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Does observation of a disabled child's action moderate action execution? Implication for the use of Action Observation Therapy for patient rehabilitation

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ABSTRACT

Background: Research investigating action observation-execution priming has mainly manipulated congruent versus incongruent action, and aspects of action expertise/capability. More specifically, the literature suggests enhanced performance priming following action observation by actors closely matched to participant expertise. The aim of the present study was to extend the understanding of action expertise effects by investigating action priming in healthy participants after observing a mild hemiparetic child actor versus a neurologically healthy child actor.

Methods: 16 healthy right-handed children, aged 6–13 years were tested. Several motor assessments were performed, including gross and fine manual motor ability, and upper limb kinematics measured using a precise robotic device. A cross-over design consisted in two experimental conditions (observing actions performed by a child with hemiparesis versus observing actions performed by a healthy child) and a pre-observation double baseline control condition, with the data analyzed using repeated measures ANOVA.

Results: Relative to baseline, both types of action observation conditions enhanced fine manual dexterity, but observing the hemiparetic child enhanced gross manual dexterity and upper limb velocity kinematics relative to observing actions performed by a healthy child. No effects were shown on measures of smoothness and accuracy.

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Discussion: Contradictorily to hypotheses discussed in the literature, results here showed evidence of enhanced action execution when healthy children observed hemiparetic compared to healthy child actions. These results are discussed in terms of how patient compared to healthy actors may be useful for clinical action observation priming therapy.

1. Introduction

In 1992, neurons discharging both when a monkey executed an action and when he observed the same action being performed were discovered (Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992). This population of neurons has been called "mirror neurons" and the discovery highlighted the link between perception and action, since the observed actions looked like being reflected in the motor representation of the observer (Buccino et al., 2001). With the technological and scientific progress, researchers have been allowed to precisely localize the mirror neuron system (MNS) in the human brain and support the matching system of action execution and action observation (AO) (Buccino et al., 2001; Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995). These articles reported that observation and execution of actions showed recruitment of fronto-parietal circuits including inferior frontal gyrus (IFG), ventral premotor cortex (VPMC) and inferior parietal lobule (IPL).

Although much is known about the neuroscience of the MNS, the roles of the MNS in cognition remain lively debated in the scientific literature. In relatively early work, Rizzolatti (2005) proposed that the MNS was important for a variety of different cognitions, including action intention or goal understanding (Iacoboni & Mazziotta, 2007), imitation (Nishitani & Hari, 2000), empathy (Wicker et al., 2003) and language processing or speech production (Fadiga, Craighero, Buccino, & Rizzolatti, 2002). Investigations into action priming focus on goal understanding and imitation cognitive processes and consistently demonstrate that AO can moderate action execution (e.g., Edwards, Humphreys, & Castiello, 2003; Hardwick & Edwards, 2011; Salama, Turner, & Edwards, 2011; Gianelli, Dalla Volta, Barbieri, & Gentilucci, 2008; etc.). For example, in Edwards et al. (2003), participants observed the experimenter making a prehensile action to an object, and then the participant made an action to the same or a different object. In 20% of the trials, the observation and execution was to the same object (which they termed a valid prime) and in the other 80% of trials, the prime was invalid (for example, observation of an action to a small object, but action execution to a large object; and vice versa). Results showed a priming effect for the valid compared to invalid prime, where actions executed by the participant were more rapidly initiated and other kinematic indices were improved (peak velocity, time to peak grasp, etc.). Importantly, these effects cannot be explained by expectation, where performance should have been better for the invalid than valid prime.

The action priming effect considers that AO activates MNS networks through an internal motor simulation of the observed action, and that subsequent action execution is facilitated by the prior neural activation and internal motor simulation. This re-activation of the MNS and the internal motor simulation for execution causes neural efficiencies in action planning cognition (see Edwards et al., 2003). Based on this premise, expertise ought to moderate action priming. The observer might only benefit from AO if they are able to perform the observed action. Some researchers have investigated what happens in the MNS when a physically impossible action is observed (Longo, Kosobud, & Bertenthal, 2008; Stevens, Fonlupt, Shiffrar, & Decety, 2000). In a PET study (positron emission tomography), Stevens et al. (2000) showed that observing physically impossible actions showed no MNS activation, whereas observing physically possible actions did show MNS activation. This finding suggests that action priming should only be possible following observation of possible actions.

