Upper Extremity Kinematics in Pediatric and Young Adult Populations during Activities of Daily Living

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Abstract

Age-related differences in upper extremity (UE) kinematics during activities of daily living are poorly understood. To develop control databases for clinical studies, a greater understanding of UE mechanics and potential changes in motion as a function of age is needed. The purpose of this research was to examine age-related differences in three-dimensional UE kinematics between young adult and pediatric groups while performing activities of daily living. Fifteen young adults (n = 15) aged 18-24 years (mean age: 20.2 years) and fifteen pediatric participants (n = 15) aged 7-9 years (mean age: 8.3 years) participated in the study. An eight-camera Vicon MCam system was used to record UE motion during the performance of three tasks: drinking, eating, and a simulated perineal care task. Significant differences in mean maximum joint angles were found between the age groups for all three tasks. No significant differences were found in kinematics data between the dominant and non-dominant arms for any task. Differential UE movement patterns may exist due to differences in experience with the tasks, anthropometrics, techniques used to complete the task, and/or neuromaturational levels. These results emphasize the need for age-matched control data for clinical studies of UE motion.

Keywords: Activities of daily living, Upper extremity biomechanics, Kinematics

1. Introduction

Compared to gait analysis, upper extremity (UE) motion analysis has lagged behind in development due to its complex, high degree-of-freedom, and non-cyclical nature [1]. Over the last decade, there has been an increase in the number of studies using motion capture to assess UE motion [2-9]. However, further research on UE biomechanics during activities of daily living (ADLs) in children and adults is warranted. As the UE is a critical component of many ADLs, such as feeding, toileting, and drinking, further research is needed to understand the mechanics of UE motion and changes that may occur as a function of age.

While gait patterns have been studied extensively across the life span, few researchers have examined age-related differences in UE kinematics during ADLs [7,10-13]. Petuskey et al. [7] published the only known study to examine age-related differences across children of varying ages. Maitra and Junkins [13] examined differences in UE kinematics between young adults and elderly individuals. However, the majority of research studies have tended to pool individuals of various ages into single age groups. Numerous pediatric studies have pooled data across wide age spans [4,6,11,14-18]. Similarly, adult studies have included young adults in their samples [19-25]. The broad age ranges used in these studies merge individuals with different experience levels, neuromaturational levels, and anthropometric features. As a result, age-related changes in patterns of UE motion cannot be appreciated.

Pheasant [26] reported anthropometric changes with age that may affect UE motion during the performance of ADLs. Young adults aged 19 to 25 years had increased shoulder to elbow and elbow to fingertip lengths compared to those of adults aged 45 to 65 years. In addition, both the young adult (19 to 25 years) and adult (45 to 65 years) age groups had increased arm lengths compared to that of an older adult (65 to 80 years) age group. Similarly, young adults had larger measurements in head length, head breadth, chest depth, shoulder to elbow length, and elbow to fingertip length compared to those of children aged seven to nine years. These differences in anthropometry and neuromaturational levels may be associated with differential movement patterns across the age span.

Studies that examine differences in UE motion between age groups will facilitate a greater understanding of the role of development on the motions of the UE. Knowledge of changes in UE movement patterns as a function of age is needed to establish valid control databases for the identification of movement deviations in clinical populations (e.g., cerebral

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palsy). Therefore, the present study examines age-related differences in three-dimensional UE kinematics between young adult and pediatric groups while performing ADLs.

2. Method

2.1 Participants

Fifteen young adults (n = 15; 5 male, 10 female) aged 18-24 years (mean ± standard deviation (SD): age 20.2 ± 1.9 years; height: 1.32 ± 0.71 m; weight: 29.7 ± 5.8 kg) and fifteen pediatric participants (n = 15; 5 male, 10 female) aged 7-9 years (mean ± SD: age 8.3 ± 0.8 years; height: 1.70 ± 0.1 m; weight: 68.2 ± 16.7 kg) participated in the study with consent. Pilot work showed that children under the age of 7 years had difficulty following instructions and holding a spoon. Therefore, the minimum age permitted to participate was 7.0 years of age. An upper bound of 9.0 years of age was selected to provide a narrow age range for this initial study. Participants were excluded if there was a history of UE disorders such as fractures, major lacerations, or burns. Participants were recruited from the Fredericton area through advertisements and word-of-mouth. The protocol was approved by the University of New Brunswick Research Ethics Committee and was in accordance with the Helsinki Declaration. Consent, parental/guardian consent, and/or assent were obtained from each participant.

