Journal of Biomechanics 76 (2018) 119–128

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

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

Sarah A.F. Taylor [a], Angela E. Kedgley [b], Alexander Humphries [a], Aliah F. Shaheen [a,c,*]

[a] Centre for Biomedical Engineering, Department of Mechanical Engineering Sciences, University of Surrey, Staghill Campus, Guildford GU2 7XH, UK
[b] Department of Bioengineering, Imperial College London, South Kensington Campus, London SW7 2AZ, UK
[c] Department of Life Sciences, Brunel University London, Kingston Lane, Uxbridge, Middlesex UB8 3PH, UK

ARTICLE INFO

Article history:
Accepted 30 May 2018

Keywords:
Activities of daily living (ADLs)
Thorax
Shoulder
Elbow
Wrist
Range of motion
Kinematics

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.

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 (Metcalf 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.),

* Corresponding author at: Department of Life Sciences, Brunel University London, Kingston Lane, Uxbridge, Middlesex UB8 3PH, UK.

E-mail address: aliah.shaheen@brunel.ac.uk (A.F. Shaheen).

https://doi.org/10.1016/j.jbiomech.2018.05.040
0021-9290/

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
Showing the five activities of daily living (ADL), the instructions given to the subjects for performing a functional task and the corresponding simulated task. Note that in all tasks the starting and finishing positions of the hand were pre-determined.

ADL	Functional task (FT)	Simulated task (ST)
Wash	Use the sponge to wash your contralateral armpit	Touch your contralateral armpit (van Andel et al., 2008, Murray and Johnson, 2004)
Eat	Use the spoon and bowl to feed yourself	Touch your mouth (Mackey et al., 2006)
Comb	Use the comb to comb the centre section of your hair from the front to the back of your head	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)
Retrieve from shelf	Retrieve the bottle on the shelf and place it on the table on the cross	Point at the cross on the bottle in front of you (Petuskey et al., 2007) and then point at the cross on the table
Perineal care	Touch the marker on the underside of your seat, going around the back of your body	Touch your back pocket (Doorenbosch et al., 2003, Petuskey et al., 2007, van Andel et al., 2008)

0 to 100% of the movement cycle of the joint rotations in each task were computed for each participant. These mean angles represented the movement patterns (temporal characteristic of joint movement). Using these values, maximum, minimum and ranges of motion (difference between maximum and minimum) were computed for the joint rotations of interest. The standard deviations between the three repeats of each task for each participant were used to calculate intra-subject variability. Inter-subject variability was calculated as the standard deviation between the means of the different subjects. This was done independently for the thoracic lateral rotation, axial rotation and forward flexion, the humerothoracic elevation plane, elevation angle and internal/external rotation, elbow flexion, forearm pronation and wrist radial/ulnar deviation and flexion.

Paired *t*-tests were used to assess differences between maximum, minimum and ranges of motion of the joint rotations of interest in FT and ST for each movement. To capture variations in the time-dependent variables (movement patterns and intra-subject variability) two-factor repeated measures ANOVA tests with Bonferroni corrections were used; the first factor was the type of movement (FT vs. ST) and the second was the percentage of movement (from 0 to 100% at 10% intervals). This would allow an assessment of differences in the mean joint rotations between FT and ST and the interaction effect between task and percentage of movement would reveal whether the difference was true for all or part of the movement cycle. Plots of the means of joint angles in FT and ST against the movement cycle were used to interpret the interaction effect where it was significant. The statistical tests were carried out independently for the joint rotations of interest listed above and the significance was set at $p < 0.05$.

3. Results

The comparison between FT and ST for the five chosen ADLs was achieved by considering movement characteristics (maximum and minimum angles, ranges of motion and movement patterns) and movement variability (intra-subject and inter-subject variations).

For the perineal care task, wrist rotations were not calculated due to large gaps in the data of the markers attached to the hand when participants reached underneath the seat.

3.1. Movement characteristics

The maximum and minimum angles of joint rotations and ranges of motion for the FTs and STs are shown in Figs. 1–4 for the thorax, humerothroacic joint, elbow/forearm and wrist respectively. For the thoracic rotations, differences between the FTs and STs can be seen in lateral flexion, axial rotation and flexion for all ADLs except the comb task (Fig. 1). The thoracic RoMs were significantly greater when performing FTs compared to STs. The majority of the differences are in lateral flexion and axial rotation where FTs had 4–15°, and 2.5–10° greater RoMs in these movements respectively. A substantial difference of approximately 15° in the range of thoracic lateral flexion can be seen for the perineal care trials. The FT eat trials showed increased forward flexion compared to ST (means of 24° and 11°); the difference was present for the minimum and maximum angles as well as in the RoM. In FT eat trials, participants got closer to the bowl to avoid spilling the contents of the spoon and maintained an increased forward flexion throughout the trial in preparation for eating.

