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ORIGINAL REPORT

REACH-TO-GRASP INTERJOINT COORDINATION FOR MOVING OBJECTS IN CHILDREN WITH HEMIPLEGIA

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Objective: **To evaluate interjoint coordination in children with hemiplegia as they reach to grasp objects, in both static and dynamic conditions. An *ad hoc* robotic device was used to study the dynamic condition.**
Design: **Observational study.**
Patients: **Six children with hemiplegia and 6 young adults.**
Methods: **Kinematics of the trunk and arm were studied using an optoelectronic system. In the dynamic condition the target object, a cup, was moved by the robotic device along clockwise and counterclockwise circular trajectories.**
Results: **Two main strategies were used to study the onset and offset of shoulder and elbow movements and their maximum velocities. The hand velocity profile was bell-shaped in the static condition and compatible with ramp movements for the more affected side in the dynamic condition. The time to object contact was higher for the more affected side in the dynamic condition. The temporal coordination index illustrated an immature and less flexible behaviour in children's reaching in all the examined conditions.**
Conclusion: **Study of the hand velocity profiles, the time to object contact and the temporal coordination index highlighted, first, the dependence of upper limb interjoint coordination on task, context, residual resources and individual solution, and secondly, the sensory-motor deficit characteristics of the children's more affected side during dynamic reaching, raising the prospect of a promising training context in children with hemiplegia.**

Key words: reaching, hemiplegia, children, moving target, interjoint coordination.

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INTRODUCTION

During activities of daily living, the upper limbs are involved in numerous and complex tasks in relationship with objects, persons and the environment. The visuo-motor integration of prehension has been analysed and divided into sub-components, such as reaching, grasping, manipulation, arm transport with or without handling objects, and release (1, 2).

Many studies have described the reaching and grasping movements of subjects with or without disabilities, in both adults and children; however, a review of the literature is difficult due to both the different tasks and contexts studied and the different movement analysis methods used (3–13). Some studies have described the influence of the task and context on the reaching of children diagnosed with cerebral palsy and the relevance of this to the rehabilitation of upper limb function (3, 7). To complicate movement analysis further, the subject and/or the object target could be in motion, so that we can observe his or her relative motion. In this context, reaching control must be of the predictive or pro-active type, and it is based on spatial and temporal features, depending on task demands. In the published literature, this complexity inherent to the reaching task in children with hemiplegia has not been fully examined, even though this could provide useful information for rehabilitative training. Thus, a brief analysis of the main reaching characteristics and physiology in dynamic conditions seems useful in order to define the procedure adopted in the present study and the design chosen for the novel *ad hoc* robotic system used for moving the target.

The predictive characteristics of dynamic reaching imply 2 main consequences. First, when an object moves towards us, it moves along its projection cone on the retina, generating a retinal image that grows as the object nears and shrinks as the object moves away (14, 15). When an object moves at constant velocity, the hand-object time-to-contact, or tau margin (15), is used to select the movement start with respect to the task demands. If the object moves with acceleration, it is necessary to integrate visual information with previous experience (13). Secondly, reaching for a stationary or moving object requires non-linear coordination between the elbow and the shoulder (3, 16). Since reaching is mainly a ballistic movement, it has been hypothesized that it depends on feed-forward strategies based on the interaction among body, objects and force fields (17–19) exerted by the internal simulator for the action (20).

Taking into account the above-mentioned reaching characteristics, our training experiences for children with cerebral palsy were in agreement with the effectiveness of reaching training based on moving objects. Thus, we decided to develop an *ad hoc* 3 degree of freedom (DOF) apparatus in order to impose

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Table I. *Children with hemiplegia*

Diagnosis	Side	Age, years	Sex	Fugl-Meyer	Melbourne	MAS biceps
AIS	Left	13	Female	30	55	3
CP	Right	8	Male	43	77	0
CP	Left	12	Male	44	78	1+
TBI	Right	12	Female	42	68	2
CP	Left	17	Male	50	64	1
AIS	Right	12	Male	49	77	1

AIS: arterial ischaemic stroke; CP: cerebral palsy; TBI: traumatic brain injury; MAS: Modified Ashworth Scale.

settable motion laws on objects. It represents an improvement with respect to: a moving target on a flat surface by means of x-y robot (7), a small cube with 4 wheels (i.e. like a small car) rolling down on an inclined ramp (21) or the intercepting with a joystick of a moving point on a screen (8).

The aim of this paper was to study shoulder and elbow inter-joint coordination of reaching during grasping tasks under static and dynamic conditions, using the above-mentioned system, in healthy young subjects and in children diagnosed with hemiplegia. We have used 2 indexes not yet evaluated in children with hemiplegia, i.e. the tau variable (15) and the temporal coordination (TC) index (3), also in a dynamic context.

