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THE COMBINED EFFECTS OF ACTION OBSERVATION AND PASSIVE PROPRIOCEPTIVE TRAINING ON ADAPTIVE MOTOR LEARNING

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Abstract—Sensorimotor adaptation can be induced by action observation, and also by passive training. Here, we investigated the effect of a protocol that combined action observation and passive training on visuomotor adaptation, by comparing it with the effect of action observation or passive training alone. Subjects were divided into five conditions during the training session: (1) action observation, in which the subjects watched a video of a model who adapted to a novel visuomotor rotation; (2) proprioceptive training, in which the subject's arm was moved passively to target locations that were associated with desired trajectories; (3) combined training, in which the subjects watched the video of a model during a half of the session and experienced passive movements during the other half; (4) active training, in which the subjects adapted actively to the rotation; and (5) a control condition, in which the subjects did not perform any task. Following that session, all subjects adapted to the same visuomotor rotation. Results showed that the subjects in the combined training condition adapted to the rotation significantly better than those in the observation or proprioceptive training condition, although their performance was not as good as that of those who adapted actively. These findings suggest that although a protocol that combines action observation and passive training consists of all the processes involved in active training (error detection and correction, effector-specific and proprioceptively based reaching movements), these processes in that protocol may work differently as compared to a protocol in which the same processes are engaged actively. © 2016 IBRO. Published by Elsevier Ltd. All rights reserved.

Key words: observational learning, passive training, visuomotor adaptation, use dependency.

INTRODUCTION

Neural representations in the human brain are highly dynamic (Salmon and Butters, 1995; Kolb and Whishaw, 1998; Rossini et al., 2003; Lledo et al., 2006). The nervous system is capable of reorganizing sensorimotor representations, within minutes to hours, as a result of inputs from the periphery and the brain (Grafton et al., 1992; Ungerleider, 1995; Nudo et al., 1996; Kilgard et al., 2001; Mulder, 2007); and this input-dependent plasticity reflected in sensorimotor reorganization enables individuals to acquire motor skills and to recover after neural injury (Wolpaw and Tennissen, 2001). Visual and proprioceptive inputs have been distinguished as two major sources associated with this plasticity (Schmidt and Lee, 1999; Mulder, 2007).

There is ample evidence that visual inputs provided through observing the action of others can enhance motor learning (Brass et al., 2000; Mattar and Gribble, 2005; Stefan et al., 2005). For example, Mattar and Gribble (2005) showed that individuals who observed an actor performing reaching movements in novel dynamic environments performed significantly better than those who did not observe any model, and suggested that the effect of action observation might not be simply due to the use of cognitive strategies, but rather to the acquisition of a neural representation associated with the novel environments. Other studies also demonstrated that action observation could result in the acquisition of a neural representation related to pertinent movement kinematics (Hayes et al., 2010), coordination patterns (Hodges et al., 2007) and spatial–temporal goals (Vogt, 1995). These findings are also in line with the findings related to the mirror neurons that fire not only when one performs a movement, but also when she observes another who performs the same movement (Gallese et al., 1996; Rizzolatti et al., 1996; Rizzolatti and Craighero, 2004).

Studies also indicate critical roles that proprioceptive inputs play in motor control and learning. The absence of proprioceptive inputs in deafferented or stroke patients results in impairments in controlling movement and an inability to (re)acquire skilled movements (Sainburg et al., 1993; Carey et al., 1998; Tyson et al., 2007). Likewise, deprivation of proprioception due to a peripheral nerve lesion or a limb amputation causes reorganization of the motor representation (Cohen et al., 1991; Werhahn et al., 2002). On the other hand, enhancing proprioceptive inputs can improve motor leaning. Wong et al. (2012) recently demonstrated that providing proprioceptive information by moving the hand passively

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Abbreviations: ACT, active training; ANOVA, analysis of variance; BOLD, blood oxygenation level dependent; OBS, action observation; PROP, proprioceptive training; TDEL, time delay.

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could facilitate improvement in performance during a task of reproducing a specific hand trajectory (associated with drawing a circle or writing a word). Other passive training studies have also demonstrated facilitative effects of passive proprioceptive training (Cressman and Henriques, 2010; Sakamoto and Kondo, 2015). Regarding the mechanisms underlying the benefits of passive proprioceptive training, Wong et al. speculated that proprioceptive training might allow better representation of the desired movement, lead to better perception of execution errors, or change the way motor commands to muscles are computed.

