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Research report

Mirror neuron system and observational learning: Behavioral and neurophysiological evidence

Angel Lago-Rodriguez, Virginia Lopez-Alonso, Miguel Fernández-del-Olmo *

Facultade de Ciencias do Deporte e a Educación Física (INEF Galicia), Departamento de Educación Física e Deportiva, Spain

HIGHLIGHTS

- Model observation is useless for transitive tasks with only one execution strategy.
- Observational motor learning improves learner's perceptual ability.
- The performed learning protocol determines M1 excitability during action observation.
- Observers' visuo-motor experience does not determine cortico-cortical connectivity.

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ABSTRACT

Three experiments were performed to study observational learning using behavioral, perceptual, and neurophysiological data. Experiment 1 investigated whether observing an execution model, during physical practice of a transitive task that only presented one execution strategy, led to performance improvements compared with physical practice alone. Experiment 2 investigated whether performing an observational learning protocol improves subjects' action perception. In experiment 3 we evaluated whether the type of practice performed determined the activation of the Mirror Neuron System during action observation. Results showed that, compared with physical practice, observing an execution model during a task that only showed one execution strategy does not provide behavioral benefits. However, an observational learning protocol allows subjects to predict more precisely the outcome of the learned task. Finally, intersperse observation of an execution model with physical practice results in changes of primary motor cortex activity during the observation of the motor pattern previously practiced, whereas modulations in the connectivity between primary and non primary motor areas (PMv-M1; PPC-M1) were not affected by the practice protocol performed by the observer.

1. Introduction

Mirror neurons, a special class of neurons first found in the monkey premotor cortex [1,2], become activated both when a person executes an action and during observation of someone else executing a similar action [3]. Mirror neurons have been proposed as the neurophysiological basis of the perceptual-motor transformation mechanism [4], which allows subjects to transform visual information into motor commands [5]. Thanks to this visuo-motor transformation, humans would be able to learn how to execute an action based on the information taken from an execution model [6,7]. Groups of cortical areas where these neurons are localized have been called Mirror Neuron System (MNS) (for a review see [3]). The MNS has been proposed as the neurophysiological mechanism of observational learning [5], allowing an observer to replicate the action presented by the execution model [8].

During acquisition of a motor task, observational learning has been suggested to allow learners to determine which is the more efficient execution strategy [9,10], yielding better performance compared with physical practice. In addition, there is evidence of interactions between action performance and action perception (for a review see [11]), which can occur either online – both events occur simultaneously – and offline – with action execution and perception arising at different times (for a review see [12]). Indeed, the ability to perceive actions made by others is related with the observer's visuo-motor experience [13–17], which may be determined by the practice protocol performed by the subject.

In the current study we have explored the effects of an observational learning protocol on motor performance and action perception in a novel object-directed finger task with only one execution strategy. Moreover, we have studied whether the practice

* Corresponding author at: Facultade de Ciencias do Deporte e a Educación Física (INEF Galicia), Departamento de Educación Física e Deportiva, Avd. Ernesto Che Guevara 121, Pazos-Liáns, 15179 Oleiros, A Coruña, Spain. Tel.: +34 98116700094086.
E-mail address: mafo@udc.es (M. Fernández-del-Olmo).

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protocol determines the activation of the MNS during the observation of the previously trained action. First, we evaluated whether the observational learning is more efficient than physical practice during the acquisition of a new specific motor pattern. In a second experiment, we explored the effects that observational learning exerts over subjects' ability to predict an action outcome, by asking them to estimate the result of an observed performance. Finally, using single and paired pulse transcraneal magnetic stimulation (TMS), we measured the activity of MNS areas in subjects performing different visuo-motor practice protocols.

2. Experiment 1

Observational learning is one of the most common methods used in order to acquire a motor task [18,19]. It combines action execution and model observation [20,21], and can be organized in different ways: i) presenting the execution model before the physical practice period (observational practice, OP), or ii) interspersing the observation of the execution model and action execution (interspersed observational learning, IOL). There is evidence indicating that these two specific observational learning protocols lead to distinct results in the performance of motor tasks (see [22]).

The effectiveness of observational learning has been reported for transitive actions (object-directed) [23–25]. Some authors have suggested that during the acquisition of a transitive task the model allows learners to determine the best execution strategy, yielding to performance improvements [9,10]. Thus, the observational learning would be useless when the task to be learned is characterized by one execution strategy. The aim of the first experiment was to study the behavioral effects of two different observational learning protocols (OP and IOL) and a physical practice protocol, during the performance of a transitive task that only presented one execution strategy. We hypothesized that the observational learning protocols do not lead to a better performance compared with the physical practice protocol.

2.1. Materials and methods

2.1.1. Subjects

Twenty-seven right-handed subjects (19 males and 8 females), between 20 and 28 years (mean age: 21.1 ± 1.8), participated in this experiment. All the subjects were informed about the aim of the study and provided their informed consent. The experimental procedure was approved by the Ethics Committee of Universidade da Coruña.

2.1.2. General procedure and protocols

Subjects were randomly distributed into 3 groups (9 subjects per group): Interspersed Observational Learning (IOL; 4 males and 5 females; mean age: 20.6 ± 0.7), Observational Practice (OP; 8 males and 1 female; mean age: 20.9 ± 1.4) and Physical Practice (PP; 7 males and 2 females; mean age: 21.8 ± 2.5). All of them participated in 3 sessions performed in three consecutive days.