METHODS

Subjects

A convenience sample of 6 children with mild hemiplegia (2 females and 4 males, mean and standard deviation (SD) age: 12 years (SD 3) and 6 healthy right-handed young adults (1 female and 5 males, mean age 23 years (SD 1), age range 22–24 years) were included in this study. The cause of hemiparesis was cerebral palsy (CP) for 3 subjects, arterial ischaemic stroke (AIS) for 2, and traumatic brain injury (TBI) for 1. We administered the Fugl-Meyer Upper Limb Subtest (22), Melbourne Unilateral Upper Limb (23) and Modified Ashworth Scale for biceps; see Table I for a detailed description of the children with hemiplegia.

The inclusion criteria for all subjects were: absence of seizures; arousal problem; visual deficits; cognitive and gross sensorial deficits; and ability in reaching and gross prehension. The children were enrolled after standard neurological and functional examinations.

We compared 12-year-old children with 23-year-old adults, because in previous studies (24, 25) significant differences in the reach-to-grasp movement were found only between children younger than 6 years and adults, while older children showed adult-like behaviour. In addition, the enrolled children were affected by an event that involved both sides, or at birth or in early infancy they had not developed a clear dominant side, in contrast to the healthy subjects. Thus, we decided to compare the mature reaching strategy of healthy young adults with the inter-limb coordination on more affected and less affected sides of children with hemiplegia.

The protocol was approved by the ethics and medical board of the Children's Hospital "Bambino Gesù", Rome, Italy. The goals and procedure were explained to the healthy subjects and children with hemiplegia and their parents before the experiment started; their informed consent was obtained only after oral and written information was presented.

Equipment

We developed an *ad hoc* 3DOF robotic system, with 3 miniaturized digital servomotors, one for each degree of freedom. Two motors allowed the rotation of a stick (height 25 cm) around the x- and y-axes, moving the object on a spherical surface; the third motor imposed a rotation around the z-axis (Fig. 1A). The motors were fully programmable via software (LabView, National Instruments, Austin, TX, USA) and they allowed different trajectories for the robot handle, with a smooth start and stop. The 3DOF system was fixed to a desk, which was adjustable in height and located in the centre of the Movement Laboratory (14×7 m^2).

The movements of the target and the subject were measured using an optoelectronic system (Vicon MX, Oxford, UK), which recorded the 3D position of reflective markers (diameter 14 mm) with 8 cameras, set at 120 Hz. The working volume ($1 \times 1 \times 1$ m^3) was calibrated in accordance with the manufacturer's recommendations to provide a global accuracy of less than 1 mm. In particular, in all trials, the same skilled therapist placed 10 markers on: the trunk (one on the upper and lower portions of the sternum, on 7th cervical vertebra and 10th thoracic vertebra) and on the reaching arm (one on each of the shoulder, external elbow, internal and external wrist and the 3rd metacarpal of each hand) (Fig. 1B.). Two cameras videotaped each trial in the frontal and lateral plane, to facilitate clinical interpretation during data analysis.

Experimental conditions

We chose a paper cup as the reaching and grasping target, because this is a familiar task with ecological value. The subjects sat comfortably in front of the target, with hips and knees at 90°, feet on the floor and hands on the desk. The cup was fixed to the top of the robot stick with a magnet and located at eye-level, in a median position relative to the body and at 80% of the arm length. By doing so, the object trajectories lay inside the subject's peripersonal reaching space, i.e. the subjects could reach the object without trunk movements.

The target was presented in 3 different conditions: (*i*) stationary, in the median position relative to the body; (*ii*) moving on a circular clockwise trajectory; and (*iii*) moving on a counterclockwise trajectory (trajectory centred with respect to the stationary position, diameter

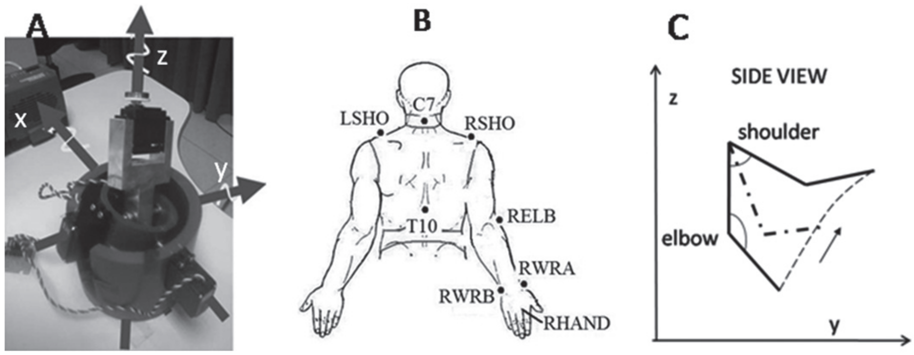

Fig. 1. (A) The 3 degrees of freedom (3DOF) robot. (B) Rear view of marker locations on the trunk and upper limbs. (C) Elbow and shoulder angles in one subject; the arrow indicates the movement direction along the dashed line.

400 mm, speed 2°/sec). Each condition was presented 3 times in succession; trials were performed by the young adults using the dominant side, for a total of 9 trials, and by the children using both the more and the less affected arm, for a total of 18 trials.

