ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil

INTERJOINT COORDINATION DURING REACHING IN 6-YEAR-OLD CHILDREN

Rogério B. Balthazar
PPGNC, Univerisade Federal do ABC – Santo André - SP
rogerio_bb@yahoo.com.br

Fábia C. Silva-Amann
PPGNC, Universidade Federal do ABC – Santo André - SP
fabia.fisio@hotmail.com

Ruth F. Santos-Galduroz
CMCC, Universidade Federal do ABC – Santo André – SP
ruth.galduroz@ufabc.edu.br

Léia B. Bagesteiro
CECS, Universidade Federal do ABC – Santo André - SP
leia.bagesteiro@ufabc.edu.br

Abstract. *Reaching has been investigated for many years as a model for understanding upper limb motor control and development. However, few studies have address the question of how 6-year-old children coordinate their limbs and, until now, none of them have included handedness and the process of literacy in their analysis. Therefore, the aim of the present study was to evaluate shoulder and elbow interjoint coordination of 6-year-old children when reaching for ipsilateral and contralateral targets with dominant and non-dominant arms. Thirty children perfomed reaching movements in the horizontal plane toward one of three targets with their dominant and non-dominant arms. Handedness, visual acuity and motor development were assessed by specific tests. Linear and angular kinematic variables were calculated from markers placed on the shoulder, elbow and hand by a video camera system. Results indicated that non-dominant arm movements were faster, curvier and presented greater elbow excursion for the ipsilateral target as compared to the dominant arm, whereas dominant arm movements were faster and presented greater shoulder excursion than non-dominant hand for the contralateral target. We conclude that 6-year-old children do not produce an adult-like reaching profile but they presented different interjoint coordination for right and left arms.*

Keywords: *reaching, handedness, children, coordination*

1 INTRODUCTION

Many researchers have been using the ability to reach as a model to study upper limbs motor behaviour, searching for answers and explanations about upper limb motor control, coordination and handedness. Unfortunately, although it is a topic widely discussed in the scientific community, it is also biased, because despite the extensive number of publications, the majority of the authors are dedicated to the study of motor control in adults (Morasso, 1983; Jeannerod, 1986) and just few are interested in infants and motor development (von Hofsten, 1981, 1991; Mathew and Cook, 1990; Thelen et al, 1996; Konczak and Dichgans, 1997; Kuhtz-Buschbeck et al, 1998; Schneiberg et al, 2002).

Reaching is an important milestone in motor development (Adolph and Joh, 2007; Hofsten, 1991). It's a rudimentary movement that appears early in childhood and serves as the foundation for fundamental manipulative skills development (Gallahue and Ozmund, 2004). These abilities are responsible for creating opportunities for children to better Interact with their environment through object's manipulation and yet they are useful throughout life at upper limb daily activities (Johnson e Blasco, 1997; Adolph e Joh, 2007; Cohen, 2009).

At young age, the first reaches are awkward and uncontrolled. As infants grow up their movements become more accurate and coordinated toward a mature or adult-like profile (Gallahue and Ozmund, 2004). Kinematic analysis of reaching have proven the aforementioned statement and have highlighted important characteristics that differentiate a mature profile from an immature one. Immature reaches present a curved hand trajectory, more than one velocity peaks and large accuracy errors (von Hofsten, 1979, 1991; Mathew and Cook, 1990; Thelen et al, 1996; Konczak and Dichgans, 1997; Kuhtz-Buschbeck et al, 1998), while mature reaches present a straight hand trajectory, a single velocity peak and small accuracy errors (Morasso, 1983; Jeannerod, 1986; Schmidt and Lee, 2011). These variables are invariant features of reaching because all fast mature reaches present the same behavior. However, these features alone do not provide enough information to discriminate mature and immature reaching, which imposes the need for other variable that can add more information for understanding reaching development.

Some authors argue that coordination is an essential variable for better understanding development of reaching. Schneiberg et al (2002) shown that hand path, velocity profile and interjoint coordination can have different speed of development, i.e., infants and adults can present similar hand paths and velocity profiles but different interjoint coordinations, thus, judging reaching maturity based on a few invariant features can lead to wrong conclusions about the developmental level of reaching.