The contrary investigation of the correspondence between AO and the observers action expertise or capability comes from research where participants observe skilled actions. Calvo-Merino, Glaser, Grèzes, Passingham, and Haggard (2005) showed that participant's motor experience (experts versus novices) caused moderated MNS activity. When expert compared to novice dancers observed dance in which they had expertise, there was greater MNS activation compared to observing a dance that they were not expert in performing, or in comparison to novice participants. They proposed that the observed actions were represented in the participant's personal motor repertoire, and that expertise moderated the amount of MNS activity during observation. Similar results have been reported in music expertise (Haslinger et al., 2005; D'Ausilio, Altenmüller, Olivetti Belardinelli, & Lotze, M, 2006), Parkinson disease (Castiello, Ansuini, Bulgheroni, Scaravilli, & Nicoletti, 2009) and comparing babies that can or cannot walk (van Elk, van Schie, Hunnius, Vesper, & Bekkering, 2008).

In the present paper, we questioned what would happen in action priming when participants observed actions performed by a person with unilateral impaired action caused by brain damage in early infancy (unilateral cerebral palsy; CP). The condition is defined as "a group of permanent disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, perception, cognition, communication and behavior, by epilepsy and by secondary musculoskeletal problems (Rosenbaum, Paneth, Leviton, Goldstein, & Bax, 2006)". The contralesional movements of these patients are impacted by limb spasticity and a loss of motor control, leading to reduced, slower and sometimes abnormal acceleration profiles (Rosenbaum et al., 2006). However, even if these action kinematics are less efficient, they remain possible to imitate by a healthy observer. If the observed action of the patient is considered as less efficient, we might predict deterioration in action priming relative to observation of a healthy child model (as in Edwards et al., 2003). However, as the observed action is physically possible for the observer, we might also predict no difference in action priming, as demonstrated in Longo et al. (2008). Therefore, we either expect no difference in priming or deterioration following CP compared to healthy child action observation for gross and fine manual ability and upper-limb kinematics.

2. Methods

2.1. Participants

The participants consisted of sixteen right-handed children recruited from a participant volunteer group. They were aged 6–13 years (mean 8.9 years, SD = 2.2) and consisted of four boys and twelve girls. The children were all healthy and did not have attention-deficit hyperactivity disorder. The Saint-Luc Biomedical Hospital-Faculty Ethics Committee approved the research protocol prior to any experimentation and all parents provided their informed consent prior to their child participating in the study. The protocol is registered at ClinicalTrials.gov (NCT02543424).

2.2. Upper limb assessment

Gross manual dexterity, fine manual dexterity and upper limb kinematic motor measures were computed. The gross manual dexterity was assessed with the Box and Block test (Mathiowetz, Federman, & Wiemer, 1985), in which the child participant grasped and moved 25 mm cubed blocks from one compartment of the box to the other, with their dominant hand as many times as possible in 1 min. Fine manual dexterity was measured using three sub-tasks of the Purdue Pegboard test: dominant hand, both hands and assembly (Gardner & Broman, 1979). In the two first subtests, children had to grasp and put in to two rows of holes, as many of 3 mm diameter pegs as they could in 30 s either with the dominant or both hands. During the assembly subtest, children used both hands alternatively to construct towers of four small elements (peg, first washer, collar and second washer). They had to construct as many towers as possible in 1 min. The number of elements moved in the allotted time was recorded, with a bigger number indicating a better gross or fine upper limb manual ability.

Upper limb movement kinematics were measured using the REAplan robot (version 2.1; see Fig. 1.1). The REAplan is an end-effector robot that can both rehabilitate (e.g., facilitate) and assess participants upper limb actions in a horizontal plane (Sapin, 2010). Participants were presented with four tasks, with the visual images of the test displayed on a big screen, and the participant having to make corresponding actions to the stimuli using the robot handle. Through the handle, force and horizontal X and Y plane position trajectory were measured over time (125 Hz), giving precise and reliable measures of participants kinematics that were used to calculate the participant's velocity, smoothness and accuracy (see below for more details). For the current study, the REAplan robot was used in a passive mode permitting the participants to control their own movements.