The subjects were asked to reach, grasp and place the cup on the desk. No instructions were given about the execution time or the grasp position. In the stationary condition the subjects received a verbal "go" signal, while, when the object was moving, the subjects were instructed to start whenever they wanted, but not until the cup had completed the first turn.

Data analysis

From the raw data we analysed the kinematic variables as follows. First, we computed the distance between the shoulder and the object at the grasp time and the shoulder displacement as the difference between the shoulder position at onset of the movement and grasp time, in percentage, in order to estimate the trunk contribution to the arm transport phase. Secondly, we computed the hand velocity, the position in which the hand reached the object to evaluate the grip phase and the tau margin, i.e. the difference between the time of hand-object contact and the hand movement onset. Thirdly, we used the TC index, defined by Cirstea et al. (3) as the difference between the shoulder and elbow temporal angles, to evaluate the interjoint coordination; the shoulder and elbow temporal angles were evaluated on the sagittal plane and their velocities were obtained by numerical differentiation of the markers' position.

We computed the duration and amplitude of the 4 segments in which the TC index was differentiated by means of the stationary velocity points and movement inversion (i.e. shoulder and elbow maximum velocities and elbow angle inversion). We treated the TC index differently from Cirstea et al. (3), in fact, we observed the relation between elbow and shoulder flexion-extension and not between elbow flexion-extension and shoulder ab-adduction, due to the different context of our study (Fig. 1C). The reaching in our experiments lay principally on the sagittal plane.

For homogeneity, the criteria selected to cluster trials were: subject groups and object dynamics. In particular, 3 groups were considered: healthy young subjects (HY), children's less affected side (LA) and children's more affected side (MA). Moreover, 3 conditions were compared: stationary (S), in which the target object was static; ipsilateral (I), in which the object approached from the same hemispace as the used hand; and contralateral (C), in which the object approached from the opposite hemispace. For example, if the trial was performed using the right hand, clockwise rotations were considered as I and counterclockwise ones as C.

Analysis of variance (ANOVA) was performed to individuate the statistical significance between groups and conditions, and the Tukey multiple comparison test was performed to conduct *post-hoc* reliable comparison ($p < 0.05$).

RESULTS

Shoulder displacement towards the object was maintained at less than 15% for all subjects and conditions, with a tendency to increase on the MA side of the children in dynamic conditions (Fig. 2A). In particular, ANOVA results indicated a statistically significant difference between the MA side and HY group in both the S and C conditions (marked *) and between LA and MA side in the C condition (marked °).

The shoulder-object distance at the time of hand-object contact decreased from S to I and C conditions and the smaller distance was measured on the children's MA side (Fig. 2B). Some significant differences were observed by the ANOVA: in S condition LA and MA sides vs HY (marked *) and MA vs LA (marked °); in C condition between MA and HY (marked *).

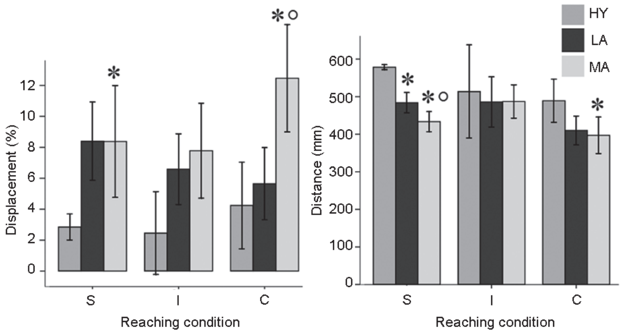

Fig. 2. (A) Shoulder displacement and (B) shoulder-object distance as a function of the reaching condition (S: stationary; I: ipsilateral; C: contralateral) and of the subject groups (HY: healthy young; LA: less affected side; MA: more affected side). The plots enable evaluation of the trunk displacement contribution during reaching. * and ° indicate post-hoc analysis of variance (ANOVA) results ($p < 0.05$) relative to MA/LA side vs HY, and MA vs LA side, respectively.

Fig. 3 shows the different points of hand-object contact along the circular trajectory of the object in the examined conditions, relative to a hand movement to intercept the object rather than to follow it.