The shoulder plane of elevation and internal/external rotation showed greater RoMs for the perineal care FT compared to ST (90° vs. 79° and 77° vs. 63° respectively). Differences in the range used between the FTs and STs were also present in the plane of elevation for the comb (68° vs. 81°) and retrieve from shelf tasks (107° vs. 129°), where STs had a greater RoM than FTs (Fig. 2). The eat FT showed approximately 16° greater maximum elevation angle and the perineal care FT showed a 17° greater internal rotation.

The forearm pronation/supination angle showed no differences between FTs and STs for the five ADLs (Fig. 3). Differences in elbow flexion can be seen for the perineal and eat trials, where ST had between 9 and 10° greater flexion angles than FT, and in retrieve from shelf, where the elbow flexion was 48° greater for FT.

The wrist rotations showed 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 (Fig. 4). The greatest differences were seen 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

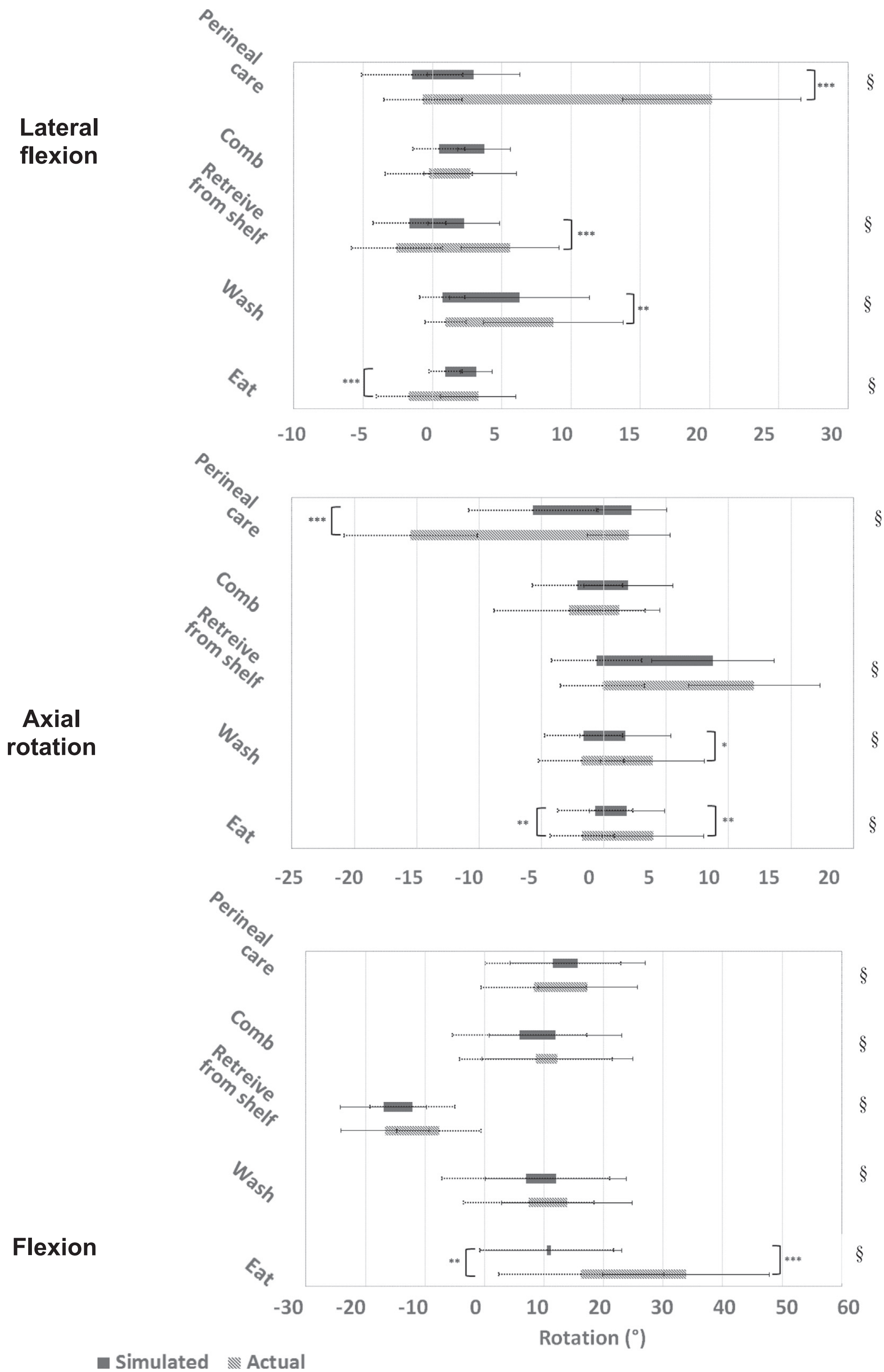

Fig. 1. The maximum, minimum and ranges of motion for the thoracic lateral flexion, axial rotation and forward flexion for the eat, wash, retrieve from shelf, comb and perineal care ADLs. Simulated tasks (STs) are shown in solid grey and functional tasks (FTs) are shown in patterned grey, error bars 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.