The aforementioned findings unambiguously indicate that providing visual inputs through action observation or providing additional proprioceptive inputs during training is beneficial for motor learning. It is unclear, however, whether combining action observation and proprioceptive training together would lead to a greater benefit as compared to that of each training method alone. Identifying a protocol that can maximize training benefits has implications for rehabilitation and optimization of sports performance. In the present study, thus, we investigated the benefits of action observation combined with passive proprioceptive training during adaptation to a novel visuomotor rotation condition.

EXPERIMENTAL PROCEDURES

Subjects

Forty-seven neurologically intact, right-handed individuals (23 men, 17 women), aged from 18 to 30 years, participated in the study. All subjects had normal or corrected-to-normal vision. They were naïve to the purpose of the study and paid for their participation. Each subject signed a consent form approved by the Institutional Review Board of the University of Wisconsin – Milwaukee prior to participation. The first eight subjects recruited for this study were tested in one of five experimental conditions (i.e., the active training condition; see below for more information); the next 32 subjects were randomly assigned to one of the other four conditions (action observation, proprioceptive training, action observation combined with proprioceptive training, time delay); and the last seven subjects were recruited and tested to compare the proprioceptive training condition with an additional condition (see the ‘Discussion’ section).

Apparatus

A robotic exoskeleton called KINARM (BKIN Technologies Ltd, Kingston, ON, Canada) was used as the experimental apparatus. Subjects sat on the KINARM chair with their dominant right arm supported on the exoskeleton that provided full gravitational support of the entire arm; and the chair was moved to bring the arm under a horizontal display. The KINARM was incorporated with a virtual reality system that projected visual stimuli (start and target circles) on the display to make them appear in the same plane as the arm. Direct vision of the subject’s hand and arm was blocked by the horizontal display; and a cursor representing the location of the subject’s index finger tip was provided to guide his/her reaching movement. The visual stimuli consisted of a central start circle (2 cm in diameter) and four target circles (2 cm in diameter) positioned 10 cm away from the start circle (Fig. 1A). The 2-D position data of the hand, elbow and shoulder were sampled at 1000 Hz, low-pass filtered at 15 Hz, and differentiated to yield resultant velocity. Data were processed and analyzed using MATLAB (The Mathworks Inc., Natick, MA).

Experimental design

The experiment consisted of three sessions: baseline, training and testing. In the baseline session, subjects performed 60 reaching movements under a normal visuomotor condition. Prior to each movement, one of the four targets was presented on the display; and the targets were presented in a pseudorandom order (i.e., each of the four targets was randomly presented once within every four trials). Subjects were instructed to move their index finger rapidly from the start circle to the target as straight and accurately as possible in response to the appearance of the target. Each trial ended 1500 ms after the appearance of the target regardless of whether the index finger hit the target or not. There was no trial in which the subject ended a movement outside the 1500-ms window or did not move at all. In the training session, subjects were assigned to one of five groups (8 subjects per group): active training (ACT), action observation (OBS), proprioceptive training (PROP), action observation combined with proprioceptive training (OBS + PROP), and time delay (TDEL) (see Fig. 1D). The subjects in the ACT group performed 120 reaching movements with their dominant arm actively under a novel visuomotor environment, in which the visual display of reaching movements was rotated 30 degrees counterclockwise about the start circle. Those in the OBS group watched a movie of a naïve model who performed 120 reaching movements under the novel visuomotor rotation condition (more information on the movie provided below). Those in the PROP group experienced 120 reaching movements passively, during which the KINARM exoskeleton moved their arm in the ‘desired’ directions, that is, toward the locations that corresponded to each of the four target positions after they were rotated 30 degrees clockwise about the start circle (Fig. 1B, gray circles; more information on the passive movements provided below). This allowed the subjects to experience repeatedly the proprioceptive inputs associated with the desired hand trajectory without having to adapt to the rotation. Those in the OBS + PROP group experienced 20 observation trials, then 20 passive movements toward the locations described above, and so on, for the total of 120 trials (i.e., 60 observation and 60 passive movement trials). No visual feedback was provided during passive movements. Those in the TDEL group sat on the chair without moving their arm for 8 min (i.e., approximate duration of the training session for the ACT group). In the testing session, all subjects performed 80 reaching