JOINTS COORDINATION DURING ARM REACHING

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Abstract. *Reaching movements to spatial targets require motor patterns at the shoulder to be coordinated carefully with those at the elbow to smoothly move the hand through space. On the one hand, studies performed predominantly on young subjects have provided a more thorough understanding of the neural mechanisms underlying motor control. In contrast, studies on reaching in older adults have suggested that the precise control mechanisms responsible for age-related changes remain controversial. Additionally, very little has been investigated on interlimb coordination differences in typically developing children. Prior research has demonstrated significant interlimb differences in the control of unilateral reaching movements, implying that movement trajectory and final position are specified and controlled differentially by the dominant and nondominant limb/hemisphere systems. The purpose of this study was to examine whether interjoint coordination remains lateralized for the different aging groups. We quantified and analyzed the kinematics and kinetics of reaching movements focusing on specific parameters to get insight into arm coordination. Intersegmental dynamics was used to calculate shoulder and elbow torques assuming that the upper extremity was two interconnected rigid links (upper arm and forearm) with frictionless joints at the shoulder and elbow. We used a virtual reality environment and examined multidirectional planar reaching in three different directions (randomly presented) to test three different subject age groups were: children (9-12 years), young (18-40 years), and elderly (65-80 years). Six measures were computed to investigate group interlimb differences: shoulder and elbow muscle torques (peak and impulse), hand-path curvature, cummulative movement distance, movement duration, peak hand velocity, and shoulder-elbow excursion ratio. Our data analysis showed differences between movement performance for all analised variables, at all ages. More specifically the results indicate that the intersegmental dynamics for the interlimb (left/right) comparisons were similar for the elderly and children groups as compared to the young. They also showed a tendency in joint torques and trajectory deviations for the right arm advantage in movement trajectory performance. These results suggest that the evident motor asymmetry for coordinating reaching movements shown in young adults may not be apparent at developing stages and might decreases with aging.*

Keywords: *arm reaching, kinetics, motor coordination, aging.*

1. INTRODUCTION

Reaching movements are essential and important arm motor components in effectively completing daily living tasks. Normal development and aging might affect motor performance changing according to different activities. Aging has often been associated with performance deficits during goal-directed movements, suggesting aging-related increases in the magnitude of neuromotor noise leading to a reduction of the pre-programmed part of the voluntary movement (Poston *et al.* 2009; Romero *et al.* 2003; Pratt *et al.* 1994; Seidler *et al.* 2002). Old age broadly impairs learning memory tasks, and object manipulation especially dexterous manipulation. Aging-related decline in hand function exists and is inevitable, this could be explained by compensatory issues related to sensorimotor control of the aging arm, including loss of independent control of right and left hands. This could also be related to aging changes in coordination that might result from deficits in neural control factors. However, it is unclear whether the expression of motor lateralization changes with the aging process. It is plausible that a significant source of coordination deficits in the elderly arise from reductions in hemispheric asymmetry, and that this decreased lateralization is compensatory. On the other hand the development of reaching has been investigated in children of different ages, showing that hand trajectories become smoother and less variable with age and interjoint coordination becomes more consistent (Schneiberg *et al.* 2002). In addition, the capacity to make use of visual feedback information advances with age too, as well as accuracy and time of response (Ferrel-Chapus *et al.* 2002; Hay *et al.* 1984; Lambert and Bard, 2005; Lhuisset and Proteau, 2002; Rival *et al.* 2003). Altogether, from these studies, it appears that the main features of the responses taken into account attain an adult-like level between 9 and 11 years. Based on previous researches (Bagesteiro and Sainburg, 2002, 2003; Przybyla *et al.* 2011; Sainburg, 2002; Sainburg and Kalakanis, 2000), we hypothesize a change in motor asymmetry associated with changes in interjoint coordination resulting from similar performance on both arms in older adults as well as children. In order to examine whether motor asymmetry changes over the lifespan, focusing on three specific age groups: children, young adults, and older adults. In particular we investigate if such modifications are associated with the emergence of variations in motor performance or development. We tested three groups, aged 9-12, 19-24, and 65-79 years. Movements were made to three different visual targets, with different joint excursion requirements, and performed with either the right arm or the left arm. We were, thus, able to examine how subjects from different age groups coordinated multidirectional reaching movements in the horizontal plane, and investigate if the dominant arm advantage in trajectory control persists and/or changes, as individuals grow older. In order to analyze movement coordination we selected specific features of the movements such as: movement distance (cumulative), movement duration, peak tangential hand velocity, hand path curvature, and joint angular displacement (elbow and shoulder) and muscle torques. Our findings could have substantial implications for understanding age-related changes in the coordination and accuracy of arm movements and the development of information processing capability to program reaching trajectories.