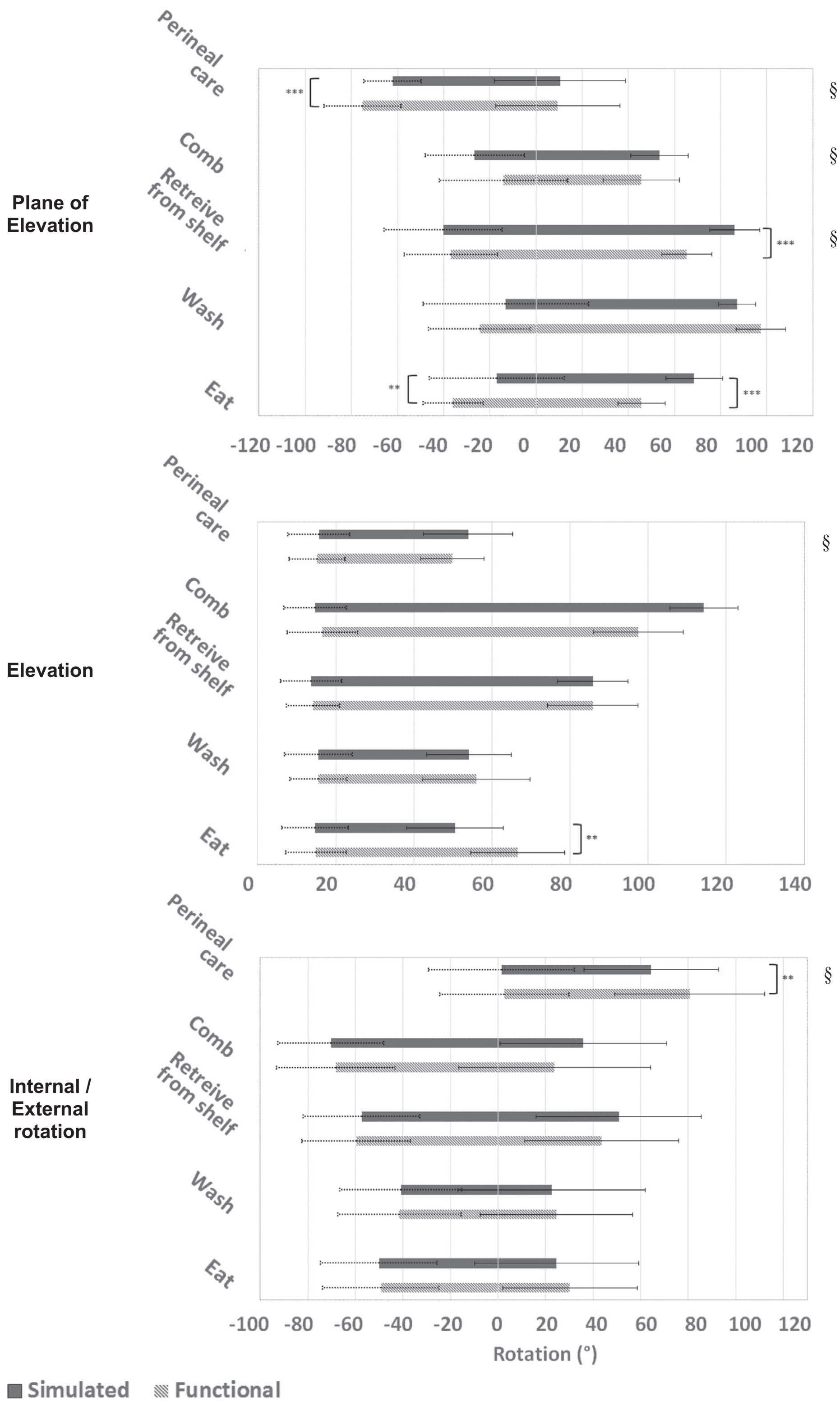

Fig. 2. The maximum, minimum and ranges of motion for the shoulder/humerothoracic plane of elevation, elevation and internal/external rotation (axial rotation) for the eat, wash, retrieve from shelf, comb and perineal care ADLs. Simulated tasks (STs) are shown in solid grey and functional tasks (FTs) 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.