Coordination and motor development have always been closed related, so that the level of skill in performing a movement is related to the ability to coordinate it ahead to environmental changes. (Gallahue and Ozmund, 2004). Previous research have shown that motor control can also be defined in terms of coordination (Bernstein, 1967) and moreover, that interjoint coordination of dominant and non-dominant hands are different due to a phenomenon called handedness.

Handedness or manual preference is the use of the dominant hand over non-dominant hand (Annet, 1978). It's a complex phenomenon composed by concepts of direction, degree and consistency. Direction of handedness is the definition of right or left handers and it is usually established early in life, around the age of 3 years old, whereas degree of handedness, the extent to which the two hands are each used for a range of tasks, and handedness consistency, the reliability with which each task is carried out by the same hand, are often consolidated later in life (McManus et al, 1988; Thelen and Corbetta, 1999). It's common to notice infants right-handers, who have just entered in elementary school, aged 5 and 6 years-old, using sometimes the right hand and sometimes the left hand when executing usual and unusual tasks. It's also possible to notice that some infants use both hands equally in tasks that usually require different functions for each hand, like cutting a paper or pointing a pencil. These observations have raised the questions of how can handedness be described in terms of motor control, not performance measures and how manual selection and handedness influences movement strategies and coordination.

Recent studies in unimanual reaching are providing some possible explanations for these questions. Ronnqvist and Domello (2006), have conducted a study with children aged from 4 months to 3 years old and found out that hands paths were less curved, more accurate and presented fewer velocity peaks for right hand reaches in contrast with the ones made with the left hand. Similar kinematic patterns were also found in adults (Bagesteiro and Sainburg, 2000; Sainburg and Kalakanis, 2000; Sainburg, 2002), suggesting that children adopt different strategies for each hand when reaching to a target. Nevertheless, until now few studies have investigated reaching at children over 3 years old (Kuhtz-Buschbeck et al, 1998 a/b; Schneiberg et al, 2002) and yet, those who have included older children, have not examined coordination strategies or handedness. Thus, the question that guides the present study is how 6-year-old children coordinate their limbs in unimanual reaching, considering the facts that elementary school entrance and the process of literacy impose new challenges and new opportunities for infants to explore handedness (McManus et al, 1998; Rodrigues et al, 2010). Therefore, the aim of this study was to evaluate shoulder and elbow interjoint coordination in children as they reach to one of three targets, as well as, to investigate how the dominant and non-dominant limb differences appear at the young age, i.e. 6 year-old children, during their developmental stage.

2 METHODS

2.1 Subjects

Thirty healthy children (15 boys and 15 girls) from elementary public schools of Ribeirão Pires – SP, Brazil, were tested. Only right-handers were selected. Handedness was determined using a 10-task battery test. All children were asked to perform ten different tasks (e.g. drawing, throwing a ball, cutting with scissors, using a pencil sharpener, opening a box, etc.) to confirm the information given by the parents regarding the children manual preference. These tests were performed during the phase of familiarization when the children first came into the testing room. The purpose of these tests was to screen for clearly right-handed children and discard mixed handed children from the experiment. The children who participated in the study performed at least nine out of ten items with their right hand. Visual acuity was assessed by Snellen E-chart and a minimum score of 0.7 for both eyes was required. Children's motor development was evaluated using the first subset of (Age Band 1) Movement-ABC (Movement Assessment Battery for Children). Parents gave informed consent for their child to participate in the experiment. Table 1 summarizes the characteristics the participants.