Gilliaux, Lejeune et al. (2014); Gilliaux, Renders et al. (2014); Gilliaux et al. (2015) defined a standardized protocol for using the REAplan robot to quantitatively assess the upper limb kinematics in healthy and brain damaged, adult and child participants. This involved the completion of four different tasks: (i) free amplitude; (ii) target pointing; (iii) circle drawing and; (iv) square drawing; with each implemented in an attractive virtual interface. Each test consisted of ten repeats of movement, and the average performance was computed. The authors also defined relevant kinematic indices for each test as described below. Children performed all kinematic assessment using their dominant hand.

In the free amplitude task, children had to reach straight out in front of them, as far as they could, before bringing their arm back to the starting position. The target pointing task consisted in making pointing movements in the most direct and precise manner toward a target placed at 10 cm distance in front of the participant. In the circle and square drawing tasks, children had to draw a circle of 4 cm radius and a square of 6 cm sides. For each task, the robot provides measures of velocity (with speed and peak speed) and smoothness (with speed and jerk metrics). The accuracy was computed using the straightness index for the free amplitude and target tasks and the shape accuracy index for the circle and square drawing tasks. Speed is the ratio between path length and elapsed time in centimetres per second, and peak speed is the maximum speed in centimetres per second. The speed and jerk metrics are both measures of movement smoothness (Rohrer et al., 2002). The speed metric index was computed by dividing average speed for the action by peak speed, with a bigger number indicating more smoothness. The jerk metric corresponds to the percentage of variability around the ratio between absolute mean jerk (i.e. variation of acceleration) and peak speed, with a lower score indicating a more constant performance for the ten trials. The straightness index was computed for free amplitude and target tests, and corresponds to the ratio between the path of action used by the participant and the minimum possible path length. Performance closer to 1 indicates straight movements. The shape accuracy index was computed for circle and square drawing tests, and corresponds to the mean distances between the participant's measured performance points and the true corresponding reference points (higher scores indicate less accurate movements).

2.3. AO stimuli

The AO stimuli consisted of seven different 10–12 min movies presented each day over a seven-day period. The movies were displayed on a DVD that the children took and watched at home. The movies contained uni- and bi-manual actions from a child daily life activities such as putting on socks, brushing teeth, breaking eggs, cutting a piece of paper, playing with PlayMobile, etc. (see Fig. 1.2). The action movies were filmed from a first-person perspective of a seven-year-old child in order to facilitate motor identification with the observed

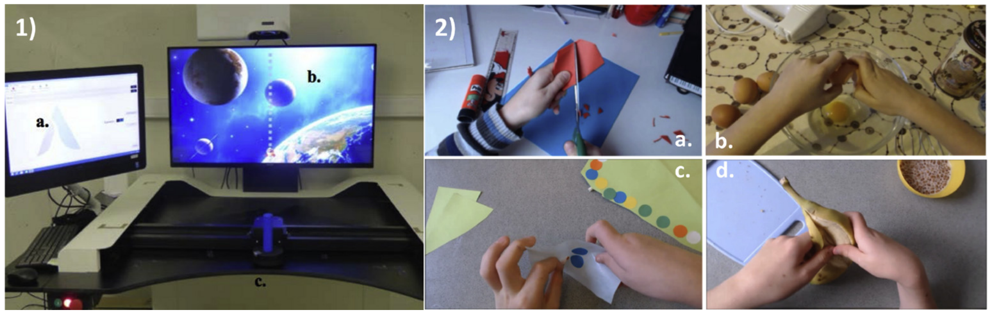

Fig. 1 – 1) View of the REAplan robotic device with (a) a therapist screen, (b) a participant screen and (c) a handle and 2) Print screens of the healthy (a & b) and CP (c & d) AO DVD.