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

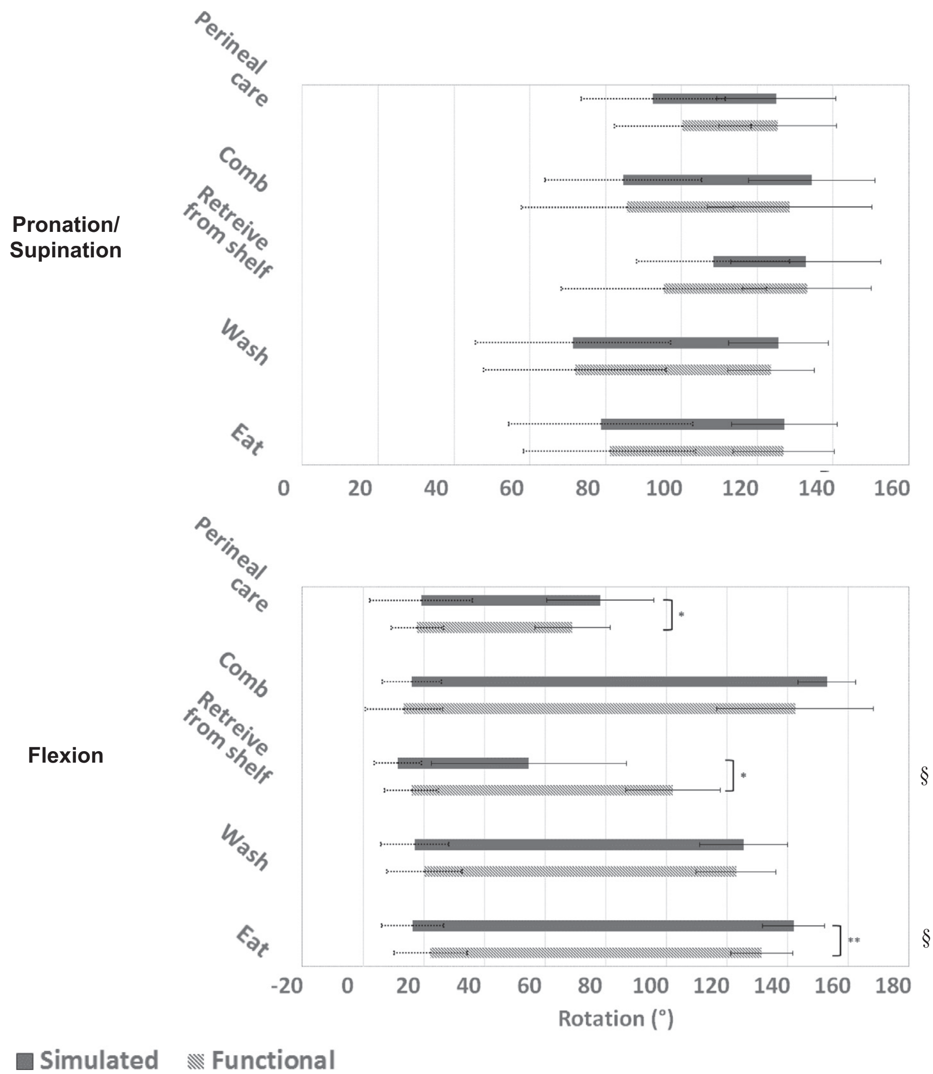

Fig. 3. The maximum, minimum and ranges of motion for the forearm pronation/supination and elbow flexion for the eat, wash, retrieve from shelf, comb and perineal care ADLs. Simulated tasks (STs) are shown in solid grey and functional tasks (FTs) are shown in patterned grey, error bars represent ± one 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.