Table 1. Summary of participants' information

Variables	Mean	Standard Deviation	Median
Age (months)	77.27	2.92	77.00
Mass (kg)	25.95	6.88	24.10
Height (m)	1.20	0.06	1.18
Dominance	0.96	0.05	1.00
MABC	77.87	12.97	81.00

Visual Acuity (RE)	1.27	0.33	1.32
Visual Acuity (LE)	1.29	0.30	1.33

2.2 Experimental setup

Figure 1 illustrates the experimental setup. The child seated in a chair with both arms supported over an ergonomic table. The wrist was immobilized using an adjustable orthesis. The table was adjusted according to the height of the child (arms positioned at 90 degrees to the trunk in the sagital plane) and the chair was positioned in front of the starting point drawn on the table. Passive markers were attached to three anatomical points (acromial process, lateral epicondilum of the humerus and head of the third metacarpus) in order to create the biomechanical model of the arm consisting of two segments (lower arm and upper arm) and 2 joints (elbow and shoulder). Movements were recorded using a camcorder (JVC GR-DVL9800) at 120 Hz data acquisition rate. Recordings from the camera were digitalized using APAS (Ariel Performance Analysis System) software. Four specific markers on the table were used for calibration of the movement area. Custom computer algorithms for data analysis (kinematic variables calculation) were written in MATLAB.

2.3 Experimental task

Four locations were drawn on the table's surface (see Figure 1 - top view). Starting point and three targets requiring 19-cm-long planar horizontal movements. Targets were numbered 1, 2 and 3, oriented 45, 90 and 135 degrees relative to the horizontal axis, respectively. Infants were instructed to move the arm from the start position to one of the three targets (randomly presented) using a single, uncorrected, rapid motion in response to a verbal command ("go" signal). Children were oriented not to move either their trunk or their head while reaching. Each participant was given a practice session (30 trials) to familiarize themselves with the task, followed by another 60-trials experimental session (20 trials/target).

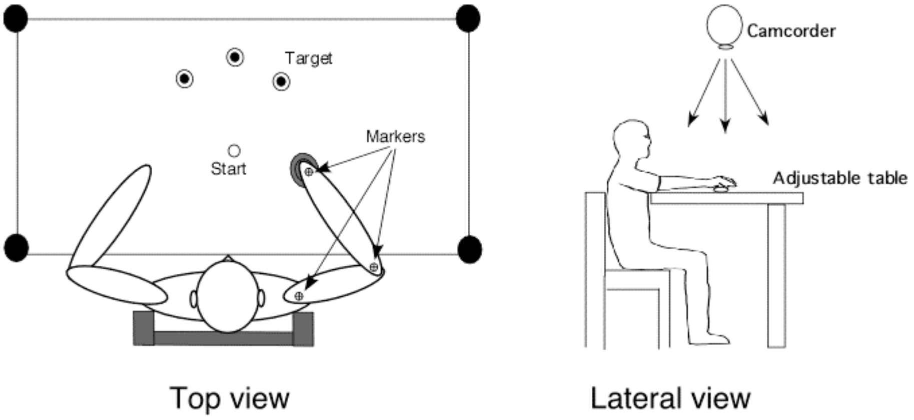


Figure 1. Experimental apparatus (top and lateral view).

2.4 Kinematic data

Two-dimensional position of the hand, elbow and shoulder were calculated from anatomical markers. Elbow and shoulder angles were calculated from this data. Because of the oscillations at the start point, the onset of movement was defined by the last minimum (below 5% peak tangential velocity) prior to hand's tangential peak velocity profile. Movement conclusion was defined as the first minimum (below 5% peak tangential hand velocity) following the peak in tangential hand velocity.

Four linear measures were calculated from hand path: linear distance, cumulative distance, movement duration and peak hand velocity. Linear distance was calculated as the difference between the final and the initial position of the hand. Cumulative distance was calculated by the sum of all hand's displacement for every two points in the trajectory. Movement duration was calculated as the elapsed time from movement start to movement end. Peak hand velocity was the maximum value obtained from the hand position differentiation curve.

