Action observation in infancy: implications for neuro-rehabilitation

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Action observation therapy has been found to be effective in improving hand motor function in both adults with stroke and children with unilateral cerebral palsy. We here propose a provocative hypothesis arguing that the same therapy might be effective in very early intervention in infants with unilateral or asymmetric brain damage, but through a different underlying mechanism. If the activation of motor networks induced in infancy by action observation enhances the excitability of the damaged sensorimotor cortex, it could also accelerate the maturation of the corticospinal tract and the adaptive shaping of the spinal motor circuits. This hypothesis should be explored carefully in prospective studies and, if confirmed, might support the use of action observation therapy at a much earlier time than experimented so far.

In recent years, several pieces of evidence have contributed to supporting the hypothesis that the motor system is part of a wider simulation network activated by a variety of conditions related to action, including motor imagery and action observation.[1] In the adult human brain, existence of a system matching the observation and the execution of actions, defined by most as the mirror neuron system, is well established.[2] Surprisingly, very little is known about its emergence and early development. Indeed, indirect evidence from ethological and behavioural studies suggests that learning through observation of others is a key mechanism for developing social-emotional functions for communication and bonding, and cognitive functions for motor learning and goal prediction.[3] Non-invasive tools to assess brain representation of complex functions, such as near-infrared spectroscopy or electroencephalography, allow for more direct demonstrations of the presence of a sensory-motor matching system in infancy.[4–7]

Studies on brain representation of action observation in infancy support the notion that mechanisms matching action and perception might be present shortly after birth, and that their neural substrate might involve a network centred on central, frontal, and parietal nodes, consistent with evidence in human adults and animal models.[8] An increasing number of reports demonstrate that, irrespective of the technique and methodology applied, the brain central regions react to both action execution and action observation as early as the first months of life, as shown by comparing the effects of observing an action with a neutral rest condition.[8] Infant studies confirm the key role of experience in modelling the action observation network and underline the importance of this system in infants with typical motor development as well as in functional reorganization following early brain damage.[9]

Existence of the mirror neuron system is gaining interest in the clinical community since the first reports of the effects of a novel therapeutic approach based on action observation in the rehabilitation of individuals with unilateral brain damage. In the first part of this paper, we will briefly review the studies on action observation therapy in adults with stroke and in children with spastic cerebral palsy (CP). In the second part of the paper, we will report on an ongoing multicentre study using action observation therapy in young infants and discuss its underlying rationale.[10]

ACTION OBSERVATION THERAPY IN ADULTS AND CHILDREN

Basic neuroscience research on mirror neurons has suggested highly appealing features for functional motor rehabilitation in individuals with focal brain lesions, which are now being confirmed by clinical studies. In 2007, Ertelt et al.[11] examined a new neuro-rehabilitative programme in adult patients with stroke, called action observation therapy, combining physical training with observations of various hand actions. The experimental group demonstrated significant improvement in motor functions compared with their pre-treatment baseline and with controls. These findings were supported by a degree of functional reorganization of the motor system, as seen in significant modifications in functional magnetic resonance imaging activations during an object manipulation task.[11]

Recently, several studies in stroke patients focussed on action observation as a promising tool for motor rehabilitation by allowing patients to train their motor functions when voluntary movement is impaired, also investigating the effects on biological parameters using brain imaging and neurophysiological techniques. In 2008, Celnik et al.[12] used transcranial magnetic stimulation to assess the effect of action observation therapy on motor memory formation in patients with chronic stroke, demonstrating differential and specific modifications in corticomotor excitability within the hand motor representation of the primary motor cortex. These results supported a potential use of action observation as a strategy to enhance motor rehabilitation in adults with stroke.

Action observation therapy has been also investigated during childhood. Sgandurra et al.[13] enrolled 24 school-aged children with unilateral CP and mild to moderate hand impairment in a randomized, evaluator-blinded, block-design trial, with two groups. For 1 hour/day for three consecutive weeks, the experimental group observed video sequences of unimanual or bimanual goal-directed actions and subsequently executed those observed actions with the hemiparetic limb or both upper limbs. The control group performed the same actions in the same order as the experimental group, but performed the actions after the observation of computer games free of biological motion. Interestingly, after the training, the experimental group had greater improvement than the control group on the Assisting Hand Assessment, a scale for bimanual evaluation used as the primary outcome measure. Buccino et al.[14] extended these findings to children with different types of CP, by assigning 15 children with unilateral or bilateral CP to either a case or a control group. Again, the only difference in the treatment received was the content of the video clips: cases observed videos with motor content, whereas controls observed videos without motor content. The functional score gains following treatment, as assessed by the Melbourne Assessment Scale for unimanual evaluation, were significantly higher in the case group compared with that of the controls. Similarly, Kim et al.[15] found greater positive effects on upper extremity function in children with CP in response to action observation physical training compared with standard physical training. Taken together, these studies provide preliminary evidence of the efficacy of action observation therapy in children with unilateral or bilateral CP, suggesting that this approach could be an effective part of paediatric neurorehabilitation programmes.

What this paper adds

- A revision of the literature on AOT in children and adults with unilateral brain damage.
- The discussion of possible mechanisms of AOT in brain damaged individuals, when applied in early infancy.

