Simulated activities of daily living do not replicate functional upper limb movement or reduce movement variability

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\begin{abstract}
Kinematic assessments of the upper limb during activities of daily living (ADLs) are used as an objective measure of upper limb function. The implementation of ADLs varies between studies: whilst some make use of props and define a functional target, others use simplified tasks to simulate the movements in ADLs. Simulated tasks have been used as an attempt to reduce the large movement variability associated with the upper limb. However, it is not known whether simulated tasks replicate the movements required to complete ADLs or reduce movement variability. The aim of this study is to evaluate the use of simulated tasks in upper limb assessments in comparison to functional movements. Therefore answering the following questions: Do simulated tasks replicate the movements required of the upper limb to perform functional activities? Do simulated tasks reduce intra- and inter-subject movement variability? Fourteen participants were asked to perform five functional tasks (eat, wash, retrieve from shelf, comb and perineal care) using two approaches: a functional and a simulated approach. Joint rotations were measured using an optoelectronic system. Differences in movement and movement variability between functional and simulated tasks were evaluated for the thorax, shoulder, elbow/forearm and wrist rotations. Simulated tasks did not accurately replicate the movements required for ADLs and there were minimal differences in movement variability between the two approaches. The study recommends the use of functional tasks with props for future assessments of the upper limb.

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\end{abstract}

1. Introduction

Current assessment of upper limb function of patients with disability or injury is primarily achieved using visual assessment and through quality of life questionnaires that assess pain, functional abilities in activities of daily living (ADLs), emotional well-being and physical strength (Habermeyer et al., 2006). Such methods are subjective and they often suffer from limitations related to reliability (Metcalfe et al., 2007, Rocourt et al., 2008, Ellis et al., 1997, Fowler and Nicol, 2001).

Three-dimensional kinematics are not routinely used in assessment of the upper limb, unlike in the lower limb where these tools have been used for decades to provide objective measures of function. This is due to a number of technical difficulties in the measurement and analysis of upper limb movement in comparison to the lower limb. The difficulties include the presence of a thick layer of soft-tissue covering the shoulder region (Shaheen et al., 2011b), the large range of motion achieved by the upper limb and difficulties in choosing appropriate computation methods (Kontaxis et al., 2009) as well as difficulties arising from the wide spectrum of use of the upper limb in ADLs (van Andel et al., 2008, Mackey et al., 2005). Upper limb movements are also associated with large intra-subject (Mackey et al., 2005, Sheikhzadeh et al., 2008, Murray and Johnson, 2004) and inter-subject (van Andel et al., 2008, Sheikhzadeh et al., 2008, Aizawa et al., 2010) movement variability, this hinders interpretation of the measured parameters (Murray and Johnson, 2004, van Andel et al., 2008, Petuskey et al., 2007) and identification of pathological movements (Mackey et al., 2005).

A number of studies have contributed to the development of objective kinematic assessments of the upper limb and have employed a number of tasks to represent ADLs to assess function (Aizawa et al., 2010, Hall et al., 2011, Mackey et al., 2005, Petuskey et al., 2007, van Andel et al., 2008, Sheikhzadeh et al., 2008). Two approaches have been used in these studies to evaluate ADLs; some have made use of props (e.g. a comb, spoon, cup etc.),
thus allowing participants to perform the actual functional task during measurement (Aizawa et al., 2010, Doorenbosch et al., 2003, Magermans et al., 2005, Veeger et al., 2006), whilst others have made use of movements designed to simulate ADLs (Petuskey et al., 2007, Mackey et al., 2006, Sheikhzadeh et al., 2008). Other studies have used a combination of the two approaches (van Andel et al., 2008) or have not specified how the tasks were carried out (Hall et al., 2011, Murray and Johnson, 2004).