2. METHODOLOGY

2.1. Participants

Three groups of healthy individuals (children, young and elder) participated in the experiment performing fast point-to-point arm reaching movements. All adults participants were right-handed, as indicated by laterality scores on a 34-item modified version of the Edinburgh Inventory (Oldfield, 1971). 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 laboratory. 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. All participants were naive to the purpose of the experiment and had normal visual acuity (uncorrected or corrected with lenses). No subject reported any history of neurological or musculoskeletal disease. Table 1 summarizes the characteristics of each subject group. A brief explanation of the experiment was given to all volunteers and a signed consent form was acquired in accordance with human subject policies. Parents gave informed consent for their child to participate in the experiment. The presence of the mother or another relative was allowed during the experiment to prevent anxiety in the children. The study was conducted in accordance with the Declaration of Helsinki and was approved by the ethical committee of the local university.

Table 1. Summary of participants' information.

Variable (mean ± SD)	Children	Young	Elder
N	9	10	10
Age (years)	9 ± 1	22 ± 3	71 ± 4
Mass (kg)	34.0 ± 8.1	70.8 ± 14.2	70.0 ± 14.5
Height (m)	1.35 ± 0.09	1.67 ± 0.07	1.65 ± 0.10

2.2. Experimental setup

Figure 1 illustrates the experiment setup. Subjects sat facing a table with both arms supported over the horizontal surface, positioned just below shoulder height (adjusted to subjects' comfort), by separated air-jets system, which reduces the effects of gravity and friction. A cursor (0.01m in diameter) representing finger position, a start circle (0.03m in diameter), and a target (0.05m in diameter) were projected on a horizontal back-projection screen positioned above the arm. A mirror, positioned parallel and below this screen, reflected the visual display, so as to give the illusion that the display was in the same horizontal plane as the fingertip. Calibration of the display assured that this projection was veridical. All joints distal to the elbow were immobilized using an adjustable brace. Position and orientation of each arm segment was sampled using a Flock of birds ® (Ascension-Technology) magnetic 6-DOF movement recording system. Four 6-DOF sensors were used to monitor arm movements. Each arm had a single sensor attached to the upper-arm segment via an adjustable plastic cuff, while another sensor was fixed to the air sled where the forearm was fitted. The sensors were positioned approximately at the center of the limb.

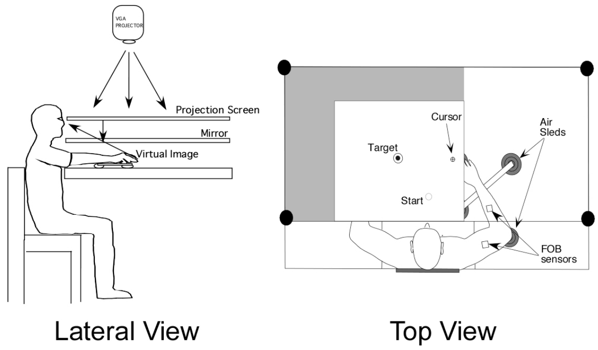

Figure 1. Experimental apparatus (lateral and top view).

Digital data was collected at 103Hz using a Macintosh computer, which controlled the sensors through separated serial ports, and stored on disk for further analysis. Custom computer algorithms for experiment control and data analysis were written in REAL BASIC™ (REAL Software, Inc.) and IgorPro™ (Wavemetrics, Inc.).

2.3. Experimental task

Throughout the experiment, the index finger position was displayed in real time as a screen cursor. We presented three targets that required 0.12-0.15m-long movements, "target 0 (T0)" oriented 45° relative to the horizontal axis, "target 1 (T1)" oriented at 90° and "target 2 (T2)" oriented at 135°. Each target was designed to gradually increase the amount of shoulder angular movement. Prior to movement, one of the three targets was randomly displayed. Participants were to hold the cursor within the starting circle for 0.5 seconds to initiate each trial. They were instructed to move the finger to the target using a single, uncorrected, rapid motion in response to an audiovisual "go" signal. Visual feedback of the cursor was provided between trials, although no visual feedback of the cursor was given during the movement. Points were awarded for final position accuracy at the end of each trial to maintain motivation. Final position errors of less than 0.1m were awarded 10 points, while errors between 0.1m and 0.2m were awarded 3 points, and errors between 0.2m and 0.3m were awarded 1 point. Each subject was given a practice session (30 trials) to familiarize themselves with the task, followed by another 90-trials experimental session. Resting periods were provided between sessions. During the experimental session, the room was dimly lit in order to improve target visualization.