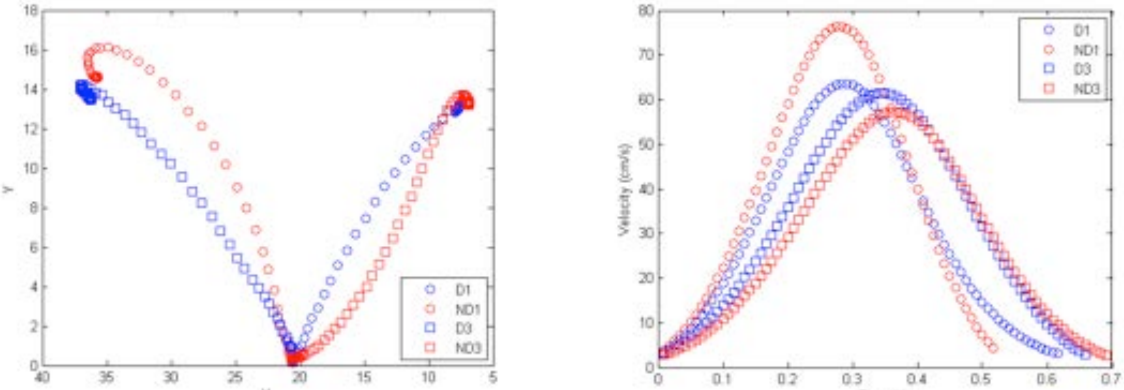
Four angular measures were calculated from elbow and shoulder position: elbow and shoulder excursion, elbow and shoulder peak of angular velocity. Elbow and shoulder excursion were calculated by the difference between final angular position and initial angular position from the elbow and shoulder displacement profiles. Peak elbow and shoulder angular velocity were computed as the maximum value obtained from elbow and shoulder position differentiation curves.

2.5 Statistical analysis

R Statistics software was used to all statistical analysis. Descriptive statistics (mean, median and standard deviation) were calculated for all variables. Shapiro-Wilks test was applied to verify the condition of normal distribution. T test and Wilcoxon signed-rank test were applied depending on the normality of the data to compare performance of hands (Dominant (right) and Non-dominant (left)) and targets (1 and 3). Significance level of 5% was used for all analysis.

3 RESULTS

Comparisons were made between reaching with dominant (D) and non-dominant (ND) arms for targets 1 and 3. Target 1 (ipsilateral target) required almost exclusively elbow excursion, while target 3 (contralateral target) required both shoulder and elbow excursions. Target 2 was included to increase randomness to the task although it was excluded from this analysis. Figure 2 shows typical graphical representations of hand trajectory and tangential velocity profile from a representative child participant on the study. As expected, movements made with the dominant arm were different (greater curvature for ND) from those made with the non-dominant arm. Also, the analysis of hand path trajectories showed that movements with the ND arm were directed laterally at the onset of movement, while movements with the D arm were initially directed toward the targets.



(a) (b)

Figure 2. Representative trials from the dominant (D) and non-dominant (ND) arm movements to targets 1 and 3: (a) Individual hand trajectories; (b) Individual tangential velocity profile.

There was significant differences between arms for the distance parameters (cumulative (CD) and linear (LD)) when moving toward target 1, but not for target 3. Movements made with the non-dominant arm (mean ± SE: 23.21±0.31 cm (CD); 19.73±0.20 cm (LD)) were significantly longer than the ones made with the dominant arm (mean ± SE: 21.89±0.23 cm (CD); 19.16±0.21 cm (LD)) ($P<0.001$ (CD); $P=0.029$ (LD)).

Peak tangential hand velocity was significantly higher for the non-dominat arm (mean ± SE: 81.73±2.03 cm/s) as compared to dominat arm (mean ± SE: 76.33±1.75 cm/s) when moving towards target 1 ($P=0.008$). However, movements toward target 3 showed that the dominant arm (mean ± SE: 68.84±1.77 cm/s) moved faster as compared to the non-dominant (mean ± SE: 66.16±1.64 cm/s) ($P=0.026$). Likewise, peak tangential acceleration followed the same pattern presented by the tangential velocity profile, i.e. movements made to target 1 showed significant greater values for the non-dominat arm (mean ± SE: 602.46±34.38 cm/s^2) as compared to the dominant (mean ± SE: 451.94±20.20 cm/s^2) ($P=0.002$), whereas movements to target 3 had higher peak acceleration for the dominant arm (mean ± SE: 350.96±16.44 cm/s^2) in contrast with the the non-dominat arm (mean ± SE: 329.48±16.01 cm/s^2) ($P=0.036$). The reliability of these differences, across all subjects, is shown in Figure 3, which compares measures of tangential velocity maxima (Fig. 3A), and tangential acceleration maxima (Fig. 3B) for dominant and nondominant arm movements towards targets 1 and 3.

