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Review article

Action observation in the modification of postural sway and gait: Theory and use in rehabilitation

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ABSTRACT

The discovery of cortical neurons responsive to both the observation of another individual's movement and one's own physical movement has spurred scientists into utilising this interplay for rehabilitation. The idea that humans can quickly transfer motor programmes or refine existing motor strategies through observation has only recently gained interest in the context of gait rehabilitation but may offer significant promise as an adjunctive therapy to routine balance training. This review is the first dedicated to action observation in postural control or gait in healthy individuals and patients. The traditional use of action observation in rehabilitation is that the observer has to carefully watch pre-recorded or physically performed actions and thereafter imitate them. Using this approach, previous studies have shown improved gait after action observation in stroke, Parkinson's disease and knee or hip replacement patients. In healthy subjects, action observation reduced postural sway from externally induced balance perturbations. Despite this initial evidence, future studies should establish whether patients are instructed to observe the same movement to be trained (i.e., replicate the observed action(s)) or observe a motor error in order to produce postural countermeasures. The best mode of motor transfer from action observation is yet to be fully explored, and may involve observing live motor acts rather than viewing video clips. Given the ease with which action observation training can be applied in the home, it offers a promising, safe and economical approach as an adjunctive therapy to routine balance training.

1. Introduction

Falls are the leading cause of disability, hospitalisation and morbidity in patients with movement disorders, but effective balance training can mitigate fall risk. The general approach for effective training involves learning or re-learning dynamic multisensory tasks which provoke the development of motor strategies and central adaptation. The implementation of different rehabilitative techniques may therefore have a positive effect in preventing falls and reducing postural and gait instability in challenging environments.

Conventional balance or gait training involves assisting movements, preserving muscular tone and modifying current gait strategies with the main focus of reducing undesirable movements. Such approaches allow patients to maintain their motor potential and utilise their remaining motor abilities. However, rehabilitation is not always fully successful and consequently physiotherapists are looking towards adjunctive therapies.

Neurorehabilitation, in which the brain is directly stimulated in order to elicit structural and functional brain changes, can improve the outcome of routine balance training [1], but surprisingly little is known about the rehabilitative effects of action observation in relation to balance or gait training. This review will detail the underlying basis of action observation training, present findings from clinical and non-clinical action observation studies of postural sway and gait and provide suggestions for future study.

2. The scientific basis of action observation

Humans have an astonishing ability to predict another person's movements and make adjustments to motor plans. Why are we so good at reading another individual's movements, and can this be applied to balance training?

Classical studies indicate that human neonates, only a few days old, can imitate the motor actions of the parent such as sticking out a tongue [2] and infants below two years of age can predict the movement goals of another individual [3], suggesting that the brain is fortified with a mechanism linking action observation, understanding and imitation. The discovery of a population of neurons responsive to both the observation of motor actions and their execution in the macaque monkey [4] provided the mechanism by which the motor actions of others could

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be understood and mimicked.

However, it was not until later that a human equivalent, referred to as the 'mirror neuron system', was established using neurophysiological, neuropsychological and neuroimaging techniques [5]. The existence of mirror neurons was further enhanced by intracranial diagnostic recordings during craniotomy which showed that there are specific cortical neuronal populations in humans that respond to both the observation of another individual's actions (action observation) and one's own physical movements [6]. The belief is that action observation causes a mental re-enactment of the observed actions. Such an internal simulation makes it possible to reactivate action representations previously stored in motor memory, transfer new motor repertoires between individuals and train regions of the brain responsible for movement.

3. Action observation and motor learning

Motor learning is critical to the outcome of balance training and involves a number of components such as sensory processing, applying decision making strategies and initiating control processes based on prediction and biomechanical constraints. Once an action is learnt, we come to perform it effortlessly such as negotiating challenging terrains during locomotion by automatically adjusting our gait. Thus, by means of motor learning, we continuously extend our motor repertoire and generate new motor skills. For example, an everyday experience faced by commuters is negotiating a moving escalator which we do so by releasing a learnt predictive postural adjustment to compensate for the mechanical balance perturbation [7].