Nevertheless, the majority of the studies making use of simulated tasks over actual functional performance of ADLs have not always clarified the reasons for using this approach; however, it is likely that simulated tasks were used as an attempt to simplify ADLs in order to obtain more repeatable movements, therefore, reducing the high intra-subject and inter-subject variability. A justification for the choice of a simulated approach to reduce the effect of variability has also been explicitly suggested in the study by Sheikhzadeh et al. (2008). However, there is no evidence to show that these tasks are representative of the movement of the upper limb joints when performing real ADLs. In addition, it is not known whether such simulated tasks are indeed able to reduce the reported movement variability.

The aim of this study was to evaluate the use of simulated tasks in ADL studies in comparison with performing functional tasks. We had two research questions: Do simulated tasks produce the same movement (maximum and minimum angles, ranges of motion and temporal characteristics of movement—hereinafter referred to as movement pattern)—as their corresponding functional tasks? Do simulated tasks improve repeatability by reducing intra-subject and inter-subject movement variability compared to functional tasks? We hypothesised that simulated tasks would produce different measures of movement to functional tasks but would reduce movement variability.

2. Materials and methods

2.1. Participants

Fourteen volunteers (8 males) with a mean age of 21.7 ± 1.3 years and no existing or previous upper limb pathology or injury were recruited for the study. Participants provided written consent to take part in the study. The study received a favourable ethical opinion from the University of Surrey Research Ethics Committee.

2.2. Laboratory and subject set-up

An 11-camera Motion Capture System (Qualisys, Gothenburg, Sweden) running at 200 Hz was used and retroreflective markers were attached on the segments of interest using hypoallergenic double-sided tape. The movement of the pelvis, thorax, scapula, humerus, forearm and hand on the dominant side were tracked using these markers. A subject calibration trial was used to define anatomical positions, where markers were attached to the pelvis (Right and Left Anterior Superior Iliac Spine and Posterior Superior Iliac Spine), the thorax (Incisura Jugularis, Process Xiphoideus, Spinal Process of the 7th Cervical and 8th Thoracic Vertebrae), the humerus (Lateral and Medial Epicondyles), the forearm (Radial and Ulnar Styloid Processes) and the hand (3rd Metacarpal). A scapula locator was also used to define the positions of anatomical landmarks on the scapula (Acromial Angle, Inferior Angle and Root of the Scapular Spine) with the arm at 60° elevation in the scapular plane (Shaheen et al., 2011a). In addition to the anatomical markers, 3-marker clusters were attached to the acromion of the scapula (Shaheen et al., 2011), humerus, forearm and hand, these were used to track the movement of the segments in dynamic trials (Kontaxis et al., 2009). In dynamic trials, the anatomical markers on the humerus, forearm and hand were removed.

2.3. Measurement procedure

Participants performed tasks representing ADLs using two approaches; functional tasks (FTs), using clear functional targets with the aid of props where appropriate, and corresponding simulated tasks (STs). The tasks were chosen because they were often used in kinematic assessments of the upper limb and they represented common ADLs: eating, washing, hair combing, retrieving an item from a shelf and perineal care. The order of the ten tasks was randomised for each participant and each task was repeated three times. Participants were not made aware that the STs were intended to represent any particular ADL. Marks on the table/shelf and floor were used to standardise the positions of the props, furniture and participant. Participants were given verbal instructions regarding the start and end position of their hand. The instructions given to the participants for each task are shown in Table 1.

A task representing perineal care was included because of its importance for independent living. In previous studies this task was simulated by touching the back pocket (Doorenbosch et al., 2003, Petuskey et al., 2007, van Andel et al., 2008); such a movement is likely to be different to the movement performed in perineal care. For the FTs, subjects were seated in a custom-made stool and they were instructed to touch a marker attached to the base of the stool. This set-up was believed to provide a more realistic demonstration of the movement involved in perineal care.