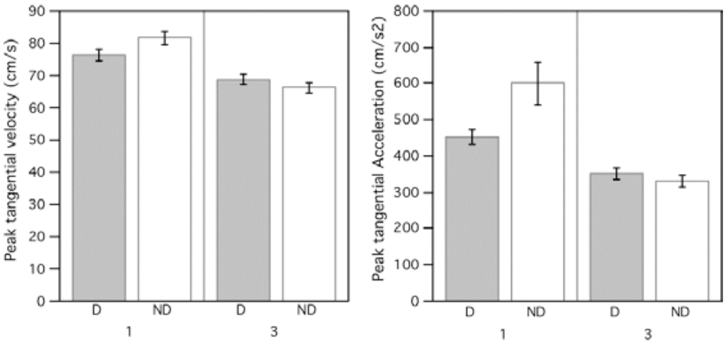


Figure 3. Linear kinematics comparisons for dominant and nondominant arm movements to target 1 and 3 across subjects. (a) Peak tangential velocity. (b) Peak tangential acceleration.

Differences between dominant and non-dominant hand path trajectories reflected distinctive joint excursions and coordination patterns. Figure 4 compares representative elbow (red) and shoulder (blue) displacements from trials performed with the dominant (left column) and non-dominant (right column) arms moving towards target 1 (top row) and 3 (bottom row). Angular kinematics analysis revealed that movements made with the non-dominnat arm to the ipsilateral target required greater elbow excursion than those performed with the dominant arm. However, when these movements were made with the dominant arm to the contralateral target, elbow excursions were similar for both arms, but shoulder excursions were greater for the dominant arm.