2.2 Instrumentation

An eight-camera Vicon MCam motion capture system (Oxford Metrics Ltd., Oxford, UK) was employed to track the three-dimensional trajectories of eighteen (n = 18) reflective markers placed on the participants’ skin at a sampling frequency of 60 Hz. Reflective marker locations were similar to those used by Rab et al. [27] except for an additional marker placed at the lateral epicondyle of the left and right humerus to compute the elbow joint center.

2.3 Procedures

All data collection occurred in the Motion Analysis Lab at the University of New Brunswick. Participants wore a tank top to allow markers to be placed directly on the skin. Each participant was asked to perform 3 ADL tasks, including drinking from a cup, eating with a spoon, and reaching to the back pocket. These tasks were selected, in consultation with an occupational therapist, due to their importance for independent living and quality of life. The tasks were performed from a seated position. These tasks were selected as they represented motions needed for many activities of daily living. A height-adjustable stool and table were used to standardize the starting posture of each participant. Participants were seated with hips and knees in approximately 90° of flexion. Both hands and forearms rested on the table with palms face down. The shoulder was in a neutral orientation (parallel with torso) while the elbow was flexed approximately 90°. Feet and hands were approximately shoulder width apart. For each task, participants were asked to perform 2-3 practice trials to review the requirements of the task. Following this, participants were then asked to perform 6 test trials for each limb (or 6 test trials total for bilateral tasks). The onset of movement from the start position for all tasks was identified as the first frame where motion of the lateral wrist marker from its resting location was observable.

Drinking Task: A cup with a diameter of 7 cm and a height of 10 cm was placed directly in front of the dominant or non-dominant arm. From the standardized starting posture, the participant was asked to reach and grasp the cup, transport the cup to the mouth, take a sip of water, transport the cup to the starting position, release the cup, and then return their hand to the initial posture. The drink cycle was subdivided into two phases for data analysis. Phase 1 of the task was defined as the period between grasping of the cup to the peak of cup sipping. Phase 2 was defined as the period following peak cup sipping to the return of the cup to its original position. The participants performed the drinking task using both the dominant and non-dominant arms.

Eating Task: A bowl was located between the dominant and non-dominant hands. From the standardized starting posture, the participant was asked to reach and grasp for a spoon beside the bowl, scoop pudding onto the spoon, transport the spoon to the mouth, eat the pudding, transport the spoon to the starting position, release the spoon, and then return their hand to the initial posture. The eating task was then divided into two phases for data analysis. Phase 1 was defined as the period between the initiation of raising the spoon to reaching the mouth with the spoon. Phase 2 was defined as the period between initiation of transporting the spoon towards the bowl and the point at which the spoon reached the bowl. The end of phase 1 and the beginning of phase 2 were defined as the maximum vertical component of the lateral hand marker.

Pocket Task: The pocket task simulated perineal care and consisted of one phase only. From the standardized starting posture, the participant was asked to reach and grasp for a marker located on the sacrum. The marker was mounted on a 4.0-cm wand. This marker was used to provide a reliable target across participants. The task began with initiation of movement from the standardized posture and ended at hand contact with the marker.

2.4 Data analysis

Coordinate data were exported from the Vicon system to binary c3d files. The data were then imported into Matlab (The MathWorks Inc., Natick, MA) for further processing using custom-made software. Coordinate data were filtered using a second-order, zero-lag low-pass Butterworth filter with a cutoff frequency of 6 Hz. The cycle time and duration of each phase of the task were computed. For both the dominant and non-dominant arm conditions, cycle time was computed for each of the 6 trials. The single left and right trials that most closely approximated the mean cycle time for each limb were selected for subsequent analysis. The UE mechanical model was designed in collaboration with two occupational therapists. The simplified model was chosen to increase the feasibility of its use in a clinical setting. The body segments were modeled...
as a series of rigid links joined by 2-3 degree-of-freedom articulations. Rigid body segments included the head, trunk, and the left and right upper arm, forearm, and hand. The wrist and elbow joint centers were calculated using the midpoint between the ulnar and styloid markers, and lateral and medial epicondyles, respectively. The shoulder joint center was approximated using de Leva’s method [28]. Embedded or local coordinate systems were computed at the joint center for each segment. Joint angles were then computed from the relative orientations of the embedded coordinate systems using Euler angles. A y-x-z rotation sequence was used, corresponding to flexion/extension, adduction/abduction, and internal/external rotation, respectively.