First evidence for the involvement of the mirror neuron system in motor learning was their discovery in the ventral premotor area (F5) of the macaque monkey [8]. Later studies in humans have revealed a complex network of mirror neurons in planning, strategic and motor areas [9,10]. By means of non-invasive techniques, it has been possible to show that action observation involves activation of specific regions of the frontal and parietal lobes; the posterior inferior frontal lobe (premotor), the ventral precentral gyrus, supramarginal cortex and rostral inferior parietal lobe [6,11], but the distribution of mirror neurons is probably scattered. During observation of complex novel motor actions, neuronal populations have been found active at the exact moment of movement initiation until its completed execution, with specific contributions from the prefrontal cortex in reorganising existing motor repertoires [12] and motor cortical changes for the muscles involved in the observed action [13], and force requirements [14]. Such a distribution and specificity is concordant with the view that action observation is an effective way of developing motor strategies and building permanent motor memories [15]. Accordingly, experiments show that observing repeated thumb movements leads to a kinematically specific memory trace of the observed movements in the motor cortex [16] and in relation to whole body motor learning, Gatti and colleagues [17] showed that the observation of novel arm and foot movements is sufficient to produce new motor kinematics. It is therefore likely that action observation leads to organisational changes in the brain which may be directly associated with motor learning.

Buccino and colleagues [1] propose four possible mechanisms where the mirror neuron system could be involved in developing new motor strategies or re-establishing previously learned motor skills: "1. Acoustic and tactile feedback enhances the acquisition of the observed motor action (i.e., conditioning). 2. The mirror neuron system has a direct influence on activation of corticospinal pathways. 3. The mirror neuron system activates previously learned movements from the stored repertoire. 4. Imagining movements that are observed may facilitate learning."

The next section reviews action observation studies with the aim of modifying postural sway or gait in healthy subjects.

4. Literature review

In March 2017, PubMed was searched for English-language studies with the terms "action observation gait/postural control/locomotion/balance", "mirror neurons gait/postural control/locomotion/balance". Inclusion criteria were any physiological studies involving the observation of gait or posture either first-hand or from video recordings, and subsequent observer replication of locomotor or balancing tasks. No studies meeting criteria were excluded. After retrieving all material along this research theme, studies were divided into material on healthy subjects and those on patients, as below.

4.1. Action observation in the control of postural sway and gait

4.1.1. Can we mimic observed gait and postural responses of another individual in routine tasks?

The potential of the mirror neuron system in gait training was demonstrated in an early study, which found improved balance responses and gait in elderly individuals moving through an activity course after having first imagined their movement (motor imagery) [18], a method associated with the activation of cortical circuits involved in motor planning and programming (some of which are shared by action observation). The neurophysiological basis of these findings were supported by Behrendt and colleagues [19] who demonstrated that healthy subjects observing another person walking, recreate a mental representation of the observed gait which they reproduce concurrently in lower limb EMG recordings. Observing the sway of others can also affect current and future postural tasks, where subjects tend to mimic the observed individual's sway. For example, in a study by Taube and colleagues [20], participants observed videos of an actor performing balance exercises over four weeks. When observers were then asked to perform a balancing task on a free-moving platform, they employed the same techniques that they had observed and significantly reduced their postural sway in the task.

4.1.2. Can we acquire anticipatory balance responses after observing gait and postural actions in challenging tasks?

Motor learning is the process in which motor strategies are formed or modified through practise, and in the context of balance control, is responsible for the development of anticipatory responses [1]. Thus, whether action observation can produce motor learning through the covert simulation of observed movements is crucial to the development of rehabilitation programmes. To that end, Patel and colleagues [7] sought to investigate differences between adaptive locomotor learning induced by first-hand experience versus action observation. Specifically, the authors studied whether observation of an actor's postural sway on a moving sled was sufficient to generate automatic compensatory postural responses. They found that after observing another individual swaying upon a sled that accelerated across a linear track, the observer produced a compensatory postural response in proportion to the size of the observed motion. The overall motor learning effect was similar to physically performing the task, but about 50% smaller. Crucially, observers generated no compensatory response after observing the sled move in isolation, suggesting that observing an actor was critical to motor learning. Similarly, Bhatt and Pai [21] showed that after observing another person slip because of a sudden unpredictable platform translation, subjects going on to perform the same experimental paradigm had lower slip displacement and velocity and greater post-slip stability compared to naïve subjects.

To summarise, updating cognitive centres with new gait patterns or postural consequences of an impending task through observation yielded tangible postural and gait benefits. It is therefore possible that observers generate new predictions about the task by covertly simulating the motor commands of the observed action. Nevertheless, observational learning is not as effective as physical motor learning when the two are compared. However, it should be pointed out that action