An acquisition test was performed in the first session (acquisition session). The acquisition test consisted of 100 trials, divided into 10 blocks. There was a rest interval of 1 min following every block. A total number of 30 execution models were presented to the IOL and OP groups. The OP group observed all the execution models before starting the physical practice, and the IOL group observed 10 execution models before starting the physical practice, and 5 more in the initial four rest intervals. This session allowed us to analyze the effects of the learning protocol on subjects' motor performance.

The second session (retention session) was performed after 24 h rest period from the acquisition session. This session consisted of a total of 20 trials, divided into 2 blocks, with a rest interval of 1 min between blocks, in order to measure subjects' ability to retain the motor adaptations achieved in the acquisition session.

The third session (transfer session), was performed after 24 h rest period from the retention session. This session consisted of a total of 20 trials, divided into 2 blocks, with a rest interval of 1 min between blocks. During this session the task was performed with a different effector from the one used in the acquisition and retention sessions in order to evaluate how transferable the achieved learning was.

Participants gained a 1 € reward each time they achieved the task objective, in order to keep all of them motivated throughout the experiment.

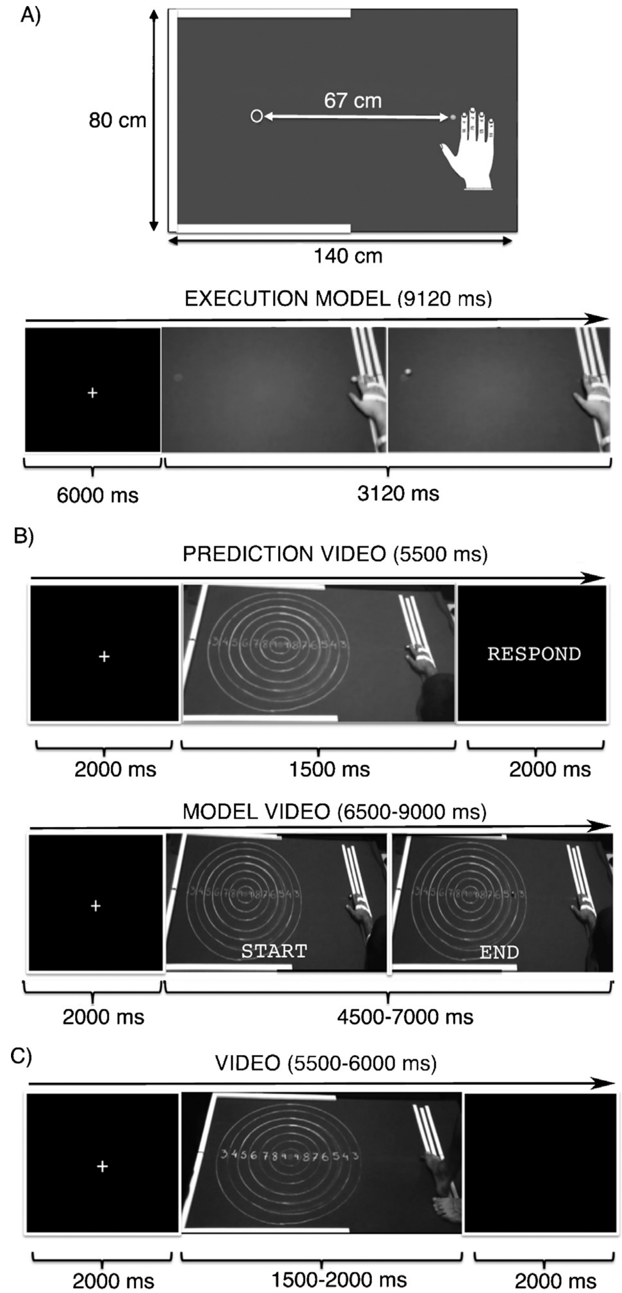

Fig. 1. Experimental protocol and clip timing used in: experiment 1 (A); experiment 2 (B); experiment 3 (C).

2.1.3. Task

Subjects were seated with their right forearm resting on a table (140 cm long and 80 cm wide), with the hand facing down with extended fingers. A ball of 2.2 cm diameter, and 44 g weight was positioned 0.5 cm of the distal interphalangeal joint of the effector finger. Subjects were asked to hit the ball using a finger of the right hand with the goal of placing the ball in a 2.6 cm diameter circle drawn on the table, which was positioned 67 cm in front of the ball starting point (see Fig. 1A). In the acquisition and retention sessions the ball was hit with the index finger, whereas in the transfer session the ball was hit with the little finger. To avoid compensatory movements both the hand and the forearm were fixed to the surface of the table, so that the possible movement was the abduction of the finger.

2.1.4. Videos

In line with previous studies [22,26] the videos displaying the execution models were extracted from a total of 100 trials, which were performed by a subject with previous task-related experience. The 5 trials with the best performance were chosen. The execution error of these models was 1.30–4.30 cm (mean: 3.16 cm ± 1.23, from a maximum error of 67 cm). Video models lasted 9120 ms (see Fig. 1A). The video began with a dark screen and a white cross in its center. After 6000 ms, the