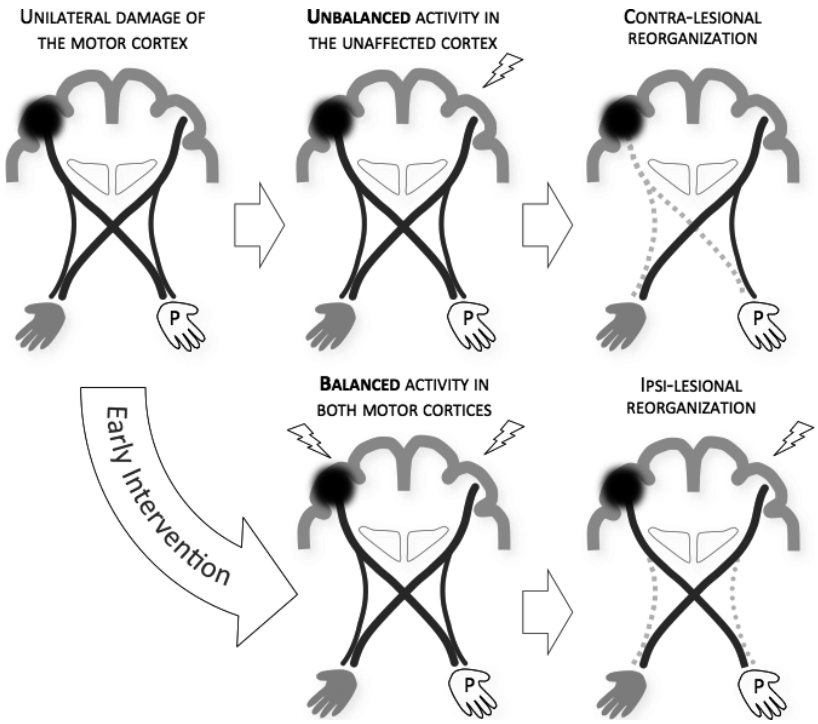

Figure 1: Proposed rationale for early intervention in perinatal unilateral brain damage. The top row represents the mechanism leading to a contralesional reorganization, based on the presence of an unbalanced cortical activity of the motor cortices. The bottom row shows the possible mechanism of early intervention based on the induction of cortical activity also in the affected hemisphere in order to prime the motor cortex to standard therapies available at a later stage. Lightning signal indicates activation of the motor cortex.

ACTION OBSERVATION THERAPY IN INFANTS WITH PERINATAL BRAIN DAMAGE

All of the studies in children and adults were aimed at improving hand function by manipulating cortical plasticity at a time when key processes of sensorimotor reorganization, specific of early brain damage, have already occurred. Evidence suggests that for infants with perinatal brain lesions, important phases of sensorimotor reorganization occur during the first year of life due to greater neuroplasticity in the early stages of brain development but, for the same reason, maladaptive forms of sensorimotor reorganization can also occur during this same time period.[6] In adult stroke, the main mechanism to restore a reconnection of the motor cortex with the spinal cord is the reorganization of function within the ipsilesional cortex, within the primary motor cortex or in non-primary motor areas. In congenital lesions, however, the specific phase of brain maturation allows for unique neuroplastic processes of sensorimotor reorganization. These unique processes are based on the existence of bilateral motor projections originating in the primary motor areas, which connect each hemisphere with both sides of the body during the first weeks of life. These tracts generally withdraw during development, but can persist in cases of cerebral damage, giving rise to contralesional reorganization of motor function, exclusive of early brain damage.[16]

In congenital brain damage, two different types of brain reorganization can be observed: ipsilesional reorganization (i.e. reorganization occurring within spared cortical tissue of the damaged hemisphere) and contralesional organisation (i.e. reorganization occurring in the undamaged cortex).[17] The latter allows the undamaged cortex to directly control both upper limbs and often involves dissociation of the primary sensory and motor pathways,[18] resulting in limited upper limb motor function.[17] Consequently, the first 3 to 6 months of life after an asymmetric brain lesion, provide a critical window of opportunity for very early intervention aimed at maintaining cortical motor control within the affected hemisphere by activating the damaged sensorimotor cortex.[19] We propose the provocative hypothesis, yet to be demonstrated, that an activation of the sensorimotor cortex might be obtained by the mechanism of action observation (Fig. 1). Early action observation might induce a cortical activation of the damaged hemisphere not based on a motor input, but rather on a sensory one (mainly visual), therefore less dependent from the activity (and hence the degree of damage) of the corticospinal tract. This rationale for infant action observation therapy is notably different from that of child and adult therapy; however, its potential effect is still unknown.[20]

If the activation of motor networks can be induced in infancy by action observation, it would be possible to use training based on movement observation coupled with actual hand motor activity (contacting the toy, and later grasping and reaching) for enhancing the excitability of the sensorimotor cortex, accelerating the maturation of the corticospinal tract, and adaptively shaping the spinal motor circuits. To examine this hypothesis, we have recently started a multicentre study of two parallel randomized sham-controlled trials involving: (1) typically developing infants; and (2) infants with asymmetric brain lesions (e.g. unilateral arterial stroke or venous infarction and asymmetric periventricular leukomalacia).[20] Infants from each group were randomized to receive either action observation training or standard toy observation training for 4 weeks, from the infant's 9th to 13th post-term weeks of age. Results of this study, or from other similar prospective studies, will determine if a novel intervention based on action observation in infants, similar to what happens in children but through a fundamentally different mechanism, is able to affect early development of reaching and grasping in typically developing infants and to improve upper limb motor activity in infants with asymmetric brain lesions. In any case, action observation therapy in infants with perinatal brain damage would not be meant to replace standard therapies that have been shown to be effective in early rehabilitation of upper limb motor function.

Regardless of the results of our clinical trial,[20] further studies are needed to elucidate the specific influence over the effects of action observation by lesion type, post-lesional reorganization, and degree of involvement of other systems such as vision, sensation, or cognitive ability. There have been recent important findings, derived from both human and non-human studies, regarding the specific mechanisms of early sensorimotor reorganization.[10,19] We believe that studies should be undertaken aimed at promoting very early bilateral motor activation in infants with perinatal brain damage.

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