For the statistical analyses, the independent variables were age group (n = 2; pediatric and young adult), task phase (n = 2), and arm (n = 2; dominant and non-dominant). The dependent variables were the maximum values of joint angles for each task (n = 7). A multivariate analysis of variance (ANOVA) was used to test for significant differences in mean maximum joint angle data across age groups and dominant/non-dominant arms. Bonferroni adjustments were used to adjust for multiple comparisons (p < 0.004).

3. Results

Significant differences (p < 0.004) in mean maximum values of joint angle parameters were found between age groups for all three tasks. No significant interactions or differences in mean maximum joint angle parameters were found between the dominant and non-dominant arms. Mean maximum and standard deviations of the selected joint angle parameters for the young adult and pediatric groups are provided in Tables 1-3. The results in Tables 1-3 are provided in terms of dominant and non-dominant arms, as well as combined arm data (dominant and non-dominant together). No significant differences in temporal-spatial data were found for the tasks (Table 4).

For the drinking task, the pediatric group had significantly larger mean maximum angle for neck flexion in phases 1 and 2.
Table 3. Mean (SD) joint angle parameters for young adult and pediatric groups during pocket task (bold values p < 0.004).

<table>
<thead>
<tr>
<th>Joint Angle</th>
<th>Paediatric</th>
<th>Dominant</th>
<th>Non-dominant</th>
<th>Young Adult</th>
<th>Dominant</th>
<th>Non-dominant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck Flexion</td>
<td>Combined Mean (SD)</td>
<td>8.25 (4.98)</td>
<td>7.79 (4.29)</td>
<td>8.14 (4.81)</td>
<td>6.15 (4.03)</td>
<td>8.14 (4.81)</td>
</tr>
<tr>
<td>Trunk Flexion</td>
<td>Combined Mean (SD)</td>
<td>10.73 (7.54)</td>
<td>10.73 (7.54)</td>
<td>6.53 (9.58)</td>
<td>9.38 (7.54)</td>
<td>6.39 (7.54)</td>
</tr>
<tr>
<td>Shoulder Flexion</td>
<td>Combined Mean (SD)</td>
<td>-52.35 (15.02)</td>
<td>-51.38 (10.39)</td>
<td>19.02 (10.46)</td>
<td>-43.50 (19.17)</td>
<td>-50.59 (16.83)</td>
</tr>
<tr>
<td>Shoulder Abduction</td>
<td>Combined Mean (SD)</td>
<td>30.92 (12.14)</td>
<td>30.86 (14.06)</td>
<td>10.46 (10.46)</td>
<td>-31.52 (11.14)</td>
<td>-31.90 (10.47)</td>
</tr>
<tr>
<td>Elbow Flexion</td>
<td>Combined Mean (SD)</td>
<td>98.06 (8.65)</td>
<td>96.87 (10.38)</td>
<td>99.24 (6.71)</td>
<td>104.33 (8.23)</td>
<td>106.25 (9.77)</td>
</tr>
<tr>
<td>Forearm Supination</td>
<td>Combined Mean (SD)</td>
<td>-102.85 (16.26)</td>
<td>-101.72 (15.12)</td>
<td>17.86 (17.86)</td>
<td>-105.62 (19.31)</td>
<td>-104.61 (19.01)</td>
</tr>
<tr>
<td>Wrist Extension</td>
<td>Combined Mean (SD)</td>
<td>14.40 (20.27)</td>
<td>15.36 (24.60)</td>
<td>13.43 (15.78)</td>
<td>13.74 (18.91)</td>
<td>12.08 (19.37)</td>
</tr>
</tbody>
</table>

Table 4. Mean (SD) temporal–spatial parameters for young adult and pediatric groups for all three ADL tasks.