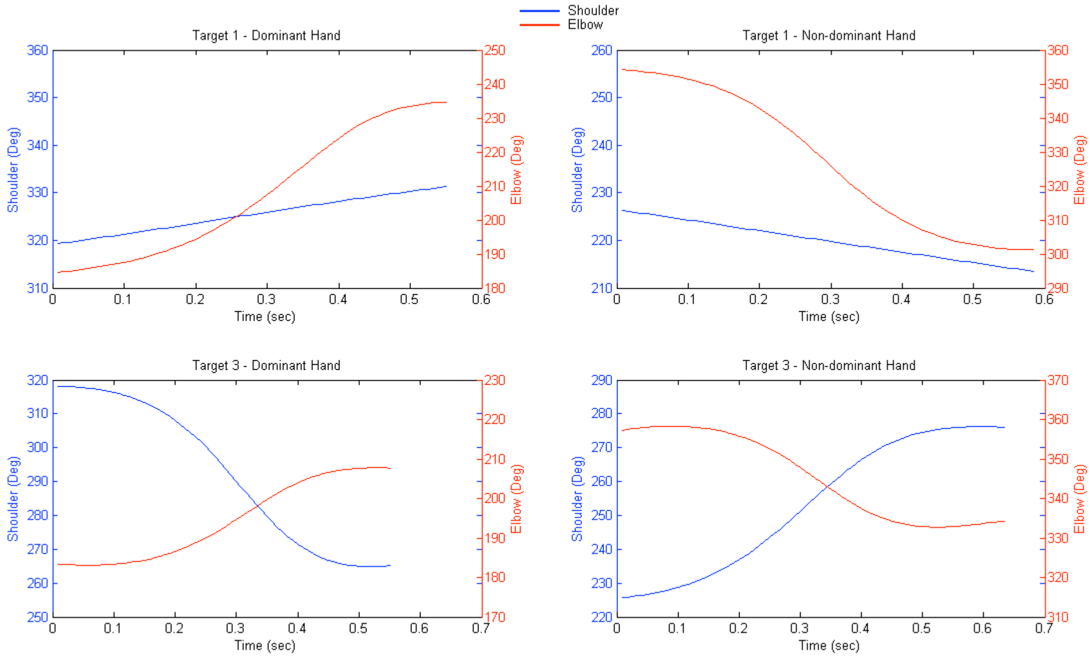


Figure 4. Four representative profiles from the dominant (left column) and non-dominant (right column) joints (elbow=red, shoulder=blue) excursions for movements to targets 1 (top row) and 3 (bottom row).

Joint angular velocities followed equivalent outcome, i.e. peak of angular velocity was higher for the elbow joint for movements to target 1, and higher for the shoulder joint for movements to target 3. Elbow peak angular velocity was significantly higher for the non-dominat arm (mean ± SE: 208.22±5.44 º/s) as compared to dominat arm (mean ± SE: 192.86±4.55 º/s) when moving towards target 1 (P=0.021). This was also true for movements toward target 3, elbow peak angular velocity for the non-dominat arm (mean ± SE: 71.34±4.39 º/s) was significantly higher than the dominat arm (mean ± SE: 64.65±4.00 º/s) (P<0.001).

Figure 5 demonstrates that these findings were consistent across all subjects and trials. Elbow excursions were significantly larger for the non-dominant arm (mean ± SE: 52.35±0.80 º) as compared to dominat arm (mean ± SE: 50.40±0.71 º) when moving towards target 1 (P=0.022). Whereas shoulder excursions were significantly smaller for the non-dominant arm (mean ± SE: 49.12±1.02 º) as compared to dominat arm (mean ± SE: 51.65±1.24 º) when moving towards target 3 (P=0.035).

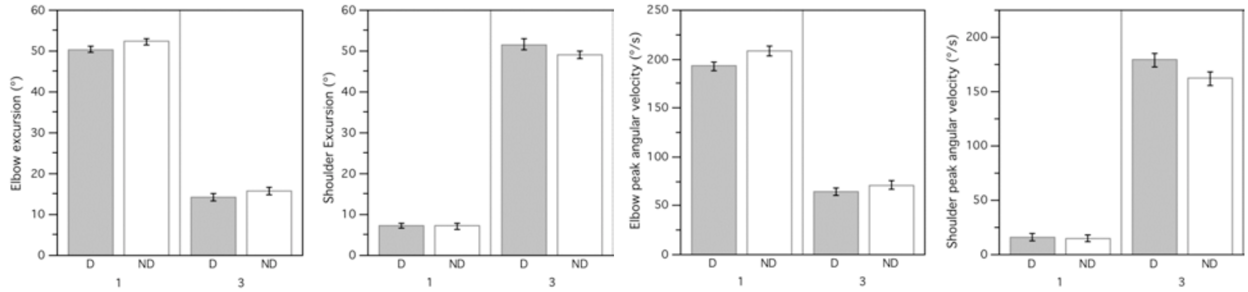


Figure 5. Angular kinematics comparisons for dominant and nondominant arm movements to target 1 and 3 across subjects. (a) Elbow excursion. (b) Shoulder excursion. (c) Elbow peak angular velocity. (d) Shoulder peak angular velocity.

4 DISCUSSION

The present study aimed to evaluate shoulder and elbow interjoint coordination in 6 year old children when reaching to visually-guided targets, in order to investigate handedness and motor coordination at their developmental stage. Our results showed different responses for dominant and non-dominant arms toward ipsilateral and contralateral targets. Non-dominant arm displayed the highest values for trajectory measures, joint excursions, velocity and acceleration profiles toward target 1, whereas dominant arm displayed the similar results to target 3, except for the trajectory measures, that were not significantly different. These results provided insightful information that helped us identify possible patterns of movement organization underlying reaching of 6-year-old children.