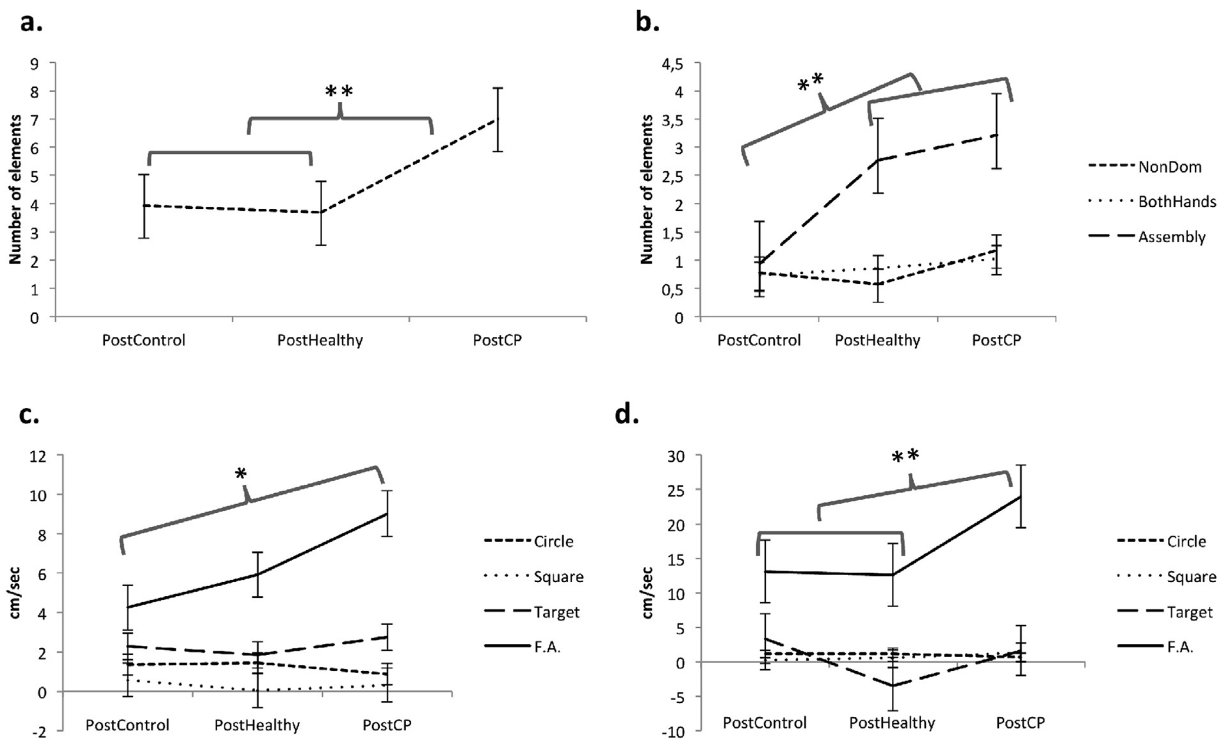

Fig. 2 – Graphical representation of significant results from the (a) Box and Block, (b) Purdue Pegboard, (c) speed and (d) peak speed indices computed with the REAplan robot. * indicates *p*-values under .05 and ** under .01.

upper limb. To make the DVD's as attractive as possible for children, the movies were inserted in a narrative story.

Two different DVD's were used matched in length, types of action, point of view, sounds (etc.). The only difference was that the actions were either performed by a healthy child or a CP child with right limb mild motor impairment. The CP child was classified with level 2 on the Manual Ability Classification System (MACS; which provide a measure of the child's manual capability between level 1 to 5; Eliasson et al., 2006). Level 2 indicates an ability to manipulate most objects, but with less good quality or speed. In the healthy model DVD, each day involved a movie associated with a step towards the child preparing a birthday surprise for his/her mother (see Fig. 1.2). The sequence of movies each day within the narrative involved the child: (i) waking up; (ii) making a birthday cake; (iii) creating a birthday card; (iv) decorating the cake; (v) doing homework; (vi) leisure time and (vii) preparing the table for the party. In the CP child model movies, the narrative around the actions was the story of a child preparing a trip to the sea and involved the child: (i) creating a belonging checklist; (ii) cleaning up his travelling bag; (iii) preparing his lunch; (iv) making a kite; (v) cooking some cookies; (vi) having leisure and homework activities, and; (vii) waking up for the travel. In order to facilitate the internal motor simulation of the observed actions, the sounds associated with the actions were included for all movies (Kohler et al., 2002). Instructions were given orally at the beginning of each film. Parents completed a daily checklist to register whether the movies were watched by the child or not, the degree of attention paid (evaluated using a Likert scale, with 1 indicating no attention and 4 indicating maximum attention) and any comments linked to the watching of the movies.

