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Learning by observing: the effect of multiple sessions of action-observation training on the spontaneous movement tempo and motor resonance

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ABSTRACT

The present study was designed to explore the changes in motor performance and motor resonance after multiple sessions of action observation (AO) training. Subjects were exposed to the observation of a video showing finger tapping movements executed at 3 Hz, a frequency higher than the spontaneous one (2 Hz) for four consecutive days. Motor performance and motor resonance were tested before the AO training on the first day, and on the last day. Results showed that multiple sessions of AO training induced a shift of the speed of execution of finger tapping movements toward the observed one and a change in motor resonance. Before the 3 Hz-AO training cortical excitability was highest during the observation of the 2 Hz video. This motor resonance effect was lost after one single session of 3 Hz-AO training whereas after multiple sessions of 3 Hz-AO training cortical excitability was highest during the observation of the 3 Hz video. Our study shows for the first time that multiple sessions of AO training are able not only to induce performance gains but also to change the way by which the observer's motor system recognizes a certain movement as belonging to the individual motor repertoire. These results may encourage the development of novel rehabilitative protocols based on multiple sessions of action observation aimed to regain a correct movement when its spontaneous speed is modified by pathologies or to modify the innate temporal properties of certain movements.

1. Introduction

When we observe other people actions we activate the same neural circuitry responsible for planning and executing our own actions (Gallese et al., 1996; Rizzolatti et al., 1996).

One important line of research in the field of action observation (AO) supports the notion that AO recalls specialized motor representations necessary to action understanding (Calvo-Merino et al., 2006). During AO, human brain is able not only to recognize the observed movement, but also to infer specific properties of the movement. Indeed, it has been demonstrated that mirror neuron system's response increases when the observed movement shares some characteristics with our motor repertoire (Calvo-Merino et al., 2006, 2005; Fiorio et al., 2010). Regarding temporal features, the mirror neuron system can recognize whether the temporal dynamics of an observed movement is natural or not (Gangitano et al., 2004) and motor pathways activation during observation reproduces with high temporal fidelity the motor commands needed to execute the observed movement (Borroni et al., 2005).

Further, starting from the notion that the increase in primary motor cortex (M1) excitability during AO is considered evidence of motor resonance effects (Avenanti et al., 2013; Fadiga et al., 1995), we recently found the highest motor resonance during the observation of a video showing finger opposition movements performed at a rate around 2 Hz, similar to the individual spontaneous movement tempo (SMT) (Avanzino et al., 2015). A large amount of evidence supports that healthy subjects have a common spontaneous movement tempo (SMT) during the execution of a number of internally generated voluntary movements (Bove et al., 2009; MacDougall and Moore, 2005; McAuley et al., 2006). When adults are asked to freely hand tap, finger tap or walk, all these tasks share a common spontaneous movement tempo set around 2 Hz (Bove et al., 2009; MacDougall and Moore, 2005).

Another research field in the context of action observation deals with the possibility to learn new skills by means of AO (Mattar and Gribble, 2005; Williams and Gribble, 2012). Several studies have consistently shown that AO is an effective way to learn or to improve the performance of a specific motor skill (for a review see Buccino, 2014; Buccino et al., 2006; Petrosini et al., 2003; Rizzolatti and Craighero, 2004). In the literature of motor learning, skilled perfor-

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mance is acquired through motor practice in several stages: a fast initial, within-session learning phase where the magnitude of the behavioural improvements is substantial; a slow, across-sessions phase in which smaller behavioural improvements are evident over days, weeks, or months of practice; and an intermediate phase that occurs between practice sessions in which the motor memory is transformed from an initial labile trace to a more stable and resistant form (*e.g.*, Doyon and Benali, 2005; Karni et al., 1998, 1995; Krakauer and Shadmehr, 2006). Different phases of motor skill learning appear to involve different physiological processes (Doyon et al., 2009, 2003; Orban et al., 2010; Penhune and Doyon, 2005). The same concepts may theoretically be applied when motor learning is achieved through action observation, however the evolution of changes in motor performance and motor resonance from those seen after a single session of AO training into those seen after multiple sessions of AO training has not been explored so far.

Regarding to SMT, in a previous work, we showed that the motor resonance for the SMT was lost after a single session of observation of a 10 min video showing the same movement executed at a rate higher than SMT (3 Hz). However, the motor system was not yet able to recognize 3 Hz as its own SMT frequency for repetitive finger movements. Indeed, we did not observe any change in motor resonance during the observation of 3 Hz video after a single session of 3 Hz-AO training even if at a behavioural level there was a shift of SMT from around 2 Hz to a faster rate, close to that of the 3 Hz video (Avanzino et al., 2015; Bove et al., 2009).