2.4. Kinematic data analysis

The 3-D positions of the index finger, elbow and shoulder points were calculated from sensor position and orientation data. Then joint angle was calculated from these data. All kinematic data was low pass filtered at 8 Hz (3rd order, no-lag, dual pass Butterworth), and differentiated to yield velocity and acceleration values. Each trial usually started with the hand at zero velocity, but small oscillations of the hand sometimes occurred within the start circle. In this case, the onset of movement was defined by the last minimum (below 8% maximum tangential velocity) prior to the maximum in the index finger's tangential velocity profile. Movement termination was defined as the first minimum (below 8% maximum tangential hand velocity) following the peak in tangential hand velocity. Hand paths were calculated from joint angle data by using the measured length of the upper arm and the distance from the elbow to the index finger tip. The angular data was transformed to a Cartesian coordinate system with origin at the shoulder. Visual inspection was performed on every single trial to ensure that movement onset, peak acceleration, peak velocity, and movement termination were correctly determined. The following kinematic measures were calculated for each trial: hand-path deviation from linearity (curvature), peak tangential hand velocity, movement duration, shoulder and elbow excursion (ratio of shoulder excursion to elbow excursion, measured at peak tangential hand velocity), and cumulative movement distance. Deviation from linearity was assessed as the minor axis divided by the major axis of the hand path. The major axis was defined as the largest distance between any two points in the path, while the minor axis was defined as the largest distance, perpendicular to the major axis, between any two points in the path (Bagesteiro and Sainburg, 2002, 2003; Sainburg, 2002). This measure reflects interjoint coordination, as differences in linearity necessarily result from differences in coordination between the segments during movement. Movement duration was defined as the elapsed time from movement start to movement end.

2.5. Kinetic data analysis

Shoulder and elbow torques were calculated using equations that model the upper arm and forearm as rigid interconnected units with frictionless joints at the shoulder and elbow. The shoulder was allowed to move freely, and the torques resulting from linear accelerations of the shoulder were included in the equations of motion for each joint.

To separately analyze the effects of intersegmental forces and muscle forces on arm motion, we partitioned the terms of the equations of motion at the joint into three main components: interaction torque, muscle torque, and net torque (Sainburg *et al.* 1999). At each joint, interaction torque represents the rotational effect of the forces caused by the rotation and linear motion of the other segment. The muscle torque predominantly represents the rotational effect of muscle forces acting on the segment. However, muscle joint torque also includes the passive effects of soft tissue deformation and does not distinguish muscle forces that counter one another during co-contraction. Finally, the net torque is equal to the combined muscle and interaction torques, which is directly proportional to the joint acceleration.

Torques were computed and analyzed for the shoulder and elbow joint as detailed in the equations (1) and (2). The mass of the forearm support is 0.58 kg, whereas the inertia is 0.0247 kg/m^2. Arm segment inertia, center of mass, and mass were computed from regression equations using subject's body mass and measured arm segment lengths (Winter, 2004).

Elbow joint torques:

$$\begin{aligned} T_{e_I} &= m_e r_e \sin(\theta_s+\theta_e)\ddot{x} - m_e r_e \cos(\theta_s+\theta_e)\ddot{y} - l_s m_e r_e \sin(\theta_e)\dot{\theta}_s^{\,2} - (I_e + m_e r_e (r_e + l_s\cos(\theta_e)))\ddot{\theta}_s \\ T_{e_N} &= (I_e + m_e r_e^{\,2})\ddot{\theta}_e \\ T_{e_M} &= T_{e_N} - T_{e_I} \end{aligned} \tag{1}$$