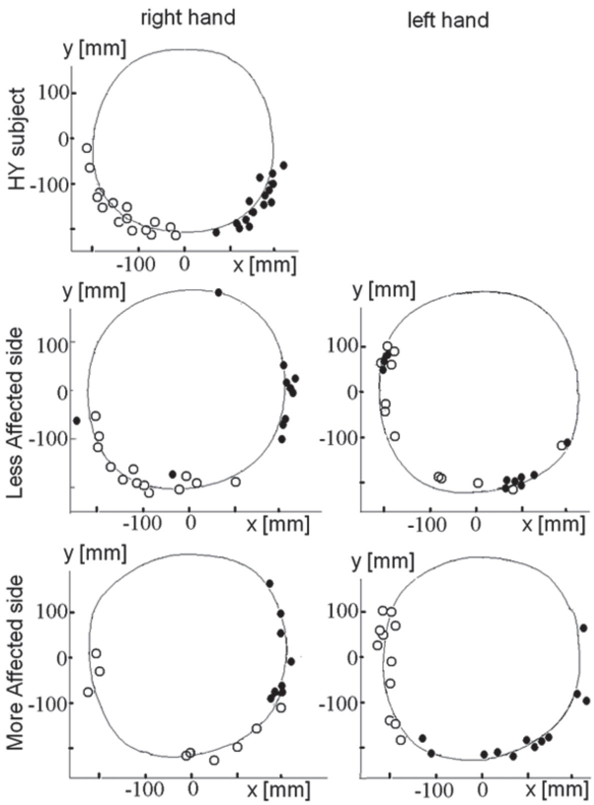

Fig. 3. Different points of hand-object contact on the circular trajectory for the healthy young (HY), less affected (LA) and more affected (MA) sides, both for the right and the left hand. Black circles: grasp point in the ipsilateral (I) condition; white circles: grasp point in the contralateral (C) condition.

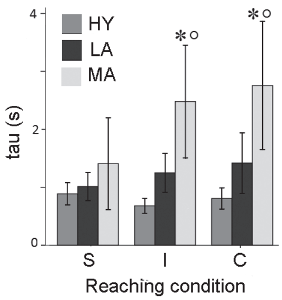

Fig. 4. Tau margin as a function of the reaching condition (S: stationary; I: ipsilateral; C: contralateral) and of the subject groups (HY: healthy young; LA: less affected side ; MA: more affected side). * and ° indicate *post-hoc* analysis of variance (ANOVA) results ($p < 0.05$) relative to MA/LA side vs HY, and MA vs LA side, respectively.

Fig. 4 shows the mean and SD values of the tau margin. The collected values indicated a tendency towards invariance in the reaching strategy among conditions, except among I and C conditions on the children's MA side: in fact, the tau margin showed a higher value than in the HY and LA side groups. A significant difference was observed between the children's MA side and other 2 groups in dynamic conditions, marked * and ° in Fig. 4.

Fig. 5 plots the hand velocity as a function of time for the groups examined (HY, LA and MA) and chosen conditions (S, I and C). It is possible to observe that a bell-shaped profile was present when the reaching was towards a stationary object, while in the dynamic condition it is possible to observe a velocity profile compatible with ramp movement, i.e. lower amplitude and more peaks. This behaviour was more visible in C condition on the MA side.

We used the TC index to define the different reaching strategies on the basis of the onset and offsets of shoulder and elbow movements and the stationary points of the velocities (Figs 6 and 7). In particular, on the sagittal plane, in a similar way as computed by Cirstea et al. (3), we referred to the maximum shoulder velocity (point a, Fig. 6C), the minimum flexion elbow velocity (point b, Fig. 6D) and the minimum elbow angle (point c, Fig. 6B). The reaching strategies were clustered in the order in which these events occurred. As shown in Table II, the strategy frequency differs between HY and children with hemiplegia. In HY subjects 2 strategies were selected: b-a-c (see Fig. 6) in 83% of trials (i.e. the elbow reaches its maximum flexion velocity and changes the direction of movement after the shoulder reaches its maximum velocity) and b-c-a in the remaining 17% of trials. In children, the strategies, organized in the decreasing order, were: b-c-a (i.e. the elbow reaches its maximum flexion velocity and inverts its motion before the shoulder reaches its maximum velocity) see Fig. 7, b-a-c (previously described) and a-b-c (i.e. shoulder and elbow reached the maximum velocity before the elbow inversion of movement).

We analysed and compared the strategy that occurred with higher frequency for both groups, i.e. b-c-a and b-a-c for HY and children, respectively (Table III). The HY b-a-c strategy