2.4. Data analysis

The humeral centre-of-rotation was defined relative to a cluster on the scapula using a functional trial and a least-squares solution (Gamage and Lasenby, 2002). Coordinate frames for the pelvis, thorax, humerus, forearm and hand were defined and Euler rotation sequences were used to compute joint angular rotations based on the recommendations of the ISB (Wu et al., 2005, Wu et al., 2002). The movement of a marker on the hand was used to determine the start and end of movement; this was used to define a movement cycle. Joint rotations were then normalised to 100% of the cycle time, this was to remove the effect of relative timing in completing the movement and allow comparisons between trials and subjects. Following normalisation, mean joint angles from Table 1

<table>
<thead>
<tr>
<th>ADL</th>
<th>Functional task (FT)</th>
<th>Simulated task (ST)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wash</td>
<td>Use the sponge to wash your contralateral armpit</td>
<td>Touch your contralateral armpit (van Andel et al., 2008, Murray and Johnson, 2004)</td>
</tr>
<tr>
<td>Eat</td>
<td>Use the spoon and bowl to feed yourself</td>
<td>Touch your mouth (Mackey et al., 2006)</td>
</tr>
<tr>
<td>Comb</td>
<td>Use the comb to comb the centre section of your hair from the front to the back of your head</td>
<td>Pass your hand over your head and touch the back of your neck (Sheikhzadeh et al., 2008, van Andel et al., 2008, Murray and Johnson, 2004, Veeger et al., 2006)</td>
</tr>
<tr>
<td>Retrieve from shelf</td>
<td>Retrieve the bottle on the shelf and place it on the table on the cross</td>
<td>Point at the cross on the bottle in front of you (Petuskey et al., 2007) and then point at the cross on the table</td>
</tr>
<tr>
<td>Perineal care</td>
<td>Touch the marker on the underside of your seat, going around the back of your body</td>
<td>Touch your back pocket (Doorenbosch et al., 2003, Petuskey et al., 2007, van Andel et al., 2008)</td>
</tr>
</tbody>
</table>
showed greater RoMs for the perineal care FT compared to ST.

The forearm pronation/supination showed no differences between FTs and STs for all movements considered except the wash task. When the differences were significant, FTs showed lower minimum and higher maximum angles and therefore greater RoMs than STs.

The greatest differences were in the radial deviation for eat, where FT showed approximately 18° greater radial deviation than ST, and in the wrist flexion of the retrieve from shelf trials, where FT showed approximately 25° greater flexion than ST.

Table 2 shows the results of the ANOVA tests for the differences in movement patterns between FTs and STs. The results show that differences in the movement pattern were present for all segment/joint rotations and for the five ADLs. These differences were sometimes present at different parts of the cycle as evidenced by the results of the interaction effect between the task and cycle percentage.

The movement patterns for FT and ST for the comb task were the most similar; differences were only found in the middle of the movement cycle for thorax flexion and approximately between 30 and 70% of the cycle for the wrist radial/ulnar deviation. The four other ADLs showed substantial differences between the patterns adopted in FTs and corresponding STs.

3.2. Movement variability

The results of the repeated-measures ANOVA for intra-subject variability are shown in Table 3 and the mean intra-subject variations for the eat and wash tasks are shown in Fig. 5 and those for the retrieve from shelf, comb and perineal care tasks are shown in Fig. 6 – these are averaged over the full movement pattern for visual representation. The results show high intra-subject variation in the upper limb joints/angles (shoulder, elbow/forearm and wrist) with the mean approaching 8° for some shoulder rotations. Smaller intra-subject variations for the thoracic rotations were found, with the means typically ranging between 1° and 4°.

In contrast to the study hypothesis, the ANOVA tests show few differences in the intra-subject movement variability between FTs and STs. Furthermore, the variation seemed to be unrelated to the RoM at the joint. For example, whilst smaller ranges of wrist flexion in STs (eat and comb) also showed smaller variations in movement; the opposite was true for lateral flexion, where a significantly larger RoM for FT of perineal care also showed a smaller intra-subject variation.

Means of inter-subject variability of the rotations averaged over the full cycle (0–100%) of the 10 tasks are shown in Table 4. The inter-subject variability in FTs and STs are largely comparable. Generally, the simulated tasks have lower variabilities in thoracic (1–11° compared to 3–13°) and wrist rotations (8–17° compared 11–16°) between subjects. The biggest difference in inter-subject variability is in forearm pronation in the retrieve from shelf (~7°) and comb (~4°) tasks; where STs have lower variability.