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

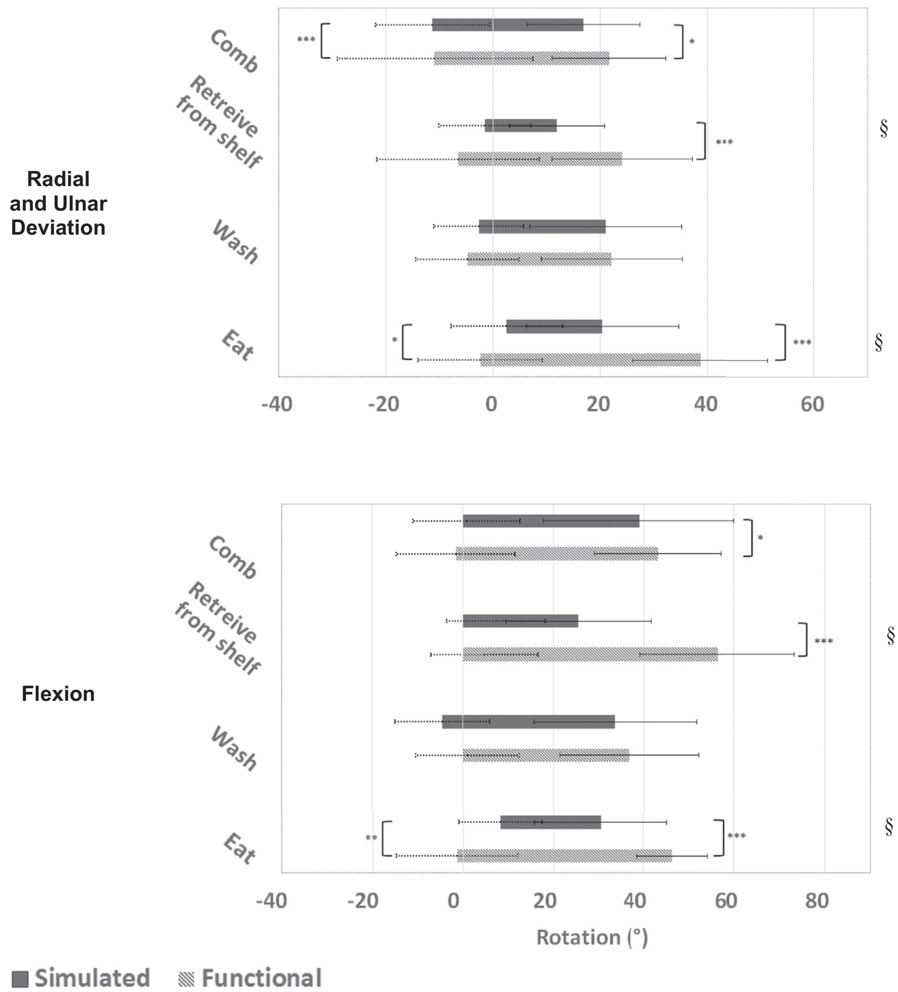

Fig. 4. The maximum, minimum and ranges of motion for the wrist radial/ulnar deviation and flexion for the eat, wash, retrieve from shelf and comb ADLs. Simulated tasks (STs) are shown in solid grey and functional tasks (FTs) are shown in patterned grey, error bars represent ± one standard deviation 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.

Table 2
Results of the repeated-measures ANOVA tests for differences in the movement patterns 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.

Segment/Joint	Rotation	Eat		Wash		Retrieve from shelf		Comb		Perineal care	
		Task p-value	Task × Percentage p-value	Task p-value	Task × Percentage p-value	Task p-value	Task × Percentage p-value	Task p-value	Task × Percentage p-value	Task p-value	Task × Percentage p-value
Thorax	Lateral flexion	0.226	**<0.001**	**0.008**	**0.004**	**0.046**	**<0.001**	0.367	0.083	**<0.001**	**<0.001**
	Axial rotation	0.113	**0.001**	0.309	**0.004**	0.370	**0.028**	0.628	0.199	**<0.001**	**<0.001**
	Flexion	**<0.001**	**<0.001**	0.580	**0.025**	0.275	**0.008**	0.465	**<0.001**	0.669	**<0.001**
Humero-thoracic	Plane of elevation	**0.004**	0.069	0.909	**0.008**	**<0.001**	**<0.001**	0.878	0.316	**0.018**	0.152
	Elevation	0.152	**<0.001**	**0.047**	**0.044**	0.414	0.075	0.485	**0.057**	**<0.001**	**<0.001**
	Internal rotation	0.693	**0.001**	0.742	0.225	**0.010**	**<0.001**	0.572	0.153	**0.002**	**0.037**
Forearm	Pronation	0.529	0.051	**0.011**	**0.005**	0.071	0.285	0.766	0.135	0.334	0.263
Elbow	Flexion	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.669	0.183	**<0.001**	**<0.001**
Wrist	Radial deviation	**0.022**	**<0.001**	0.620	0.054	0.087	**<0.001**	**0.007**	0.720		
	Flexion	**0.022**	**0.001**	0.117	**0.045**	**0.001**	**<0.001**	0.464	0.158		

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.

Segment/Joint	Rotation	Eat		Wash		Retrieve from shelf		Comb		Perineal Care	
		Task p-value	Task × Percentage p-value	Task p-value	Task × Percentage p-value	Task p-value	Task × Percentage p-value	Task p-value	Task × Percentage p-value	Task p-value	Task × Percentage p-value
Thorax	Lateral flexion	**0.036**	0.298	0.712	0.502	**0.002**	**0.038**	0.491	0.328	**0.001**	**0.028**
	Axial rotation	0.579	0.556	0.695	0.256	0.608	0.178	0.584	0.284	0.124	0.387
	Flexion	0.158	**0.009**	0.212	0.488	0.159	0.324	0.150	0.441	0.482	0.123
Humero-thoracic	Plane of elevation	0.239	0.209	0.378	0.290	0.524	0.217	0.426	0.460	0.124	0.297
	Elevation	0.394	**0.022**	0.890	0.120	0.728	**0.030**	0.882	0.514	0.357	0.525
	Internal rotation	0.600	0.253	0.449	0.540	0.454	0.136	0.458	0.376	0.341	0.113
Forearm	Pronation	0.136	**0.033**	0.262	**0.031**	0.779	0.200	0.161	0.632	0.080	0.339
Elbow	Flexion	**0.003**	**<0.001**	0.499	**<0.001**	**0.041**	0.175	0.375	0.437	0.425	0.149
Wrist	Radial deviation	0.358	0.105	0.133	0.227	0.055	0.056	**0.026**	**0.016**		
	Flexion	**0.007**	**0.022**	0.157	0.249	**0.044**	0.144	0.264	0.702		