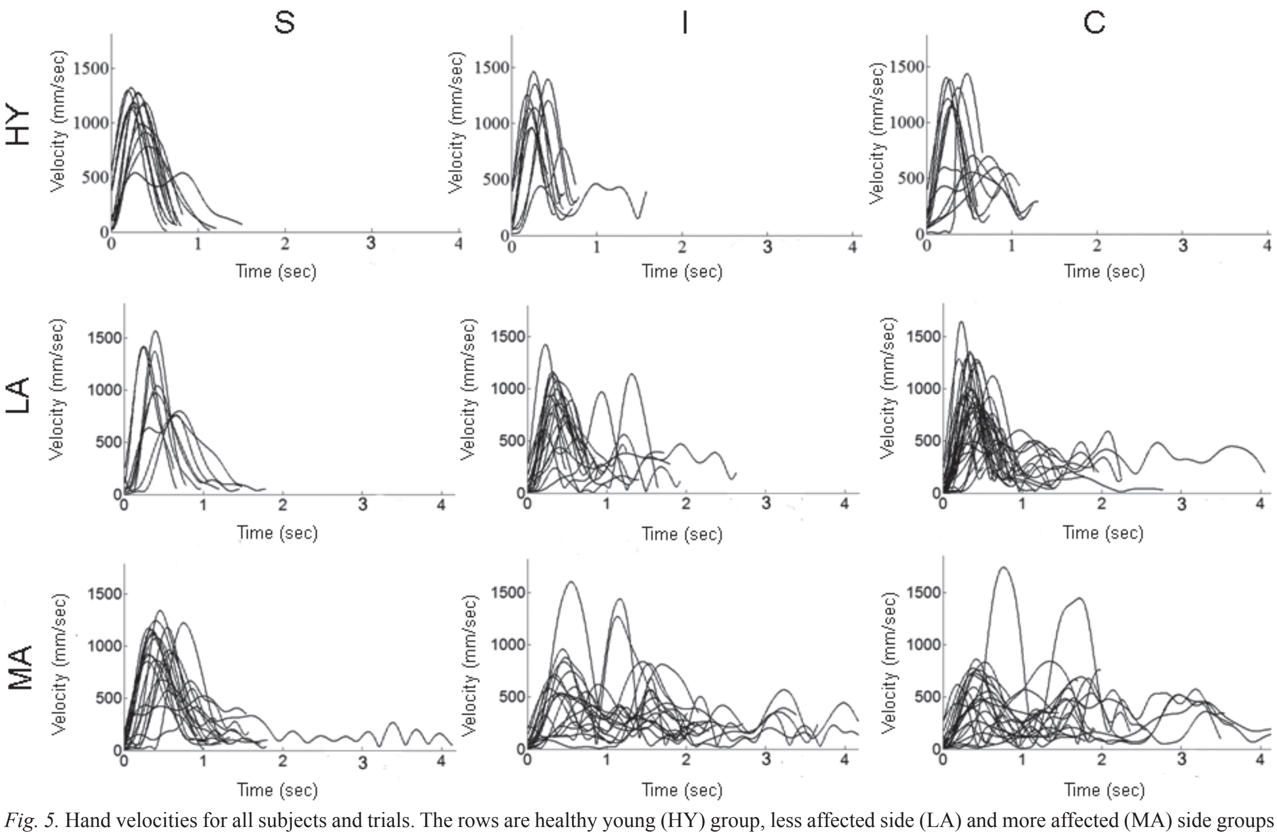

Fig. 5. Hand velocities for all subjects and trials. The rows are healthy young (HY) group, less affected side (LA) and more affected (MA) side groups of children; the columns are target conditions (S: stationary; I: ipsilateral; C: contralateral).

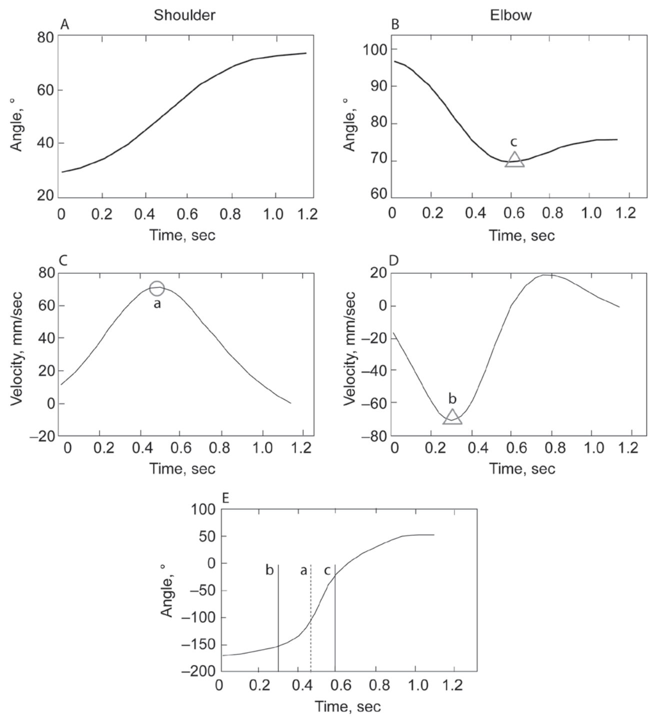

Fig. 6. b-a-c strategy in one healthy young (HY) subject. (A and B) Shoulder and elbow angles; (C and D) their velocities; and (E) the temporal coordination (TC) index. Circle point marked a indicates the maximum of the shoulder velocity (C); triangle points marked b and c indicate the minimum of the elbow (B) and velocity (D).