4. Discussion

This study compared two approaches used in kinematic assessments of upper limb ADLs. Functional tasks were used to assess movement of the upper limb where the ultimate functional aim was to evaluate the effectiveness of the hand approaches on movement patterns and RoMs. The results showed significant differences in the movement patterns and RoMs between FTs and STs for most of the tasks. The differences were larger for perineal care and retrieve from shelf tasks, where FTs showed greater RoMs than STs.

The results of this study have implications for the design of hand approaches for ADLs. For tasks such as perineal care and retrieve from shelf, FTs showed greater RoMs and therefore required greater RoM at the shoulder, elbow, and wrist. This suggests that FTs may be more challenging for individuals with limited shoulder and wrist mobility. Furthermore, the greater RoMs in FTs may increase the risk of injury or reduce the quality of movement.

The findings of this study also suggest that FTs may be more beneficial for tasks requiring greater RoM at the shoulder, elbow, and wrist. The use of FTs may improve movement efficiency and reduce the risk of injury. However, further research is needed to determine the optimal degree of RoM for specific ADLs and target populations.

In conclusion, this study provides valuable insights into the movement patterns and RoMs of FTs and STs for upper limb ADLs. The findings suggest that FTs may be more challenging for individuals with limited shoulder and wrist mobility, but also may be more beneficial for tasks requiring greater RoM at the shoulder, elbow, and wrist.

References

[Insert references here]
Fig. 1. The maximum, minimum and ranges of motion for the thoracic lateral flexion, axial rotation and forward flexion for the eat, wash, retrieve from shelf, comb and perineal care ADLs. Simulated tasks (STs) are shown in solid grey and functional tasks (FTs) are shown in patterned grey, error bars represent ± one standard deviation of the means of maximum and minimum angles. * show significant differences in maximum/minimum angles and § show a significant difference in the range of motion.
was defined. Simulated tasks were based on movements that have been used in previous upper limb kinematic studies (see Table 1) to simulate ADLs. Simulated tasks have been used as an attempt to improve interpretability of upper limb movement data by reducing movement variation whilst maintaining the functional demands and movement characteristics expected of performing ADLs (Sheikhzadeh et al., 2008, van Andel et al., 2008). The results suggest that these simulated tasks do not replicate the movement.

Fig. 2. The maximum, minimum and ranges of motion for the shoulder/humerothoracic plane of elevation, elevation and internal/external rotation (axial rotation) for the eat, wash, retrieve from shelf, comb and perineal care ADLs. Simulated tasks (STs) are shown in solid grey and functional tasks (FTs) are shown in patterned grey, error bars represent ± one standard deviation of the means of maximum and minimum angles. * show significant differences in maximum/minimum angles and § show a significant difference in the range of motion.
characteristics of the thorax and upper limb joints in functional ADLs. Furthermore, the perceived advantage of a reduction in movement variability when simplifying functional tasks was shown not to be true for the majority of joint rotations. Where there is a reduction in movement variability of the thorax and wrist joints (ranging between 1 and 4° of intra-subject and inter-subject variations) in the simulated tasks, there is also a substantial reduction in the RoMs performed (up to 15° for the thorax and 20° for the wrist).

In line with previous kinematic studies of upper limb movement (Aizawa et al., 2010, Magermans et al., 2005, van Andel et al., 2008), there were considerable differences in the movement strategies used between individuals, this was the case with both functional and simulated movements. This is also demonstrated in the inter-subject variability of the rotations for the shoulder (up to 35°), elbow/forearm (up to 28°) and wrist angles (up to 17°) shown in Table 4. This variability was largely comparable between the two approaches.

Unfortunately, the current set-up did not allow the wrist rotations for the perineal care tasks to be reported with sufficient reliability. This could have been mitigated if the optoelectronic system set-up was changed so that the movements of the hand under the seat were picked up by some cameras. Perineal care is an important task for patients and it is also one which requires a different shoulder rotation (plane of elevation and internal rotation) to the other ADLs. Replicating such a task in upper limb assessments is sensitive due to its nature; however, the results show that such a movement cannot be simplified to touching the back pocket. We suggest that a task closer to the actual movement performed is important for future assessments of the upper limb.