The aim of the present study was to assess whether, by means of multiple sessions of AO training, lasting 4 days, it was possible to change the observer's SMT together with the observer's motor resonance with SMT. We hypothesized that a paradigm consisting of multiple sessions of AO training, might be able to (i) behaviourally consolidate a new SMT and (ii) shift the motor resonance, as tested with Transcranial Magnetic Stimulation (TMS), towards the trained SMT.

2. Material and methods

2.1. Participants

A total of 25 subjects gave their consent to the participation to the study. Given that the video displaying the finger motor sequence at 2 Hz was considered as the “SMT video” only subjects whose SMT was close to that of our SMT video (*i.e.*, 2 Hz) were enrolled in this study. As in a previous study from our group (Avanzino et al., 2015), subjects with a SMT between 1.70 and 2.20 Hz were here included. Six subjects were discarded since their SMT did not fit the inclusion criteria for this study.

A number of 19 healthy subjects were finally enrolled in the study. Twelve subjects (6 males, 6 females; mean age ± SD=21.9 ± 2.2) participated in the Main experiment, while 7 subjects (4 males, 3 females; mean age ± SD=22.4 ± 1.9) took part in the Control experiment. Subjects had no history of psychiatric/neurological diseases and no contraindication to TMS. All participants were naïve to the purpose of the experiment and they gave written informed consent before participation. The experimental protocol was approved by the ethics committee of the University of Genoa and was carried out in agreement with legal requirements and international norms (Declaration of Helsinki, 1964). Right hand dominance was evaluated by using the Edinburgh Handedness Inventory (Oldfield, 1971).

2.2. Experimental paradigm

The experimental paradigm is summarised in Fig. 1. This study consisted of a Main experiment and a Control experiment. The Main experiment aimed to evaluate the behavioural and neurophysiological effects of an AO training lasting 4 days, during which subjects observed a 10 min video displaying repetitive finger opposition movements performed with the right hand at a rate of 3 Hz, faster than subjects' SMT. The Control experiment was introduced to test whether the mere observation of a visual periodic stimulus for 4 consecutive days (*i.e.*, a metronome beating at 3 Hz with no audio) had an influence on motor system's response.

2.2.1. Main experiment

Subjects participated to the experiment for 5 consecutive days. On day1, participants' SMT was evaluated by asking them to perform at their spontaneous rate a finger opposition movement task (see Section 2.3.1 for more details on motor task). Then motor resonance was evaluated by assessing the excitability of the primary motor cortex using TMS delivered while participants were watching different videos showing either a static hand or a hand executing the sequential finger opposition movements at 2 Hz and 3 Hz (day1 before AO training). A detailed description of the videos can be found in Section 2.3.2. The videos were randomly presented. After 10 min break, subjects had to carefully watch a 10-min video showing the finger opposition movements sequence performed at a frequency of 3 Hz (3 Hz-AO training). After the 3 Hz-AO training, subjects were asked to perform again the motor task to test for the effect of AO training on SMT. The experimental session ended with the motor resonance evaluation in order to test for the short-term effect of the 3 Hz-AO training (day1 after AO training). During the following three days (day2, day3 and day4), subjects were asked to watch again the 10-min video of 3 Hz finger opposition movements and to execute the motor task before and immediately after the 3 Hz-AO training.

On day5 subjects performed the motor task to test for the effect of multiple sessions of 3 Hz-AO training on SMT. At last, the motor resonance evaluation was repeated in order to test for the effect of multiple sessions of 3 Hz-AO training.

2.2.2. Control experiment

In the Control experiment, the experimental paradigm was the same described in the Main experiment except for the training. The 3 Hz AO training (10-min video showing the finger opposition movements sequence performed at a frequency of 3 Hz) was replaced by a 10 min video showing a metronome beating at 3 Hz rate without any acoustic information (metronome training).

2.3. Experimental procedures

2.3.1. Motor task

In both Main and Control experiments subjects were asked to perform a motor task to assess participants' SMT. Particularly, in both the Experiments, the motor task was executed twice on day1, day2, day3 and day4 (before and after the 10 min video) and once on day5 (see Fig. 1). Subjects seated on a comfortable chair in a quiet room and wore a sensor-engineered glove on their right hand (ETT S.p.A., Italy). The motor task consisted in the execution of a finger opposition movement (opposition of thumb to index, medium, ring, and little finger) at their own spontaneous rate. The motor task was performed twice, for a period of 60 s. An eyes-closed paradigm was chosen to rule out the possibility of confounding effects attributable to visual information.

2.3.2. Videos

Different video clips were presented on a 19-in. screen located 60 cm from the subjects. Video clips showed either a right static hand or a right hand executing a finger motor sequence (opposition of thumb to index, medium, ring and little finger) at different rates. Each movie clip was obtained by filming on a white background the right hand of a human demonstrator from a third-person perspective who performed the finger motor sequence paced with a metronome at 2 Hz and 3 Hz. The sound of the metronome was silenced to avoid an acoustic training