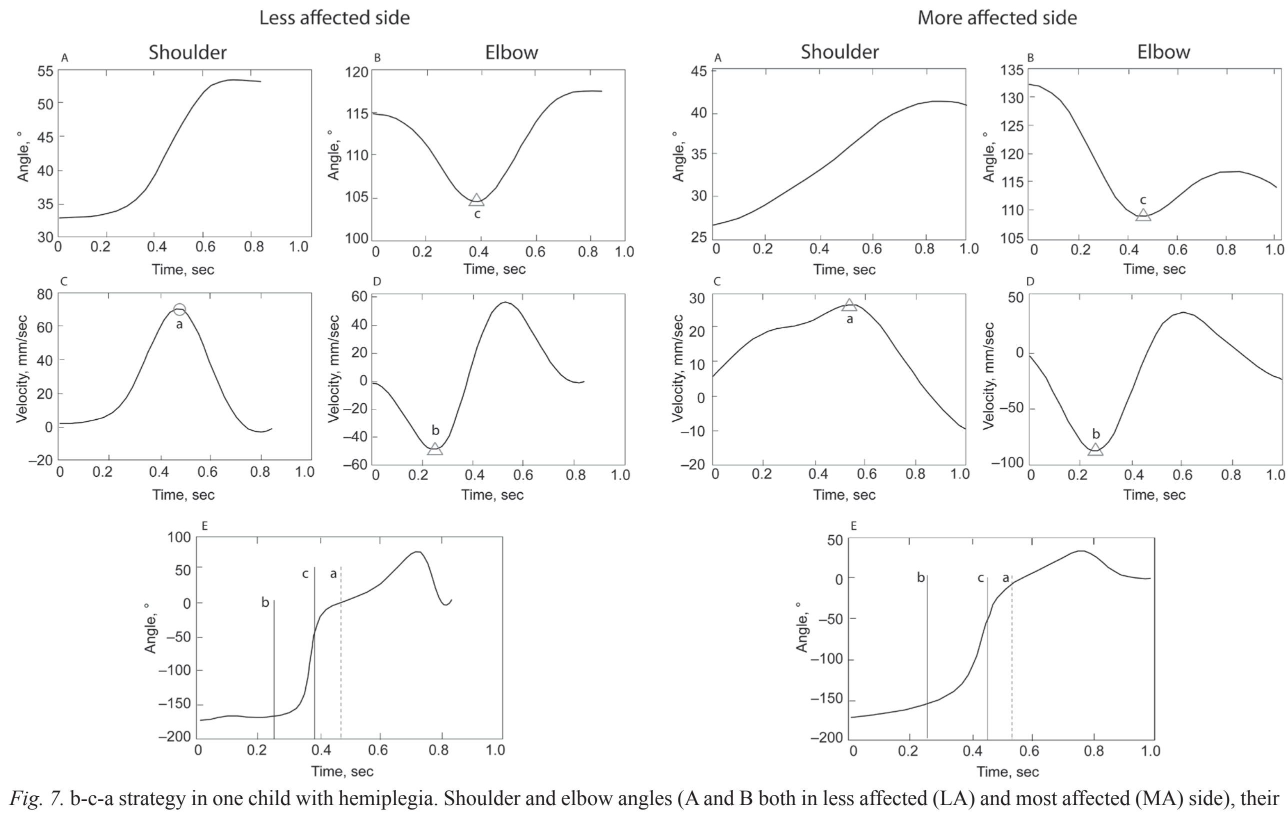

Fig. 7. b-c-a strategy in one child with hemiplegia. Shoulder and elbow angles (A and B both in less affected (LA) and most affected (MA) side), their velocities (C and D both in LA and MA side) and the temporal coordination (TC) index (E in LA and MA side). Circle point marked a indicates the maximum of the shoulder velocity (C both in LA and MA side); triangle points marked b and c indicate the minimum of the elbow (B both in LA and MA side) and velocity (D both in LA and MA side).

Table II. *Share (%) of trials performed with the different strategies. The data are collected for the healthy young (HY) group and both sides (MA and LA) of children with hemiplegia and clustered according to the trial conditions stationary (S), ipsilateral (I) and contralateral (C).*

	HY			CP-LA			CP-MA			AIS-LA			AIS-MA			TBI-LA			TBI-MA		
Strategy (%)	S	I	C	S	I	C	S	I	C	S	I	C	S	I	C	S	I	C	S	I	C
b-c-a	17	17	17	100	86	67	50	78	62.5	100	83	67	100	80	83	100	100	100	33	33	–
b-a-c	83	83	83	–	1	33	40	22	25	–	17	33	–	–	17	–	–	–	67	–	33
a-b-c	–	–	–	–	–	–	10		12.5	–	–	–	–	20	–	–	–	–	–	67	67

AIS: arterial ischaemic stroke; CP: cerebral palsy; TBI: traumatic brain injury.

was characterized by different TC among the tested conditions and the maximum TC amplitude was distributed as follows: in the S condition, it was after the elbow angle inversion (fourth amplitude); in the I condition, it was between the movement onset and the elbow maximum flexion velocity (first amplitude); and in the C condition, it was between the maximum shoulder velocity and the elbow angle inversion (third amplitude). In children, the b-a-c strategy was never used in the S condition for the LA side, and in the dynamic condition the maximum amplitude was the same for the LA side, while on the MA side it was in the fourth and the second amplitude for the I and C conditions, respectively. In children and HY b-c-a strategy, the higher TC index variation was between the maximum elbow flexion velocity and its inversion of movement in all the tested conditions, both for the LA and MA sides (second amplitude).

DISCUSSION

When we compared shoulder displacement, tau margin values, and favourite contact points of reaching, it was possible to observe a different behaviour of the MA side vs both the LA side and HY groups. While in the LA and HY groups it was possible to recognize adaptation to the task demands, in the MA side group adaptive behaviour was less evident. In particular, in the HY subjects and LA side groups, we observed a constant tau margin and 2 separated contact zones along the object trajectory for I and C conditions. Instead, regarding the MA side group, the shoulder displacement and tau margin were higher, especially in the C condition, and the contact points in the 2 dynamic conditions were less separated from each other along the trajectory.