Upper limb studies generally use the thorax as a reference for the movement of the humerus (Aizawa et al., 2010, Petuskey et al., 2007, Hall et al., 2011, Mackey et al., 2005, Murray and Johnson, 2004) or the scapula (Magermans et al., 2005, Sheikhzadeh et al., 2008, van Andel et al., 2008); but thoracic rotations are not often reported. The differences in thoracic rotations between the simulated and the functional ADLs, as well as between the 5 different activities, highlight the important role that the thorax plays in completing upper limb tasks even in a normal population. It is likely that the role of the thorax is of heightened importance in patients with upper limb movement limitations because compensatory movements of the upper limb are likely to

![Fig. 3. The maximum, minimum and ranges of motion for the forearm pronation/supination and elbow flexion for the eat, wash, retrieve from shelf, comb and perineal care ADLs. Simulated tasks (STs) are shown in solid grey and functional tasks (FTs) are shown in patterned grey, error bars represent ± one standard deviation of the means of maximum and minimum angles. * show significant differences in maximum/minimum angles and § show a significant difference in the range of motion.](image-url)
first occur at the thorax. Future assessments of the upper limb should include a measure of thoracic rotations with respect to the pelvis or to a global coordinate system.

It is important to acknowledge that ultimately, the functional tasks used in the experimental set-up are also an imitation of ADLs performed in the real world. In reality, neither of the approaches...
Table 3
Results of the repeated-measures ANOVA tests for differences in the intra-subject movement variability between functional and simulated tasks for the five activities of daily living, including results of testing for interactions with the percentage of the movement (Task × Percentage). The significance level was set at p < 0.05, significant values are in bold.

<table>
<thead>
<tr>
<th>Segment/Joint</th>
<th>Rotation</th>
<th>Eat Task p-value</th>
<th>Eat Task × Percentage p-value</th>
<th>Wash Task p-value</th>
<th>Wash Task × Percentage p-value</th>
<th>Retrieve from shelf Task p-value</th>
<th>Retrieve from shelf Task × Percentage p-value</th>
<th>Comb Task p-value</th>
<th>Comb Task × Percentage p-value</th>
<th>Perineal Care Task p-value</th>
<th>Perineal Care Task × Percentage p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thorax</td>
<td>Lateral flexion</td>
<td>0.036</td>
<td>0.298</td>
<td>0.712</td>
<td>0.502</td>
<td>0.002</td>
<td>0.038</td>
<td>0.491</td>
<td>0.328</td>
<td>0.001</td>
<td>0.028</td>
</tr>
<tr>
<td></td>
<td>Axial rotation</td>
<td>0.579</td>
<td>0.556</td>
<td>0.695</td>
<td>0.256</td>
<td>0.608</td>
<td>0.178</td>
<td>0.584</td>
<td>0.284</td>
<td>0.124</td>
<td>0.387</td>
</tr>
<tr>
<td></td>
<td>Flexion</td>
<td>0.158</td>
<td>0.009</td>
<td>0.212</td>
<td>0.488</td>
<td>0.159</td>
<td>0.324</td>
<td>0.150</td>
<td>0.441</td>
<td>0.482</td>
<td>0.123</td>
</tr>
<tr>
<td>Humero-thoracic</td>
<td>Plane of elevation</td>
<td>0.239</td>
<td>0.209</td>
<td>0.378</td>
<td>0.290</td>
<td>0.524</td>
<td>0.217</td>
<td>0.426</td>
<td>0.460</td>
<td>0.124</td>
<td>0.297</td>
</tr>
<tr>
<td>Forearm</td>
<td>Pronation</td>
<td>0.136</td>
<td>0.033</td>
<td>0.262</td>
<td>0.031</td>
<td>0.779</td>
<td>0.200</td>
<td>0.161</td>
<td>0.632</td>
<td>0.341</td>
<td>0.113</td>
</tr>
<tr>
<td>Elbow</td>
<td>Flexion</td>
<td>0.003</td>
<td>&lt;0.001</td>
<td>0.099</td>
<td>&lt;0.001</td>
<td>0.041</td>
<td>0.175</td>
<td>0.375</td>
<td>0.437</td>
<td>0.425</td>
<td>0.149</td>
</tr>
<tr>
<td>Wrist</td>
<td>Radial deviation</td>
<td>0.358</td>
<td>0.105</td>
<td>0.133</td>
<td>0.227</td>
<td>0.055</td>
<td>0.056</td>
<td>0.026</td>
<td>0.016</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flexion</td>
<td>0.007</td>
<td>0.022</td>
<td>0.157</td>
<td>0.249</td>
<td>0.044</td>
<td>0.144</td>
<td>0.264</td>
<td>0.702</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 5. Intra-subject variability for the thoracic, shoulder/humerothoracic, elbow/forearm and wrist rotations for the eat and wash ADLs, the values shown are averages for the variability across 0–100% of the movement cycle. Simulated tasks (STs) are shown in solid grey and functional tasks (FTs) are shown in patterned grey, error bars represent one standard deviation of the mean. * show significant differences in the intra-subject variability between functional and simulated tasks (Task column shown in Table 3).
truly reflect how the upper limb is used in everyday activities. Kinematic assessments require that movements are standardised for the purposes of obtaining a laboratory measurement. This has similarly been the case with gait analysis studies, albeit to a much lesser degree, for example gait analysis is generally performed on levelled surfaces and require the person to walk in straight lines. This remains a generic limitation of kinematic measures obtained with the purpose of assessing function. The argument made in this study is that a further simplification of the tasks and the absence of a clear functional target in upper limb assessments may result in losing valuable information regarding its function. In addition, participants are more likely to revert to postures and movement strategies used in daily life when provided with props and instructed to perform a familiar task. This argument is supported by some of the movement strategies shown in this study, for example, participants maintained a forward flexed thorax at the start of the tasks.