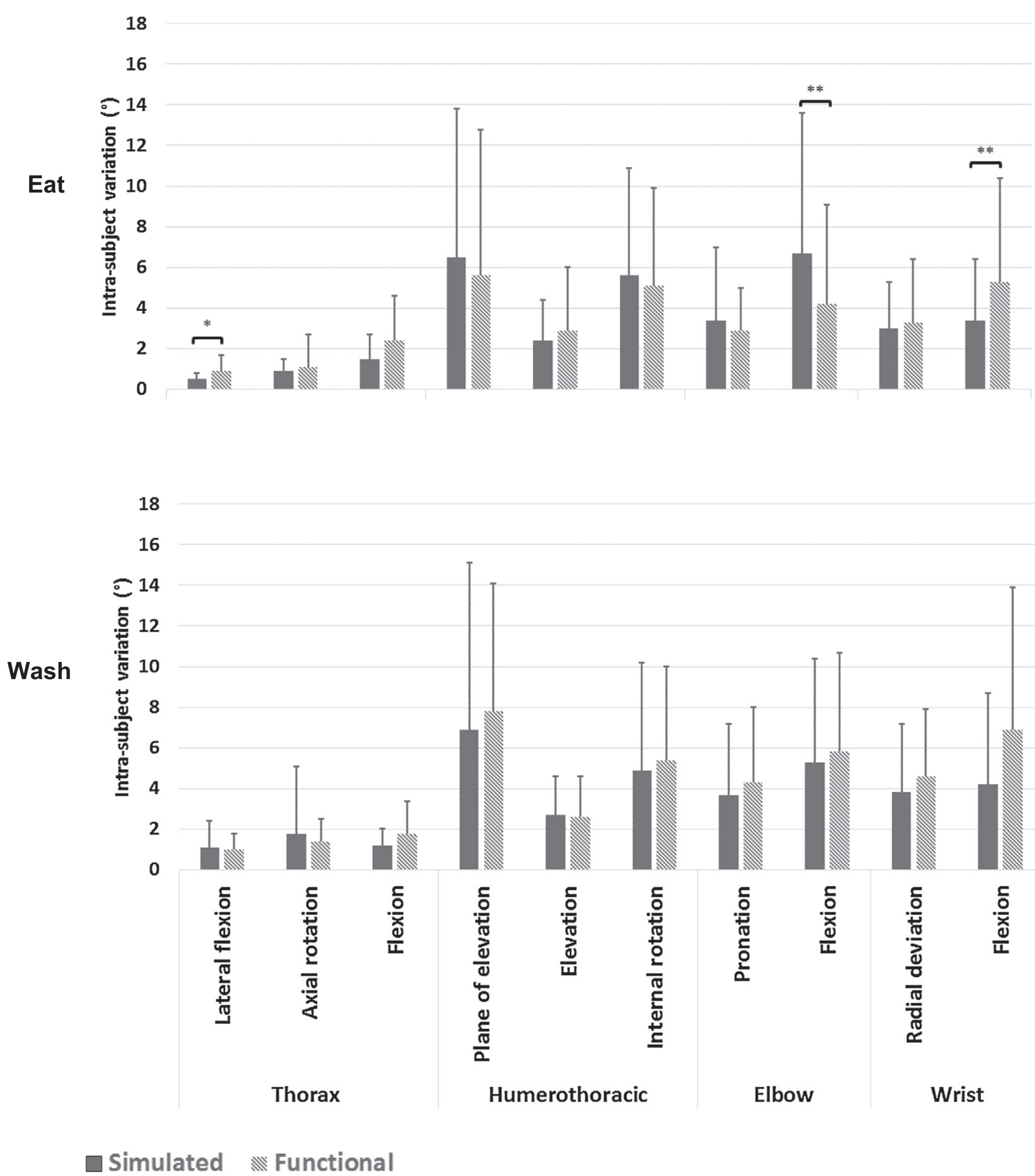

Fig. 5. Intra-subject variability for the thoracic, shoulder/humerothoracic, elbow/forearm and wrist rotations for the eat and wash ADLs, the values shown are averages for the variability across 0–100% of the movement cycle. Simulated tasks (STs) are shown in solid grey and functional tasks (FTs) are 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).