Shoulder joint torques:

$$\begin{aligned} T_{s_I} &= (m_s r_s \sin(\theta_s) + m_e l_s \sin(\theta_s))\ddot{x} - (m_s r_s \cos(\theta_s) + m_e l_s \cos(\theta_s))\ddot{y} \\ &\quad -(m_e r_e (l_e \cos(\theta_e)\ddot{\theta}_e + l_s \sin(\theta_e)\dot{\theta}_e^{\,2} + 2 l_s \sin(\theta_e)\dot{\theta}_s\dot{\theta}_e + l_s \sin(\theta_e)\dot{\theta}_s^{\,2})) \\ T_{s_N} &= (I_s + m_s r_s^2 + m_e l_s^2 + m_e l_s r_e \cos(\theta_e))\ddot{\theta}_s \\ T_{s_M} &= T_{s_N} - T_{s_I} + T_{e_M} \end{aligned} \tag{2}$$

where: $\boldsymbol{m}$ is mass of segment, $\boldsymbol{r}$ is center of mass of segment, $\boldsymbol{l}$ is length of segment, $\boldsymbol{I}$ is inertia of segment, $\boldsymbol{\theta_s}$ is shoulder angle, $\boldsymbol{\theta_e}$ is angle between center of mass of lower arm segment and upper arm, $\boldsymbol{x}$ is shoulder position along x direction, $\boldsymbol{y}$ is shoulder position along y direction, $\boldsymbol{Te_I}$ is Elbow Interaction torque, $\boldsymbol{Te_M}$ is Elbow Muscle torque, $\boldsymbol{Te_N}$ is Elbow Net torque, $\boldsymbol{Ts_I}$ is Shoulder Interaction torque, $\boldsymbol{Ts_M}$ is Shoulder Muscle torque, $\boldsymbol{Ts_N}$ is Shoulder Net torque. The subscripts are defined as follows: $\boldsymbol{s}$ is upper arm segment, $\boldsymbol{e}$ is lower arm segment (including support and air sled device).

Shoulder and elbow torque impulse was calculated by integrating the absolute values of the torque profiles at each joint over the interval corresponding to the segment (movement initiation to movement end). Total torque impulse for each segment was calculated as the sum of the torque impulses.

2.6. Statistical analysis

Means of the individual dependent measures of task performance were analyzed using repeated-measures ANOVA (3 (Age) x 3 (Target) x 2 (Hand)) with one between-subject factor (Age: Children, Young, and Elder) and two within-subject factors (Target direction: 45º, 90º and 135º; and Hand: Dominant and Non-dominant). Subjects were treated as a random factor. For all analysis, statistical significance was tested using an alpha value of 0.05 and Tukey-Kramer honestly significantly different (HSD) tests were used for post-hoc analysis.

3. RESULTS

3.1. Hand kinematics

Figure 2 shows typical velocity profiles of a representative participant from each group. Interestingly, both hands of each individual group moved at similar velocities for the different targets. However, the young (1.10 ± 0.31m/s) group moved faster than the elderly (0.64 ± 0.27m/s) and children (0.53 ± 0.15m/s) (mean ± SD). Figure 2 insets show typical handpaths of a representative participant from each group. The young group showed slightly more curved handpaths for the nondominant hand (0.133 ± 0.041) as compared to the dominant hand (0.100 ± 0.033); they also showed a tendency to overshoot. The children group showed patterns (D: 0.122 ± 0.048; ND: 0.145 ± 0.045) as compared to the young, whereas the older group showed less curved handpaths and comparable deviation from linearity for both hands (D: 0.082 ± 0.036; ND: 0.097 ± 0.042) as compared to the younger groups.

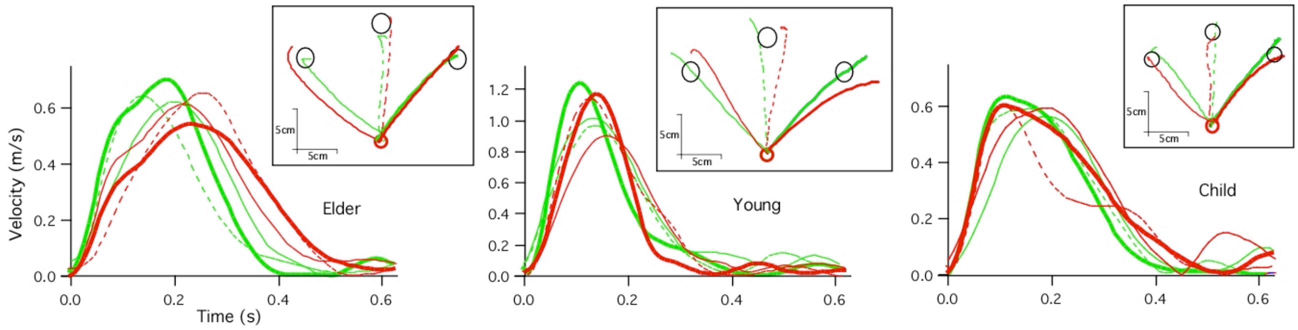

Figure 2. Tangential velocity profiles for representative subjects from each age group (Elder, Young and Child, from left to right, respectively). (Insets) Hand path trajectories for movements toward the three different targets (displayed at the same coordinate system). (Nondominant = red, Dominant = green; T0 = thick solid line, T1 = dashed line and T2 = thin solid line).