2.4. *Experimental design and procedure*

The experiment design used a single-blind cross over method. There were three types of condition: a double baseline considered as control condition (with no DVD watching), a “healthy DVD condition” and a “CP DVD condition”. Children always began with the double baseline control condition followed by the DVD conditions presented to each child participant in a counterbalanced order. The children were randomly separated into two groups, with one being given the healthy DVD condition first, and then the CP DVD condition, and the second group starting with the CP DVD condition followed by the healthy DVD condition. A person independent of the main researcher performed the randomization of groups, ensuring that the experimenter was not aware of the condition phase that the participant was involved in until the end of data collection. The group allocation was instructed to parents using an envelope given to them at the beginning of each condition. The envelopes contained a DVD and an instruction paper. In both conditions, the parents were informed to show one movie (in sequence) each day for seven days. Before and after each condition, the child participants and their parents met the researcher at the Catholic University of Louvain laboratories, and all of the assessments were performed. Therefore, each session started with a pre-condition measure session, then seven days of one of the DVD conditions, followed by a post-condition evaluation. The second type of DVD condition was then given followed by a final post-condition evaluation.

The procedures for all of the testing sessions were similar. The children and their parents attended the Catholic University of Louvain laboratories. Children were tested in a separate room from the parents using a standardised test order, with breaks when needed. Following a practice, the children were evaluated on the Box and Block and Purdue Pegboard tests. Then, the upper limb kinematics of children was assessed with the REAplan tasks, each consisting of a practice followed by ten performances, as described above. The entire evaluation lasted 30–45 min. At the end of testing sessions 2 and 3, the parents received the instructions envelope for the following week (for the DVD condition), and both parents and children were thanked.

2.5. *Statistical analyses*

The normal distribution and equality of variance were verified for all comparisons, and the significance level was .05. Statistical tests were performed using SPSS 23.0 software (SPSS Inc., Chicago, IL, USA). The dependent variables were changes in performance relative to the first baseline. Each dependent variable was analysed using a repeated measure analysis of variance (ANOVAs), with the condition as an independent variable (control, post-Healthy DVD, post-CP DVD). Additionally, when several tasks tested the same dependent variable (i.e. the speed), the task constituted another independent variable. When needed, post-hoc analyses were performed using Bonferroni correction.

3. Results

Analysis of the Box and block task showed a significant effect of condition [$F(2,30) = 7.59$ $p = .002$ $\eta^2 = .34$], with more blocks displaced following the CP DVD observation than healthy DVD and control conditions. Analyses of the Purdue Pegboard tests also showed a significant main effect of DVD condition [$F(2,30) = 5.87$ $p = .007$ $\eta^2 = .28$], a marginal effect of the Purdue Pegboard subtests [$F(2,30) = 3.28$ $p = .051$ $\eta^2 = .18$] and a significant interaction between the condition and the subtests [$F(4,60) = 7.07$ $p = .000$ $\eta^2 = .32$]. In the analyses of the interaction, the assembly subtest only showed significant differences between DVD conditions (healthy and CP) versus control condition, with more elements moved in the allotted time following CP and healthy DVD conditions in comparison to the control condition.

Analyses of upper limb kinematics assessed with the REAplan robot tasks showed various significant effects. For speed index, there was no main effect of DVD condition [$F(1.99, 29.91) = 1.75$ $p = .191$ $\eta^2 = .10$], a main effect of tasks [$F(1.26, 18.98) = 5.42$ $p = .025$ $\eta^2 = .26$] and an interaction between condition and tasks [$F(2.96, 44.41) = 3.48$ $p = .024$ $\eta^2 = .19$]. Analysis of the interaction showed that the DVD conditions only modulated speed in the free amplitude task, with significantly faster speed after observing the CP DVD compared to the healthy DVD and control conditions. Peak speed index showed a main effect of DVD condition [$F(2,30) = 6.76$ $p = .004$ $\eta^2 = .31$], a main effect of tasks [$F(1.90, 28.56) = 9.59$ $p = .001$ $\eta^2 = .39$], and an interaction [$F(3.31, 49.69) = 4.89$ $p = .004$ $\eta^2 = .25$]. The DVD conditions only modulated peak speed in the free amplitude task, where peak speed was significantly higher after watching the CP DVD compared to control and healthy DVD conditions. All other kinematics variables of smoothness and accuracy showed no significant results (no main effects or interactions; all $F < 2.40$ $p > .11$). Significant results are graphically summarized in Fig. 2 (a,b,c,d) and all data are presented in Table 1.