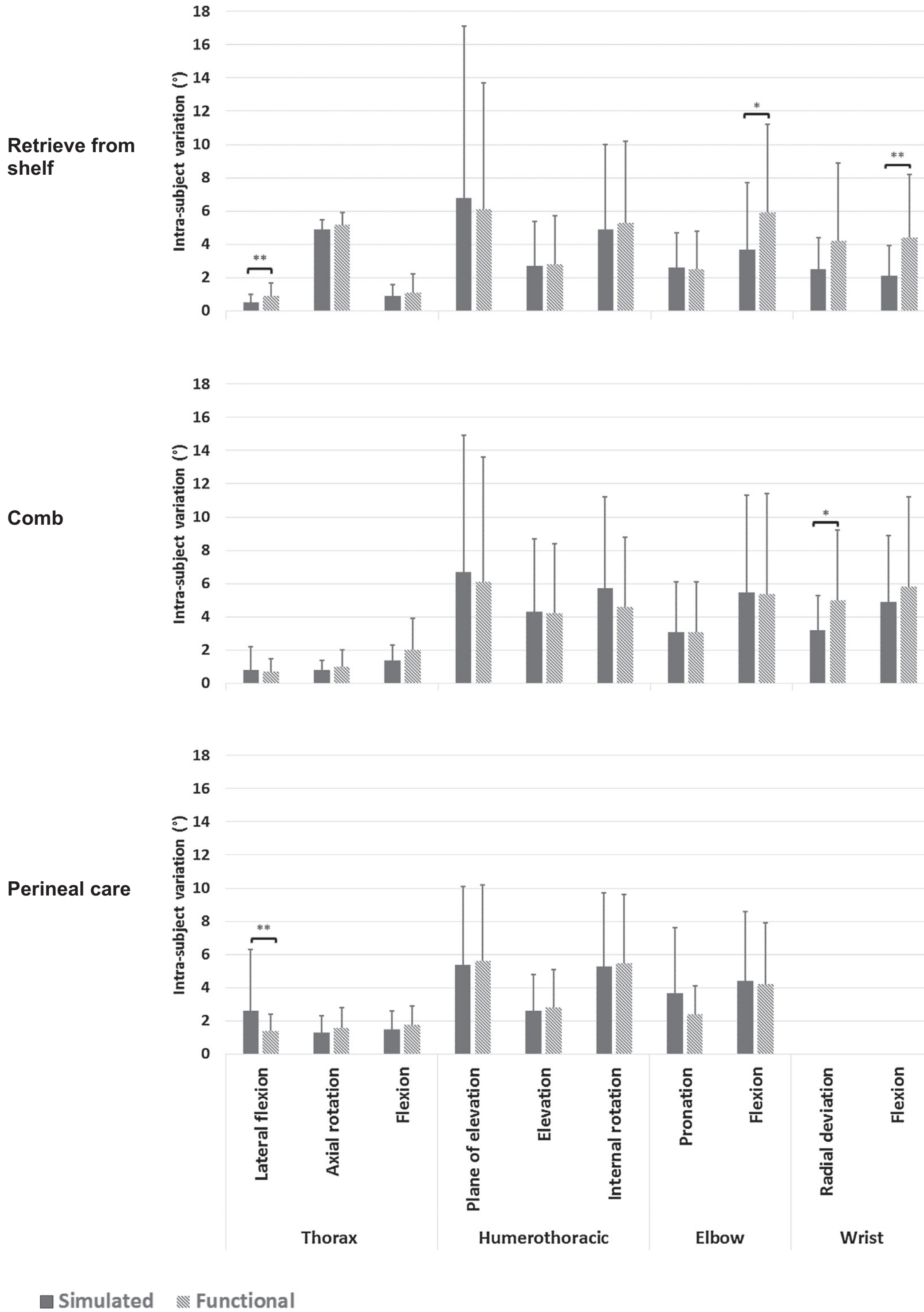

Fig. 6. Intra-subject variability for the thoracic, shoulder/humerothoracic, elbow/forearm and wrist rotations for the retrieve from shelf, comb and perineal care ADLs, note that wrist rotations are not presented for the perineal care tasks trials because of gaps in the hand markers data. The values 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).

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

Table 4
The mean inter-subject variabilities for the different rotation when using the simulated and functional approaches. Inter-subject variability is computed using the standard deviation of the mean rotations of all subjects, the values here are averaged across the full (0–100%) movement cycle.

		Inter-subject variability (°)									
		Eat		Wash		Retrieve from shelf		Comb		Perineal care	
Segment/Joint	Rotation	Functional	Simulated	Functional	Simulated	Functional	Simulated	Functional	Simulated	Functional	Simulated
Thorax	Lateral flexion	2.7	1.2	3.6	3.1	2.7	2.4	3.3	2.0	4.7	3.4
	Axial rotation	3.5	3.0	3.6	3.4	3.9	3.6	4.1	3.5	4.7	3.9
	Flexion	13.3	11.3	11.1	12.7	6.7	6.7	12.8	10.9	8.6	11.5
Humero-thoracic	Plane of elevation	16.8	20.6	18.4	21.9	18.6	18.4	18.3	17.6	23.9	24.8
	Elevation	10.3	10.5	11.5	10.5	10.3	9.9	12.0	10.8	7.9	10.4
	Internal rotation	28.6	29.4	28.2	31.2	29.6	30.0	34.6	31.8	29.6	27.7
Forearm	Pronation	19.4	22.8	22.0	22.8	26.3	19.5	28.0	23.9	18.2	18.5
Elbow	Flexion	11.7	14.2	17.1	15.2	15.9	15.3	16.4	18.1	11.3	15.2
Wrist	Radial deviation	13.8	12.5	10.5	11.2	12.1	8.4	11.2	11.2		
	Flexion	13.2	12.1	16.0	13.4	14.0	12.9	14.5	17.0		

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.

Acknowledgements

The authors would like to thank Mr David Gould for his technical support over the course of this study.

Conflict of interest

No conflicts of interest.