These effects were consistent across subjects, as shown in the graphs of average (± SE) hand path curvature (Fig.3A). The hand paths of the nondominant hand were significantly more curved than the dominant hand for the young group and children, whereas the older group showed smaller and similar curvature for both hands, producing a less lateralized handpath curvature with no obvious direction dependency. Our ANOVA confirmed these effects by revealing a significant main effect for group [$P = 0.0002$], indicating that the elderly (0.090 ± 0.040) had the straightest hand path compared with young (0.117 ± 0.041) and children (0.134 ± 0.048) subjects. There was also a significant group and hand interaction [$P = 0.0486$], showing that elderly subjects had comparable hand path curvatures, while young adults and children presented interlimb differences.

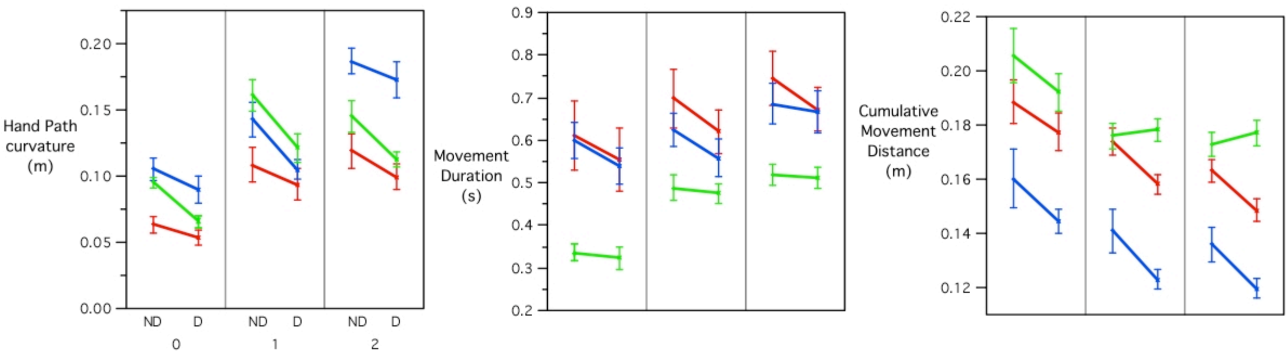

Figure 3. Means and SE for (A) hand path curvature, (B) movement duration, and (C) cumulative movement distance, for the three age groups by target (0, 1, 2) across subjects. (ND = nondominant, D = dominant; Elder = red, Young = green, and Children = blue).

Figure 3B shows mean (± SE) movement duration across subjects for each target in each group. Consistent with these plots, our ANOVA revealed that there was a significant main effect of group [$P = 0.0047$], with longer times for the elder group (0.65 ± 0.21s) relative to children (0.61 ± 0.14s) and the young group (0.44 ± 0.11s). There was also a marginally significant interaction between group and hand [$P = 0.0546$], such that the duration of movements for the nondominant hand of children and elder subjects were significantly longer than the dominant hand, whereas the young group showed similar duration for both hands. Figure 3C shows the means and standard errors of cumulative distance, across subjects for each target in each group. Consistent with these plots, our ANOVA revealed a significant main effect for group [$P < 0.0001$], which indicated that the distance was greater for the young group (0.184 ± 0.022m) compared with elderly (0.168 ± 0.021m) and children (0.137 ± 0.023m). There was also a significant interaction between hand and group [$P = 0.0142$], indicating that the dominant arm (0.129 ± 0.016m) of the children group had the shortest distance compared to the nondominant arms of the young (0.185 ± 0.026m) and elderly (0.175 ± 0.020m) groups.