Fig. 6. Intra-subject variability for the thoracic, shoulder/humerothoracic, elbow/forearm and wrist rotations for the retrieve from shelf, comb and perineal care ADLs, note that wrist rotations are not presented for the perineal care tasks trials because of gaps in the hand markers data. The values shown are averages for the variability across 0–100% of the movement cycle. Simulated tasks (STs) are shown in solid grey and functional tasks (FTs) are shown in patterned grey, error bars represent one standard deviation of the mean. * show significant differences in the intra-subject variability between functional and simulated tasks (Task column shown in Table 3).
and end of the eating trials when provided with a spoon and a bowl despite having the same start and end hand positions as the simulated task.

One aspect of importance which is absent in upper limb kinematic assessments and has not been directly compared in this study is the muscular power requirements of completing ADLs (Habermeyer et al., 2006). This is of particular importance to clinical populations. The simplification of ADLs in the simulated movements means that the power required to complete these tasks are reduced and thus an important aspect of functional movement is overlooked. A patient with muscle weakness may be able to achieve a similar RoM to their normal state; however, it is maintaining the upper limb position as well as the controlled negotiation of a prop as they complete an ADL that may present a problem. By integrating the functional component into the ADLs chosen, it is more likely that compensatory movements that are a result of muscle weakness will be identified.

This study has shown that simulated tasks do not reduce intra- and inter-subject variability. However, such tasks still have the advantage of being overall easier to implement in a laboratory setting because of the absence of props. This may be one of the reasons that this approach was used in previous studies.

In addition to generic limitations of kinematic assessments discussed here, the study is also limited by the small number of participants and the inclusion of asymptomatic subjects only. Including patient populations may reveal compensatory movements that have not been captured in this study group.

In conclusion, this study recommends the use of functional tasks to replicate movements in ADLs. Simulated tasks do not replicate the movements required to perform ADLs and thus cannot be used to assess upper limb functional requirements. In addition, these tasks fail at reducing the movement variability naturally present in upper limb movements.

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Conflict of interest

No conflicts of interest.

References