References

Aizawa, J., Masuda, T., Koyama, T., Nakamaru, K., Isozaki, K., Okawa, A., Morita, S., 2010. Three-dimensional motion of the upper extremity joints during various activities of daily living. J. Biomech. 43 (15), 2915–2922.
Doorenbosch, C.A., Harlaar, J., Veeger, D.H., 2003. The globe system: an unambiguous description of shoulder positions in daily life movements. J. Rehabil. Res. Dev. 40 (2), 147.
Ellis, B., Bruton, A., Goddard, J.R., 1997. Joint angle measurement: a comparative study of the reliability of goniometry and wire tracing for the hand. Clin. Rehab. 11 (4), 314–320.
Fowler, N.K., Nicol, A.C., 2001. Functional and biomechanical assessment of the normal and rheumatoid hand. Clin. Biomech. 16 (8), 660–666.
Gamage, S.S.H.U., Lasenby, J., 2002. New least squares solutions for estimating the average centre of rotation and the axis of rotation. J. Biomech. 35 (1), 87–93.
Habermeyer, P., Magosch, P., Lichtenberg, S., 2006. Classifications and Scores of the Shoulder. Springer Science & Business Media.
Hall, L.C., Middlebrook, E.E., Dickerson, C.R., 2011. Analysis of the influence of rotator cuff impingements on upper limb kinematics in an elderly population during activities of daily living. Clin. Biomech. 26 (6), 579–584.
Kontaxis, A., Cutti, A.G., Johnson, G.R., Veeger, H., 2009. A framework for the definition of standardized protocols for measuring upper-extremity kinematics. Clin. Biomech. 24 (3), 246–253.
Mackey, A.H., Walt, S.E., Lobb, G.A., Stott, N.S., 2005. Reliability of upper and lower limb three-dimensional kinematics in children with hemiplegia. Gait & Posture 22 (1), 1–9.
Mackey, A.H., Walt, S.E., Stott, N.S., 2006. Deficits in upper-limb task performance in children with hemiplegic cerebral palsy as defined by 3-dimensional kinematics. Arch. Phys. Med. Rehab. 87 (2), 207–215.
Magermans, D.J., Chadwick, E., Veeger, H., van der Helm, F., 2005. Requirements for upper extremity motions during activities of daily living. Clin. Biomech. 20 (6), 591–599.
Metcalf, C., Adams, J., Burridge, J., Yule, V., Chappell, P., 2007. A review of clinical upper limb assessments within the framework of the WHO ICF. Musculoskeletal Care 5 (3), 160–173.
Murray, I.A., Johnson, G.R., 2004. A study of the external forces and moments at the shoulder and elbow while performing every day tasks. Clin. Biomech. 19 (6), 586–594.
Petuskey, K., Bagley, A., Abdala, E., James, M.A., Rab, G., 2007. Upper extremity kinematics during functional activities: three-dimensional studies in a normal pediatric population. Gait & Posture 25 (4), 573–579.
Rocourt, M.H., Radlinger, L., Kalberer, F., Sanavi, S., Schmid, N.S., Leunig, M., Hertel, R., 2008. Evaluation of intratester and intertester reliability of the Constant-Murley shoulder assessment. J. Shoulder Elbow Surg. 17 (2), 364–369.
Shaheen, A.F., Alexander, C.M., Bull, A., 2011a. Effects of attachment position and shoulder orientation during calibration on the accuracy of the acromial tracker. J. Biomech. 44 (7), 1410–1413.
Shaheen, A.F., Alexander, C.M., Bull, A., 2011b. Tracking the scapula using the scapula locator with and without feedback from pressure-sensors: a comparative study. J. Biomech. 44 (8), 1633–1636.
Sheikhzadeh, A., Yoon, J., Pinto, V.J., Kwon, Y.W., 2008. Three-dimensional motion of the scapula and shoulder during activities of daily living. J. Shoulder Elbow Surg. 17 (6), 936–942.
van Andel, C.J., Wolterbeek, N., Doorenbosch, C.A., Veeger, D.H., Harlaar, J., 2008. Complete 3D kinematics of upper extremity functional tasks. Gait & Posture 27 (1), 120–127.
Veeger, H., Magermans, D.J., Nagels, J., Chadwick, E., van der Helm, F., 2006. A kinematical analysis of the shoulder after arthroplasty during a hair combing task. Clin. Biomech. 21, S44.
Wu, G., Siegler, S., Allard, P., Kirtley, C., Leardini, A., Rosenbaum, D., Whittle, M., D D'Lima, D., Cristofolini, L., Witte, H., 2002. ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion—Part I: Ankle, hip, and spine. J. Biomech. 35 (4), 543–548.
Wu, G., van der Helm, F.C.T., Veeger, H.D., Makhsous, M., van Roy, P., Anglin, C., Nagels, J., Karduna, A.R., McQuade, K., Wang, X., 2005. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—Part II: shoulder, elbow, wrist and hand. J. Biomech. 38 (5), 981–992.