3.2. Hand kinetics

Representative joint torque profiles for each age group are presented in figures 4, 5 and 6. Elbow and shoulder muscle torque profiles are shown from movement initiation to 350 ms following movement initiation. Positive values indicate flexor torque; negative values indicate extensor torque. Focusing on the first 150ms of the movement the pattern of the torque profiles was fairly similar to all groups. At the elbow (dashed lines), muscle torque showed decreasing extensor phases as target direction moved towards the medial line (increasing the amount of shoulder motion), whereas shoulder muscle torque (solid lines) started with an extensor phase and gradually changed to a flexor phase. We quantified the initial peak joint muscle torque across groups. Elderly and children showed no significant differences between nondominant and dominant arms, whereas the young group presented significantly higher values for the dominant arm. Our ANOVA revealed a significant main effect of group on initial peak shoulder [$P < 0.0001$] and elbow [$P < 0.0001$] muscle torques. At the elbow joint the young group showed greater peak flexor muscle torque (4.20 ± 2.96Nm) as compared to the elderly (2.06 ± 1.92Nm) and children (1.16 ± 0.89Nm). Also, there was an interaction between hand and group for peak shoulder muscle torque [$P = 0.0277$] showing that peak torques for the dominant arm of the young group (4.16 ± 1.38Nm) are significantly higher than the nondominant arm (3.13 ± 1.51Nm) while the elderly and children groups had no significant interlimb differences.

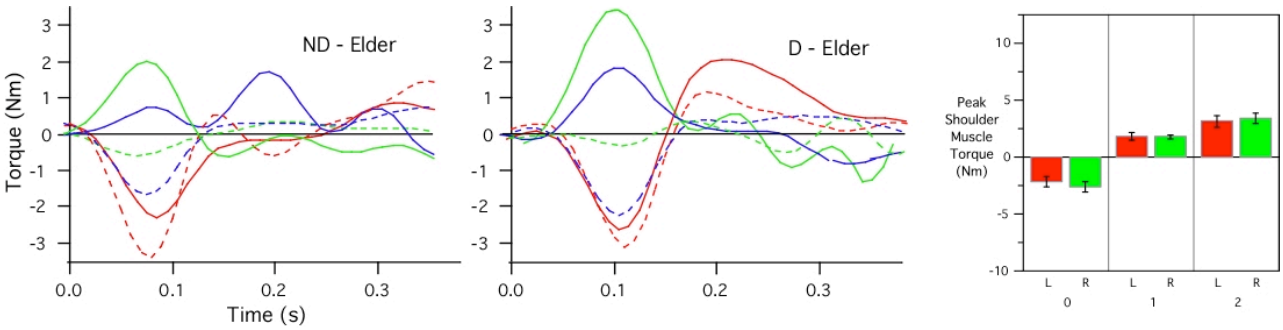

Figure 4. (A) Muscle torque profiles for a representative elder subject. (B) Means and SE for peak shoulder muscle torque for both arms by targets. (ND = nondominant (L), D = dominant (R); T0 = red, T1 = blue and T2 = green; Shoulder = solid line, Elbow = dashed line).

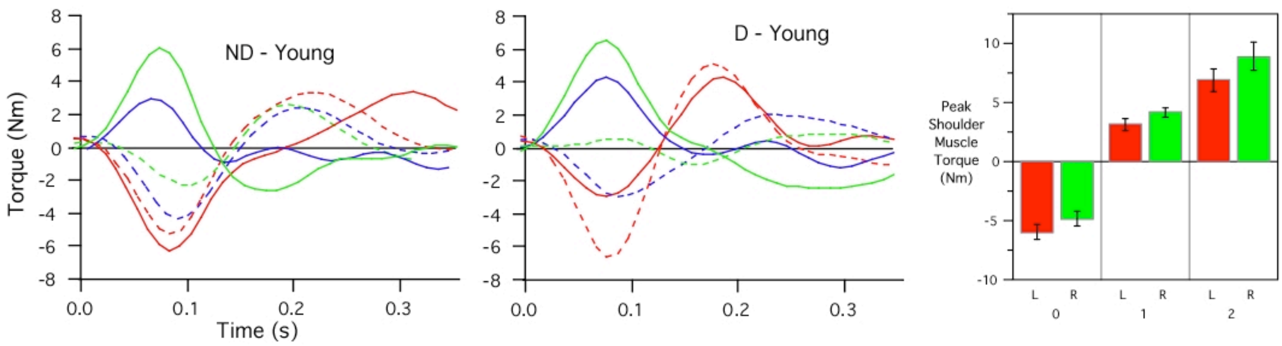

Figure 5. (A) Muscle torque profiles for a representative young subject. (B) Means and SE for peak shoulder muscle torque for both arms by targets. (ND = nondominant (L), D = dominant (R); T0 = red, T1 = blue and T2 = green; Shoulder = solid line, Elbow = dashed line).