<table>
<thead>
<tr>
<th>Task</th>
<th>Group</th>
<th>Mean Cycle Time (sec)</th>
<th>SD (sec)</th>
<th>% in phase 1</th>
<th>% in phase 2</th>
<th>SD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drining</td>
<td>Paed (Dominant)</td>
<td>3.71</td>
<td>0.8</td>
<td>54.23</td>
<td>45.77</td>
<td>4.88</td>
</tr>
<tr>
<td></td>
<td>Paed (Non-Dominant)</td>
<td>3.64</td>
<td>0.6</td>
<td>51.52</td>
<td>47.48</td>
<td>6.2</td>
</tr>
<tr>
<td></td>
<td>YA (Dominant)</td>
<td>3.67</td>
<td>0.38</td>
<td>52.46</td>
<td>47.54</td>
<td>2.56</td>
</tr>
<tr>
<td></td>
<td>YA (Non-Dominant)</td>
<td>3.65</td>
<td>0.33</td>
<td>51.95</td>
<td>48.05</td>
<td>2.81</td>
</tr>
<tr>
<td>Eating</td>
<td>Paed (Dominant)</td>
<td>2.71</td>
<td>0.99</td>
<td>56.01</td>
<td>43.99</td>
<td>11.78</td>
</tr>
<tr>
<td></td>
<td>Paed (Non-Dominant)</td>
<td>2.70</td>
<td>0.77</td>
<td>56.90</td>
<td>43.10</td>
<td>11.35</td>
</tr>
<tr>
<td></td>
<td>YA (Dominant)</td>
<td>2.20</td>
<td>0.41</td>
<td>58.19</td>
<td>41.81</td>
<td>8.21</td>
</tr>
<tr>
<td></td>
<td>YA (Non-Dominant)</td>
<td>2.18</td>
<td>0.42</td>
<td>57.05</td>
<td>42.95</td>
<td>4.97</td>
</tr>
<tr>
<td>Pocket</td>
<td>Paed (Dominant)</td>
<td>2.07</td>
<td>0.49</td>
<td>20.27</td>
<td>20.27</td>
<td>4.49</td>
</tr>
<tr>
<td></td>
<td>Paed (Non-Dominant)</td>
<td>1.68</td>
<td>0.42</td>
<td>15.36</td>
<td>15.36</td>
<td>2.92</td>
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<tr>
<td></td>
<td>YA (Dominant)</td>
<td>2.17</td>
<td>0.45</td>
<td>13.43</td>
<td>13.43</td>
<td>2.45</td>
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<tr>
<td></td>
<td>YA (Non-Dominant)</td>
<td>2.05</td>
<td>0.44</td>
<td>13.43</td>
<td>13.43</td>
<td>2.44</td>
</tr>
</tbody>
</table>

Figure 1. Mean joint angles during drinking task for pediatric (blue *) and adult (red o) groups. Dominant and non-dominant data were combined for each age group. Vertical lines represent the end of phase 1 for each group.

2 and shoulder abduction in phase 2 compared to those for the young adult group (Fig. 1, Table 1). Significantly lower mean maximum shoulder flexion angles were also found during phase 2 in the pediatric group. On average, the percentage of time spent in each phase was similar for the pediatric and young adult groups. Cycle time was also similar among groups and between arm conditions (Table 4). While the variability of movement was very similar across age groups, the young adult group had consistently lower variability.

For the eating task, the pediatric group had significantly lower mean maximum elbow flexion angles in phases 1 and 2 compared to those for the young adult group (Fig. 2, Table 2). In addition, the pediatric group had significantly larger mean maximum shoulder abduction angles in both phases of the task. On average, the percentage of time spent in each phase was similar for the pediatric and young adult groups (Table 4). Within groups, time to complete the entire task was similar across dominant and non-dominant arms. However, on average, the pediatric group took longer to complete the task compared to the young adult group for both arm conditions. Both groups showed similar movement variability; however, the young adult group showed more consistent elbow flexion patterns.

For the pocket task, significant group differences in mean peak joint angle values were found for trunk and neck flexion angles only (Fig. 3, Table 3). The pediatric group demonstrated significantly higher values for both angles compared to those for the young adult group during the pocket task. Cycle time was also similar across groups and between...
arm conditions (Table 4). However, on average, the pediatric group completed the task earlier when using the non-dominant arm. Compared to the pediatric group, the young adult group showed lower variability for most angles except shoulder extension and forearm supination.

![Graph showing neck and trunk flexion angles](image)

**Figure 3.** Mean joint angles during pocket task for pediatric (blue * = mean, blue solid line = standard deviation) and adult (red o = mean, red dashed line = standard deviation) groups. Dominant and non-dominant data were combined for each age group.

### 4. Discussion

Few studies have examined age-differences in UE kinematics during ADLs. Changes in movement and neuromuscular activity are known to occur as a function of age. For example, previous research has shown that with age, range of motion [10] and isometric shoulder strength [29] decrease. In addition, substantial anthropometric changes occur with age [26]. The purpose of this study was to examine the age-related differences in three-dimensional UE kinematics between young adult and pediatric groups while performing ADLs. Results show significant differences in joint angle parameters between age groups for all three ADLs tested. No significant differences were found between the dominant and non-dominant arms within each group. No significant differences were found for temporal-spatial parameters from each task.

