Naïve conditions of controls. Contrariwise, in the static phantom case, the performance during the Real condition was significantly different from the Real condition of healthy controls and it was not significantly different from their Imagery and Naïve conditions. Importantly, a significant difference was found when the transfer effect in Real condition was compared between the two phantom cases. Taken together, these findings provide the first evidence that a phantom limb can learn motor skills and transfer them to the intact limb.

Abbreviations: MD, movement duration; ER, error rates.

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1. Introduction

Amputees sometimes vividly experience the presence of their missing limb, also reporting that their phantom has certain sensory properties, like touch and pain, as well as kinesthetic perception, like being able to perform voluntary movements (Franz & Ramachandran, 1998; Jensen, Krebs, Nielsen, & Rasmussen, 1983; Raffin, Giraux, & Reilly, 2012; Raffin, Mattout, Reilly, & Giraux, 2012). Here, we focused on the motor domain and we asked whether phantom movement is not simply imagined but, rather, it entails physiological properties comparable to those subserving real movements. In order to answer this question, we took advantage of the intermanual transfer of sequence learning, which is the generalization of motor learning from one limb to another. In other words, the phenomenon occurs when certain motor skills, learned through practicing with one hand, are transferred to the other (Bonzano et al., 2011; Perez, Tanaka, et al., 2007; Perez, Wise, Willingham, & Cohen, 2007). This mechanism provides, as an important adaptive advantage for achieving goals, the ability to apply skills obtained with one hand to the opposite one. In the context of our study, intermanual transfer of sequence learning allows investigating whether an amputee showing phantom limb movements can go as far as learning motor skills with the moving-phantom limb that, in turn, can be transferred to the intact limb.

Ten healthy controls and two upper-limb amputees, one with and one without phantom movement, were recruited for the study (see experimental procedure details in section 2.2 Study design and in Fig. 1). The moving-phantom case, after a left upper-limb amputation under the shoulder, reported a vivid phantom limb sensation and the ability to move her phantom in a volitional manner. The static-phantom case, after a left upper-limb amputation under the shoulder, reported a vivid phantom limb sensation without phantom movement, i.e., he perceived the phantom limb as paralyzed. Participants took part in a sequence-learning task, consisting in a motor training in which fingers-thumb opposition sequences were learned with one hand and transfer effects were investigated on the other hand. The experiment consisted of three conditions: the Naïve condition, during which a sequence-learning effect on the right hand (intact in the amputees) was evaluated; the Real and Imagery conditions, in which a transfer effect on the right (intact) hand was evaluated after a sequence-learning training performed with the left hand (phantom in the amputees). In the training phase, participants were asked either to actually execute the sequence (Real condition) or to imagine it (Imagery condition) with the left hand. Motor performance was evaluated by means of a sensor-engineered glove (Bove et al., 2009). See details in Study design paragraph and in Fig. 1.

According to the literature (Perez, Tanaka, et al., 2007; Perez, Wise, et al., 2007), after a training with the left hand, healthy controls were expected to show a transfer effect on the right hand (i.e., improved performance in the sequence execution with respect to a not-trained condition). Furthermore, based on previous study (Amemiya, Ishizu, Ayabe, & Kojima, 2010; Land et al., 2016), this transfer effect was expected to be different after active (Real condition) and mental (Imagery condition) training.

Thus, in healthy controls, this transfer effect was likely to be different in Real and Imagery condition. Similar differences between Real and Imagery conditions were expected in the moving-phantom limb case, but not in the static-phantom

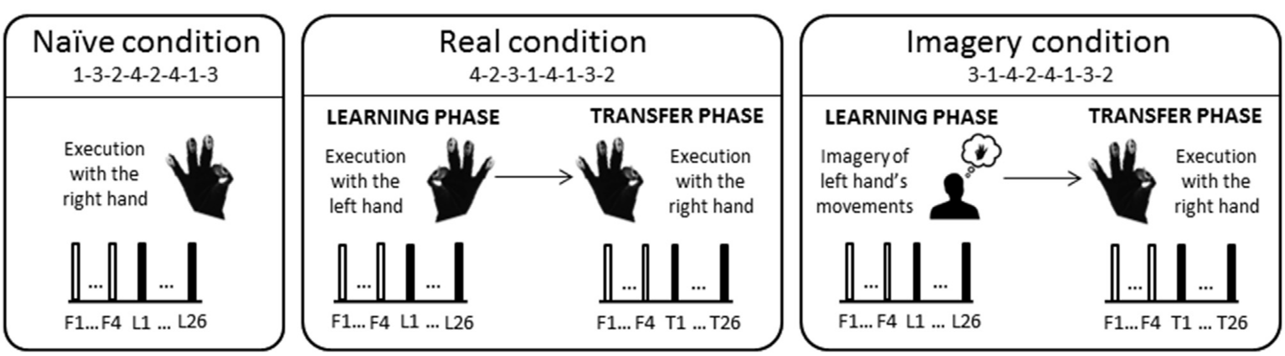

Fig. 1 – Experimental paradigm. The experiment was composed of three conditions, namely Naïve, Real and Imagery, which were executed in a random order in three different days, at least one week apart from each other. In each condition participants had to memorize a fingers-thumb opposition sequence. The order of touches in each sequence is indicated on the top of the panels where each number refers to a finger: 1-index, 2-medium, 3-ring and 4-little fingers. After having memorized the sequence participants wore an engineered glove, which recorded the kinematic parameters of the sequence execution that was performed as fast and as accurate as possible. Each session was preceded by 4 familiarization-trials (columns from F1 to F4). The Naïve condition consisted in 26 learning-trials (columns from L1 to L26) performed by both healthy participants and amputees with the right hand. In the Real condition healthy participants performed with the left hand 26 learning-trials, followed by 26 transfer-trials (columns from T1 to T26) executed with the right hand. The two amputees performed the same protocol during which the moving-phantom subject volitionally "moved" the phantom limb and the static-phantom subject tried to "move" it but reported to fail. Then, they performed the transfer phase as the other participants. During the learning phase in the Imagery condition the healthy participants and the moving-phantom case kinesthetically imagined the left hand performing the motor task. The transfer phase was performed in the same way described in the Real condition.