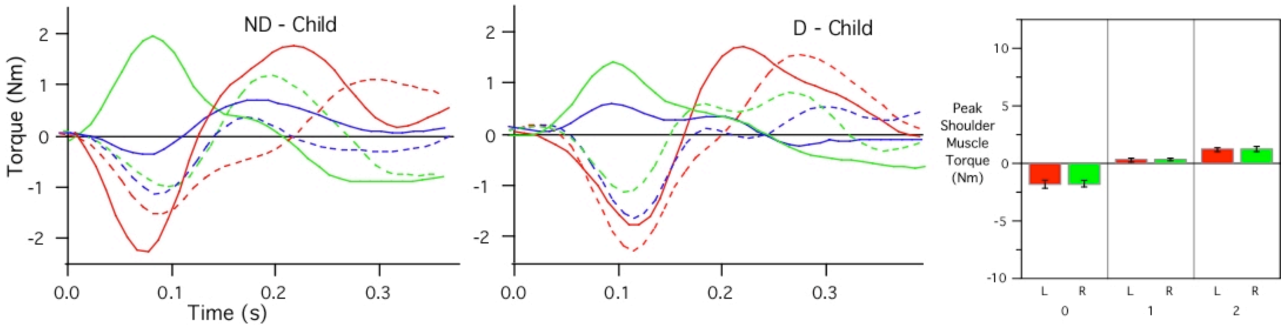

Figure 6. (A) Muscle torque profiles for a representative child subject. (B) Means and SE for peak shoulder muscle torque for both arms by targets. (ND = nondominant (L), D = dominant (R); T0 = red, T1 = blue and T2 = green; Shoulder = solid line, Elbow = dashed line).

These findings were confirmed with the measures of joint muscle torque impulse (average ±SE), calculated over the acceleration duration, for all groups shown in Fig. 7A (elbow) and 7B (shoulder). There was a significant difference between groups for elbow [$P < 0.0001$] and shoulder [$P < 0.0001$] impulses. Moreover, there was a significant interaction between hand and group [$P = 0.0011$] for shoulder impulse revealing that the young group had greater impulse for the dominant arm (0.25 ± 0.44Nms) as compared to the nondominant (0.16 ± 0.43Nms), while the elderly and children groups showed no significant difference between hands. Because this study was designed to systematically vary the intersegmental coordination requirements between targets; we designed our targets such that the shoulder/elbow ratio was greatest for the T2 movements, and least in the T0 movements. We quantified the joint contributions during motion as the ratio of shoulder excursion to elbow excursion, measured at peak tangential hand velocity (Fig. 7C). We had a significant main effect for group [$P = 0.0175$], indicating that the young (0.50 ± 0.38) had the smallest excursion ratio as compared to children (0.53 ± 0.34) and elderly groups (0.56 ± 0.32). There was also a significant main effect for hand [$P = 0.0078$], showing that the nondominant arm (0.52 ± 0.34) had a smaller excursion ratio as compared to the dominant arm (0.54 ± 0.36). Moreover, there was a group x hand interaction [$P = 0.0482$] for this ratio indicating that the nondominant ratio (0.48 ± 0.37) was smaller than the dominant (0.52 ± 0.40) for the young group, whereas elderly (D: 0.55 ± 0.33; ND: 0.56 ± 0.31) and children (D: 0.55 ± 0.36; ND: 0.51 ± 0.33) presented similar ratio for both hands. These results suggested that the lateralization shown in young subjects might not yet be evident at childhood, and that it may be reduced with aging.