4. Discussion

The literature reports a role of action capability and skill on MNS activation and AO-execution priming (e.g., Calvo-Merino et al., 2005; Edwards et al., 2003; Stevens et al., 2000). In the present research, we investigated how AO priming was modulated by differences in model characteristics. Two DVD's were used and showed both first-person perspective actions performed by a healthy child (Healthy DVD) versus a child with unilateral mild motor impairment (CP DVD), relative to a control condition baseline. If the observed action of the patient is considered as less efficient, we predict deterioration in action priming relative to observation of a healthy child model. However, as the observed action is physically possible for the observer, we can also predict no difference in action priming. We predicted one of two results. Either action performance would be better following observation of the Healthy DVD and worse following the CP DVD, possibly showing priming based on matching between observation and execution skill. Alternatively, we predicted no difference between performance after observing either the Healthy or CP DVD, but better

Table 1 – Difference in performance relative to baseline means and standard deviation.

		Post-Control – Baseline	Post-Healthy – Baseline	Post-CP – Baseline
Gross manual dexterity	Box and block (count)	3.94 (4.36)	3.69 (5.58)	7.00 (4.69)
Fine manual dexterity	Non-dominant hand (count)	.78 (1.27)	.57 (1.60)	1.18 (1.07)
	Both hands (count)	.73 (.90)	.85 (1.14)	1.02 (1.18)
	Assembly (count)	.93 (2.37)	2.77 (3.80)	3.21 (2.96)
Velocity	Speed (cm/sec)			
	Free Amplitude	4.26 (8.23)	5.92 (10.46)	9.02 (9.53)
	Target	2.29 (2.66)	1.85 (3.67)	2.75 (4.59)
	Circle	1.35 (2.13)	1.44 (2.80)	.87 (2.70)
	Square	0,57 (3.45)	.03 (4.72)	.31 (4.46)
	Peak speed (cm/sec)			
	Free Amplitude	13.09 (18.12)	12.60 (18.62)	23.99 (18.95)
	Target	3.36 (14.57)	−3.52 (14.49)	1.61 (15.29)
	Circle	1.13 (2.27)	1.20 (3.35)	.65 (3.31)
	Square	.25 (6.57)	.56 (5.71)	1.37 (5.59)
Smoothness	Speed metric			
	Free Amplitude	−.01 (.08)	.02 (.10)	−.01 (.10)
	Target	.02 (.13)	.05 (.11)	.02 (.13)
	Circle	.46 (.06)	.06 (.08)	.04 (.07)
	Square	.01 (.09)	.00 (.12)	−.01 (.12)
	Jerk metric (1/sec^2)			
	Free Amplitude	−.66 (3.41)	.21 (3.92)	.61 (5.20)
	Target	−1.31 (10.63)	.98 (12.50)	2.29 (10.38)
	Circle	.28 (2.07)	.79 (2.50)	.11 (2.22)
	Square	.06 (5.06)	−.48 (5.89)	−.29 (6.41)
Accuracy	Straightness			
	Free Amplitude	.02 (.07)	.02 (.07)	.01 (.08)
	Target	−.01 (.01)	.00 (.02)	.00 (.02)
	Shape Accuracy (cm)			
	Circle	−.09 (.31)	−.03 (.45)	−.07 (.43)
	Square	.06 (.13)	−.03 (.20)	.04 (.14)

performance than a double baseline control condition, as all observed actions were possible to perform by the participant. Our results partially support the latter prediction, whereby AO of the Healthy and CP DVD led to improved performance on the fine manual dexterity (Purdue Pegboard). However, contradictorily to our expectations, our results for the gross manual dexterity task (Box and Block) and upper limb kinematics (free amplitude task; speed and peak speed indices) showed improved performance specifically after observing the CP DVD compared to Healthy DVD and control condition. From these results, we suggest that observation of actions performed by a CP child did not seem to be categorized by the brain as an incongruent prime since there was no deterioration in performance. Moreover, these actions did not seem to be associated with actions below one's own motor performance, or as physically impossible to perform actions. Indeed, for priming, we suppose that the CP DVD observation implied stronger internal motor simulation than Healthy DVD observation.