Taking into account that the circular trajectory of the cup lay on the horizontal plane at eye-level, the object moved from left to right and vice-versa, approaching and leaving the subject during each full turn. The healthy young subjects and children selected the optimal hand-object contact zone from visual information and they seem to be facilitated by the constant velocity of the object, i.e. they seemed to be able to extract the motion invariance rules from the cyclical constancy of optical flow changes. All subjects always selected the reaching zone while the object was approaching, i.e. the condition in which it is easier to take advantage from the time-to-contact information. Furthermore, attempting to catch an approaching

Table III. T*emporal coordination (TC) analysis: mean (SD) values of TC amplitudes (amp) and durations (time) in healthy young group (HY) and children, both less (LA) and more affected (MA) side. The data are clustered according to the 3 trial conditions: stationary, ipsilateral and contralateral. The comparisons are carried out between the 2 main strategies, i.e. the b-a-c strategy for HY and the b-c-a strategy for children. The maximum range for each condition is shown in bold*

	Stationary			Ipsilateral			Contralateral		
	HY	LA	MA	HY	LA	MA	HY	LA	MA
b-a-c STRATEGY									
1 amp, degrees	8.7 (48.1)	–	**118.6 (166.8)**	**121.1 (113.7)**†	**64.2 (143.6)**	27.1 (75.1)	67.7 (87.6)	–2.0 (11.3)	41.8 (9.6)
1 time, sec	26.9 (11.6)	–	24.0 (15.6)	36.5 (9.3)	54.1 (16.2)	30.1 (16.7)	42.2 (13.9)†	49.3 (16.3)	26.4 (19.0)
2 amp, degrees	78.4 (39.3)	–	38.9 (49.1)	90.4 (33.9)	57.1 (45.8)	55.9 (61.4)	53.8 (39.8)	62.2 (46.4)	**66.7 (74.8)**
2 time, sec	21.6 (4.6)	–	8.2 (6.5)	23.8 (8.3)	24.3 (7.0)	8.7 (10.0)	20.2 (4.5)	21.1 (7.1)	28.9 (33.0)
3 amp, degrees	34.2 (28.7)	–	117.1 (80.1)	47.2 (63.7)	34.7 (41.3)	69.7 (56.4)	**86.9 (50.8)**†	**93.5 (58.4)**	59.7 (34.6)
3 time, sec	4.8 (3.3)	–	16.3 (10.9)	20.7 (19.8)	5.4 (6.0)	7.5 (7.5)	21.1 (16.5)†	20.9 (6.3)	23.6 (2.0)
4 amp, degrees	**86.9 (22.4)**	–	65.4 (28.2)	32.3 (50.8)†	27.1 (18.6)	**89.5 (73.1)**	35.0 (37.2)†	37.6 (51.5)	37.8 (63.1)
4 time, sec	46.7 (11.9)	–	51.4 (25.9)	18.9 (14.4)†	16.2 (15.3)	53.7 (21.8)	16.4 (19.1)†	8.7 (12.0)	21.1 (23.0)
b-c-a STRATEGY									
1 amp, degrees	–11.0 (2.6)	69.8 (105.1)	33.2 (79)	–8.0 (0.7)	56.6 (87.4)	44.1 (126.8)	–32.2 (33.5)	39.2 (74.1)	27.5 (133.2)
1 time, sec	19.2 (6.7)	27.7 (6.1)	25.4 (7.8)	24.4 (5.3)	28.4 (18.0)	25.1 (19.2)	21.4 (1.1)	22.4 (10.4)*	24.6 (12.5)*
2 amp, degrees	**154.9 (6.6)**	**92.7 (36.3)***	**95.6 (48.6)***	**109.8 (38.6)**	**111.9 (45.3)**	**99.9 (70.6)**	**117.0 (40.0)**	**125.9 (45.3)***	**52.5 (68.5)**
2 time, sec	25.2 (2.2)	16.1 (4.5)	13.7 (4.5)	35.6 (2.7)	22.5 (10.6)	32.5 (20.0)†	26.1 (13.8)	22.2 (10.6)	17.6 (9.8)
3 amp, degrees	1.8 (0.3)	47.5 (50.4)	52.0 (56.9)	16.8 (18.2)	35.1 (39.8)	26.7 (54.8)	21.4 (2.2)	2.7 (77.5)*	42.0 (47.0)
3 time, sec	1.4 (0.1)	11.6 (9.4)	7.0 (5.4)	10.9 (13.2)	15.8 (15.0)	10.7 (3.8)	10.7 (4.3)	27.8 (19.9)	9.1 (6.2)
4 amp, degrees	99.1 (27.1)	39.3 (46.6)	23.9 (63.2)*	33.1 (5.4)	–7.7 (61.6)	41.6 (55.3)	38.7 (45.7)	17.1 (45.4)	6.4 (77.9)
4 time, sec	54.2 (8.9)	44.5 (8.8)	53.9 (9.3)	29.1 (15.7)	33.3 (13.8)	31.7 (13.8)†	41.8 (17.0)	27.6 (13.1)†	48.8 (11.9)*‡†

Post-hoc results are indicated with an apex: *LA/MA vs HY: $p<0.05$; ‡MA vs LA: $p<0.05$; †I/C vs S: $p<0.05$.

object assured a higher grade of success than attempting to catch a leaving object, because over- or under-estimation of the object's eventual position led only to a different acceleration impact. The above-mentioned findings confirm that the reaching start is visually guided by object position in the S condition and by extracting object motion invariance in dynamic conditions (i.e. I and C).