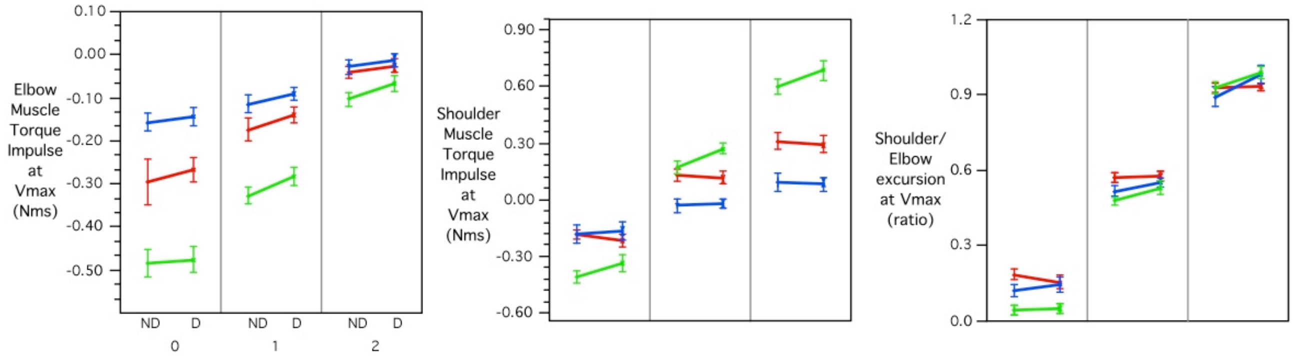

Figure 7. Means and SE for (A) elbow muscle torque impulse up to maximum tangential hand velocity location, (B) shoulder muscle torque impulse up to maximum tangential hand velocity location, and (C) shoulder/elbow excursion ratio at maximum tangential hand velocity location, for the three age groups by target (0, 1, 2) across subjects. (ND = nondominant, D = dominant; Elder = red, Young = green, and Children = blue).

We found strong hand-group interaction at the shoulder joint parameters emphasizing interlimb differences for the young but not for elderly or children. However this was not evident at the elbow joint indicating that interjoint coordination might be greatly related to synchronization of upper and lower arm segments. In conclusion, joint torques increase significantly with intersegmental coordination in young adults, while remaining comparable in older adults and children.

4. DISCUSSION

The present study was undertaken to investigate if motor asymmetry, as defined by particular movement parameters, changes over certain age stages across the lifespan. In the current study, to follow the development of those motor capabilities, we acquired arm segments 3D motions and calculated arm trajectories aimed at visual targets. These movements were produced by three different age groups: (9-12), (19-24), and (65-79) years. In our task, subjects were requested to aim at visually presented targets, starting to move as soon as possible after audio-visual target presentation, with a single, quick, uncorrected movement. Targets could appear at a specific distance from the start circle, in one of three possible directions. We instructed subjects to avoid correcting their trajectories after initiation. Also, we did not allow visual feedback during trajectory production, so that subjects were not tempted to correct their trajectories ''in flight''. Elder adults produced less curved trajectories and there was no significant interlimb difference as compared to children and young adults. Movement durations were shorter for the young and they increased with age, however there were not significantly interlimb differences for all groups. Cumulative distance decreased significantly with aging and interlimb differences were evident at the groups. As for the analysis of joint amplitudes (shoulder and elbow angular motion) and the three characteristics of joint control: shoulder/elbow ratio, peak muscle torque and impulse; elderly and children groups presented similar interlimb shoulder joint features whereas the young maintain the well documented asymmetry. These findings are consistent with previous studies on motor development in children (Heineman *et al.* 2010; Rueckriegel *et al.* 2008; Sveistrup *et al.* 2008; Olivier *et al.* 2007; Lambert and Bard, 2005; Rival *et al.* 2003; Ferrel-Chapus *et al.* 2002). Also, the joint relationships differences might be an aspect tendency demonstrating an earlier acquisition of an adult-like trajectory motion. Previous researches showed evidence that in conditions in which speed is emphasized, young and elderly adults can move at similar speeds without sacrificing accuracy; suggesting partially strategic changes employed by older adults to maintain accuracy of performance (Paizis *et al.* 2008; Hirschfeld, 2007; Francis and Spirduso, 2000; Pohl *et al.* 1996). Also, earlier results suggest that elderly subjects appear to reduce the lateralized interjoint coordination shown aging differences (Przybyla *et al.* 2011). Moreover, these analyses might indicate that the dominant arm advantage for dynamic strategy previously shown for young adults may not yet be apparent at the children stage. This data may also support the idea that learning reaching movements by acquiring an internal motor model of limb dynamics could be achieved during development. Overall our findings suggest that interlimb joint coordination asymmetry reduces for older adults as compared to the young. Moreover, this asymmetrical pattern may not be so evidence at early age as suggested by similar elbow and shoulder kinetics for the children data.

5. ACKNOWLEDGEMENTS

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