While we expected improved action performance following AO on all upper limb measures, there were only effects on measures of gross and fine manual dexterity, and robotic task velocity kinematics (speed and peak speed indices). No effects were found on measures of smoothness and accuracy. Although unexpected, these results showing specific effects on certain measures may be explained by the conclusions of Edwards et al. (2003). They proposed that AO primes components involved in action planning, such as movement timing (involving peak speed relative to movement phase). Kinematics of smoothness may be less involved in planning, and more like automatic ballistic kinematics that are not planned, but automatically happen because of the action plan. Also, accuracy may be difficult to show effects in healthy participants because of ceiling effects. However, as our results show effects on the Box and Block, and Purdue Pegboard test measures, we expect these results will transfer to other measures of action performance, including ecological measures.

From these data, the question arises of how and why these somehow altered actions facilitate performance in healthy participants? A first potential explanation might emerge from a study by Vogt et al. (2007). They trained participants to perform certain guitar chords, and then compared MNS activation while participants watched the trained chord actions versus new chord actions. Interestingly, the authors reported that actions that were not part of the observer's trained motor repertoire activated some areas of MNS more than the practiced chord actions. Like in the present study, the participants of Vogt et al. (2007) were able to perform both types of observed action (i.e., they were both biomechanically possible). However, more activation for observation of the novel action (shown in Vogt et al., 2007) would predict that novel compared to well-trained actions would cause larger priming effects, as in the present study. A second explanation for these results, which may be related to the previous explanation, could be that the internal motor simulation is driven by attentional focus. It might be that novel actions require or attract more attention, and this increased attention increases internal motor simulation (Hardwick, Mcallister, Holmes, & Edwards, 2012), and in the case of the current research, the action priming effect. Another third possible explanation can be provided from a study by Moriuchi et al. (2014). The authors measured the cortical excitability of the primary motor cortex (M1) in participants watching catching actions either at normal or lower speeds (half- and quarter-speed). Results showed that M1 excitability was higher while watching the actions at low speeds in comparison to normal speed. Based on this finding, the authors suggested that the lower speeds gives the opportunity for the observer to better assimilate the actions, deconstruct them and recognize each of the different elements and intentions. A similar suggestion can be proposed for the results of the present paper, as one of the main distinction between the two DVD's used in AO was a difference in speed during execution specifically in the CP DVD (caused by spasticity and/or paresis of the limb). This lower speed during observed actions might have caused greater motor internal simulation than normal speed actions performed by the healthy child, causing more motor facilitation following the CP DVD than Healthy DVD observation. Clearly, these suggestions need further investigation.

Whatever the explanation of these results, the unexpected finding has important clinical value. Currently, Action Observation Therapy (AOT) is used with patients to improve (or rehabilitate) action performance through action observation-execution priming (Ertelt et al., 2007). Typically, AOT involves observation of a healthy model. These findings here undermine the rationale that the model needs to be healthy. These data show that observation of a patient's actions can also provide improvements in performance. This is supported by Castiello et al. (2009) who reported that Parkinson Disease (PD) patients benefited more following observation of a PD patient's actions than observation of a healthy participant's actions. This needs further investigation for children with CP.

5. Conclusion

Actions performed by a child with unilateral mild motor impairment do not seem to relate to physically impossible actions, incongruent actions or actions outside observer motor repertoire. Observation of a hemiparetic CP child by a healthy child had a positive impact on action execution, especially on gross and fine dexterity as well as velocity kinematics during gross actions. While further investigations are needed, we suggest these kinds of actions tend to relate to a novel and slower way of performing actions that attract attention. These findings could be encouraging for the use of models with motor difficulties during AO in a rehabilitative process.

Conflict of interest

The authors declare no potential conflicts of interest linked to the research, authorship and/or publication of this article.

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