Moreover, the HY and the LA side groups showed a bell-shaped hand velocity profile, i.e. a ballistic movement of the hand towards the reaching target. In contrast, the children's MA side group exhibited a ramp hand velocity profile, i.e. the subjects produced low velocities and continuous adjustments.

Study of the TC parameters provided more detailed information on the shoulder-elbow coordination than the task demands. During the reaching tasks the shoulder executed a flexion movement, driving the arm towards the object, while the elbow first flexed in order to gain clearance from the table and then extended towards the target. The selected strategies and TC index showed great variability among patients and conditions, as reported in Tables II and III.

When the HY group executed their favourite strategy (b-a-c), the shoulder reached the maximum velocity before the elbow inverted its movement, while, when the children executed their favourite strategy (b-c-a), the shoulder reached the maximum velocity after the elbow inverted its movement. Thus, children selected a simpler rule of joint co-variation, completing elbow flexion first and then moving both shoulder and elbow in extension. This difference from the healthy young adults could be attributed to the children's sensory motor deficit, considering the less complex coordination required by the b-c-a strategy, as documented by: (*i*) the differences in maximum amplitude of TC indexes; (*ii*) the greater trunk displacement; and, (*iii*) the greater variability in the hand velocity profile for the MA side.

The healthy young subjects started the reaching at the same time with respect to the action goal for all the examined conditions. In dynamic conditions, they selected 2 different contact zones for the 2 rotation directions, and different shapes in the TC index for the 3 conditions, i.e. they showed an anticipatory motor control taking into account the object motion characteristics. Our results are in agreement with the hypothesis that the reaching start is visually guided, while the arm movement is driven by proprioceptive information and previous experiences.

The children with hemiplegia seem to be able to realize the same anticipatory strategy, but they selected a simpler coordination between elbow and shoulder, moving both joints in acceleration and deceleration with more invariance through the conditions than did the healthy young subjects. Unlike Cirstea et al. (3), who found a lack of coordination between elbow and shoulder from the middle to the end of the reach in adults with hemiplegia, we found a lack of coordination at the beginning of the reach. However, while the task selected by Cirstea et al. (3) required an inversion of shoulder and elbow coordination in late reach, in our task this is required in early reach.

Thus, interjoint coordination seems to be constrained by task (i.e. to catch the target), context (i.e. dynamic conditions or the need to achieve safe table clearance), and system's residual resources (i.e. sensory motor deficit, muscles and soft tissue characteristics and previous experience). From a global examination of the collected data, it is difficult to assess whether the movement dynamic is controlled by an internal model (13), or by an internal simulator (20), or by a local attractor of dynamic balancing structured on previous experiences and tuned by means of the ongoing sensory motor information. This last option implies a continuous control that needs an integrated control variable, neither strictly efferent or afferent, as the λ proposed by Feldman & Levin (26), which comprises sensory and motor aspects, central and peripheral aspects and muscle properties. Consequently, the MA side limitation and variability could be attributed to the sensory-motor deficit during hand transportation towards the object. However, the demonstrated variability of the TC index and the kinetic/kinematic variables (i.e. the speed profile, tau margin and contact points with moving objects) seems useful to detect the adaptive strategy with respect to the tasks' demands and the sensory motor deficit in children with mild hemiplegia.

The perspective of training in dynamic conditions seems to be useful to meliorate the reaching adaptability to the tasks and contexts, as proposed by Schenk et al. (7). The observed differences in the interjoint coordination may agree with the consideration of Latash et al. (27) on the motor equivalence phenomena, which is related to the problem of the degrees of freedom redundancy in driving a multijoint arm towards a target, i.e. synergies link joints in flexible binding that is task dependent and activated by a simple timing signal. If further studies confirm our findings, that children with hemiplegia have difficulty in planning ongoing inversion of the interjoint coordination depending on the children's available resources, task and context, training could be based just on the modulation of task and context in order to improve children's resources for reaching tasks. In conclusion, children with hemiplegia cannot be considered as a homogeneous group and therefore it is important to personalize training, as recommended by Rönnquist & Rösblad (6); furthermore, from the perspective of the present study, dynamic training should be personalized with respect to the individual interjoint coordination limitation observed.

Finally, further studies are required in order to overcome the main limitations of the present study. The number of enrolled subjects should be increased, the control group should be age-matched, patients should be grouped according to age, specific diagnosis and severity, and different tasks and contexts should be tested.

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