Non-dominant arm movements were faster for target 1 and trajectories were larger and curvier as compared to the contralateral arm, resulting in excessive motion at the elbow. On the other hand, dominant arm movements were faster for target 3 as compared to non-dominant arm and despite that trajectories there was no difference between arms, and shoulder joint produced excessive excursion. There was no significant difference between arms on movement duraton. These outcomes together raised two possible explanations, maybe 6-year-old children prioritized velocity over accuracy for movements with the non-dominant arm or they are unable to scale velocity with respect to target location, something that adults are capable of doing (Gordon et al, 1994). Moreover, we could suggest that the dominant arm is able to combine accuracy and velocity on its movements but at the expense of angular kinematics; in this case shoulder excursion. Although these explanations seem reasonable, there still some additional information needed to complement these observations (kinematic variables), such as final position error and duration of acceleration and deceleration phases of movement. Thus, the main differences between arm movements were presented at the handpath trajectories, in the accuracy of movement and consequently in interjoint coordination. It seems that development of reaching is compartmentalized, where some features develop before others. An evidence of this statement is based on a theory of how visual-guided movement are controled. Some authors argue that two levels of organization are involved in controling reaching behavior, one responsible for planning movement trajectory and other responsible for specifying interjoint coordination (Flash and Hogan, 1985; Hogan and Flash, 1987; Levin, 1996). Nevertheless, 6-year-old children already developed some mature features of reaching. Velocity profiles and hand trajectories of these children were similiar to adults, but angular excursions and interjoint coordination were not (Sainburg, 2000; Bagesteiro and Sainburg, 2002), suggesting that some features are yet not fully developed at this age. Because of that, these children adopt different coordination strategies to fullfill the same task that adults do. Previous studies suggest that the development of a mature-like stereotype trajectory of the hand is accompained by concomitant changes in angular kinematics (Thelen 1993; Konczak et al, 1995, Konczak and Dichgans 1997; Berthier et al, 1999, 2005; Schneiberg et al, 2002). According to Schneiberg (2002), not all aspects of reaching develop at the same time, instead, each aspect has its own developing time rate, so that interjoint coordination do not necessarily develops with hand path or trajetory smoothness. Thus, such differences found in interjoint coordination can reflect the stage of motor development where these children are in. Moreover, handedness is not fully established at the age of 6, and its contents have also different developmental time scales. The degree and the consistency of handedness are still being developed at this age and could affect the outcome of kinematic measures. The first was controlled by handedness test applied in the study, only children with 90% score were included, but the latter was not controlled, so this consistency of handedness could have affected measures toward the hand that is most used by children at similar tasks (McManus, 1988; Thelen and Corbetta, 1999).

In addition, these children are elementary students, who have only been in the school for a year or have just entered the school, so they are learning new ways of interacting with the environment and are participating in physical education classes, where their psychomotor abilities can be reinforced through professional advice. And besides that, they are learning one of the most important abilities for children in scholastic-age, they are learning to read and write. These abilities are thought to contribute for the holistic development of the children, including of motor coordination (McManus, 1988; Rodrigues et al, 2010). Therefore, differences in interjoint coordination, found in this study, reflect the stage of 6-year-old motor development but its origin derives from several factors, some of them are maturational and others are environmental.

5 CONCLUSION

Our findings provide evidence that 6-year-old children do not produce an adult-like reaching profile because they are still in the process of motor development. They seem to adopt different coordination strategies for each arm, which is not yet similar to the movements performed by adult subjects. Further research is necessary to examine whether the nondominant and dominant arms interjoint coordination differences are restricted to fully developed individuals, or whether they start to occur at specific youth stages.

6 ACKNOWLEDGEMENTS

We thank Patrícia Hong, Marcos V. H. G. dos Santos and Annie B. Steudner for the assistance in evaluating the children and financial support from FAPESP and UFABC.

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8 RESPONSIBILITY NOTICE

Rogério Batista Balthazar and Léia Bernardi Bagesteiro are the only responsible for the printed material included in this paper.