Compared to the young adult group, the pediatric group demonstrated significantly increased neck and trunk flexion throughout the drinking task. Pediatric subjects tended to move their head and trunk toward the approaching cup. This increased forward lean may reflect a dependency on visual information during the drinking task or an inability to separate trunk motion from arm motion [11]. In phase 2 of the task, the pediatric group also showed significantly increased shoulder abduction and lower shoulder flexion angles (Table 1). At the shoulder, young adults tended to move mostly within the sagittal plane, whereas pediatric subjects moved within the frontal plane. It is possible that these frontal plane movements represent a lack of movement efficiency or neuromaturation [11]. Joint angle results were similar to the median maximum and standard deviation values reported by de los Reyes-Guzman et al. [30].

During the eating task, the pediatric group demonstrated significantly less flexion across the shoulder, elbow, and wrist joints and greater shoulder abduction than those for the young adult group (Table 2). Previous studies examining UE kinematics during eating tasks have reported similar variability but higher mean maximum elbow flexion angles compared to those in the present study [6,17]. It is likely that differences in task definitions and protocol are responsible for these differences. For example, Mackey et al. [6] used a small wooden block, instead of a spoon, for their hand to mouth task, which may have increased their mean maximum elbow flexion measurement in typically developing children aged 6-12 years. Magermans et al. [31] described shoulder motion in female adults during eating using glenohumeral motion instead of thoracohumeral motion, making it difficult to compare results to the present study. The maximum joint angles in our study were lower than those reported by Kasten et al. [17]. However, each of the maximum values provided in this latter study was for single participants only and did not represent the total sample. Comparisons to other studies are difficult due to differences in the measures used to evaluate UE motion [32,33].

Compared to the young adult group, the pediatric group showed increased head and trunk flexion while performing the pocket task (Table 3). Again, it is possible that simultaneous head, trunk, and arm movements may reflect movement synergies in children and an inability to independently move these segments during particular tasks. This technique may also have been used to alter the vertical location of the posterior marker to a more favourable position. Overall, these age-related differences in joint angles were relatively small in magnitude (< 8°). Petuskey et al. [7] compared the UE kinematics of children in three age groups (5-8, 9-12, and 13-18 years) during a simulated perineal care task (hand to back pocket). They also found significant differences in neck flexion (5-8 vs. 9-12 years; 9-12 vs. 13-18 years) and trunk flexion (9-12 vs. 13-18 years) between age groups. Similar to the present study, differences in joint angles as a function of age were no greater than 10°. In contrast, Petuskey et al. also found small (approximately 2°), but significant differences between dominant and non-dominant arms during the task for mean shoulder abduction angles. On average, the dominant arm showed larger abduction angles than those for the non-dominant arm.

Results for the pocket task were similar to those reported by Palmieri et al. [15]. Differences in the mean values of elbow flexion and shoulder abduction between studies were likely due to variations in task definition. For example, the present study required the subject to reach for the sacral area as opposed to the ipsilateral pocket. This could affect the degree of elbow flexion required to perform the task. However, as the pocket task is a simulation of perineal care, a more central target was preferred in this study. Differences in shoulder abduction angles and variability may have reflected differing starting positions when performing the tasks. Subjects in the present study initiated the task from a seated position, which may have led to greater abduction values compared to those in studies which required subjects to stand [7,15]. Comparisons to other studies were difficult due to the use of alternate shoulder
models [31] and differences in the kinematics variables used for analysis [16].

This study had several limitations that must be considered. First, the accuracy of the UE kinematics data is a function of accurate marker placement, soft tissue artifact, and motion capture system performance. Second, the eating task resulted in more variability in terms of the strategies used to grip the spoon. We did not want to induce unfamiliar movement patterns by requesting that the spoon be held differently; however, the inclusion of this task for 7-9 year olds requires further consideration. Finally, consensus among researchers has not been reached in terms of mechanical models of the UE or the types of kinematics measures that should be used to evaluate UE motion. This leads to difficulty when attempting to compare results across studies.

5. Conclusion

This study showed that age-related differences exist in movement patterns during ADLs. Differential UE movement patterns may exist due to differences in experience with the task, anthropometrics, techniques used to complete the task, and neuromaturational levels. Such information is critical to our understanding of typical movement patterns and future clinical studies involving the UE. The identification of movement deviations and their underlying causes in clinical populations is dependent on the availability of well-defined control data. Differences in UE kinematics between pediatric and young adult age groups demonstrates the importance of using age-matched control groups in future clinical studies. The results of the present study suggest that further research on age-related differences in UE movement patterns is needed to establish appropriate control databases. Future work will focus on increasing sample sizes and examining additional age divisions for comparative purposes.

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References