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Oosterwijk, Anouk; Nieuwenhuis, Marianne; van der Schans, Cees P.; Mouton, Leonora

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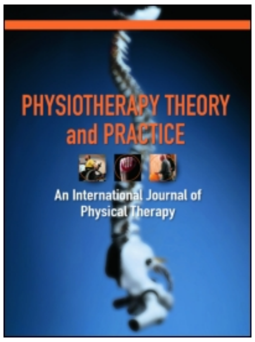

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A.M Oosterwijk, M.K Nieuwenhuis, C.P van der Schans & L.J Mouton

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REVIEW

Shoulder and elbow range of motion for the performance of activities of daily living: A systematic review

A.M Oosterwijk, MSc, PT[a,b,c], M.K Nieuwenhuis, PhD[b,d], C.P van der Schans, PhD[a,c], and L.J Mouton, PhD[d]

[a]Research group Healthy Ageing, Allied Health Care and Nursing, Hanze University of Applied Sciences Groningen, Groningen, the Netherlands; [b]Association of Dutch Burn Centers, Burn Center Martini Hospital, Groningen, the Netherlands; [c]Department of Rehabilitation, University of Groningen, University Medical Center Groningen, Groningen, the Netherlands; [d]Center for Human Movement Sciences, University of Groningen, University Medical Center Groningen, Groningen, the Netherlands

ABSTRACT

The loss of range of motion (ROM) in the upper extremities can interfere with activities of daily living (ADL) and, therefore, many interventions focus on improving impaired ROM. The question, however, is what joint angles are needed to naturally perform ADL. The present review aimed to compile and synthesize data from literature on shoulder and elbow angles that unimpaired participants used when performing ADL tasks. A search was conducted in PubMed, Cochrane, Scopus, CINAHL, and PEDro. Studies were eligible when shoulder (flexion, extension, abduction, adduction) and/or elbow (flexion, extension) angles were measured in unimpaired participants who were naturally performing ADL tasks, and angles were provided per task. Thirty-six studies involving a total of 66 ADL tasks were included. Results demonstrated that unimpaired participants used up to full elbow flexion (150°) in personal care, eating, and drinking tasks. For shoulder flexion and abduction approximately 130° was necessary. Specific ADL tasks were measured often, however, almost never for tasks such as dressing. The synthesized information can be used to interpret impairments on the individual level and to establish rehabilitation goals in terms of function and prevention of secondary conditions due to excessive use of compensatory movements.

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KEYWORDS
Contracture; range of motion; recovery of function; self-care; upper extremity

Introduction

An adequate active range of motion (ROM) in all directions in the upper extremity joints is necessary to perform all types of activities of daily living (ADL) (Pieniazek, Chwala, Szczechowicz, and Pelczar-Pieniazek, 2007; World Health Organization, 2001). When daily tasks such as eating, drinking, dressing, or personal care are impeded due to decreased ROM, then the activity must either be performed by using compensatory movement strategies (Adams, Grosland, Murphy, and McCullough, 2003; Bland, Beebe, Hardwick, and Lang, 2008; de Groot et al., 2011; Fradet et al., 2015; Metzger, Dromerick, Holley, and Lum, 2012; Pereira, Thambyah, and Lee, 2012) with the assistance of adaptive instruments or with help from other people. Each of these solutions might initially be considered as adequate, however, in the long term, they may all have physical, psychological, social, and/or financial disadvantages. For example, compensatory movements can lead to serious secondary conditions such as the overuse of muscles around the affected joint and an increased risk of soft tissue problems and degenerative joint diseases (de Groot et al., 2011; Mell, Childress, and Hughes, 2005; Veeger et al., 2006). Therefore, maintaining or restoring the ROM of joints is often a treatment goal in physical rehabilitation. However, this goal is usually established in terms of maximal ROM while, in fact, maintaining or restoring the minimal ROM necessary for the ADL of an individual could be sufficient. To set such ADL-related goals, reference values for minimally required ROM per ADL task are necessary.

Impaired ROM can occur at all ages as a consequence of medical conditions such as skin contractures due to a burn injury, muscle shortness, tendon or ligament contractures, adhesive capsulitis, bone fractures, plexus lesions, pain, or (neuromuscular) diseases such as cerebral palsy, rheumatoid arthritis, spinal cord injury, stroke, and others (Fergusson, Hutton, and Drodge, 2007; Klotz et al., 2013; Magee, 2008; Magermans, Chadwick, Veeger, and van der Helm, 2005; Petuskey et al., 2007; Skalsky and McDonald, 2012; van Andel et al., 2008; Willig et al., 1995). Residual pathologic motion patterns of upper extremity joints may persist following rehabilitation for patients who have

CONTACT A.M Oosterwijk, PT, MSc a.m.oosterwijk@pl.hanze.nl
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experienced a stroke (Kim et al., 2011) and after arthroplasty of the shoulder in patients with degenerative osteoarthritis (Kasten et al., 2010).

ROM is usually assessed as the degree of maximal mobility of a specific joint in a particular plane of movement. Although these measurements provide clinicians with valuable data, they do not specify information regarding the functional capacities of the individual patient in daily living. For instance, one patient with impaired shoulder flexion motion may not be able to raise an upper limb as far as unimpaired participants but may still be able to normally execute almost all ADL tasks. Whereas, on the other hand, another patient with approximately the same impairments can be physically disabled due to different demands of daily activities, for example, living in a house with many high cupboards. Furthermore, information concerning activity limitations is often gathered by questionnaires and/or by assessing a patient's performance on a small set of ADL tasks. However, from questionnaires, no insight into possible harmful movement patterns can be gained and, when using a small set of ADL tasks, knowledge on which set is most appropriate should be available.

In 1981, Morrey, Askew, and Chao (1981) had already drawn attention to the issue of functional ROM and performed an extensive study in which elbow angles of different movement directions were measured while participants (age range 21–75 years) performed 15 different ADL tasks. Since that time, the data of this study have been used as a reference. However, the use of these data is limited as only the elbow was assessed, and the 15 tasks that were analyzed did not address full ADL. Over the past decades, numerous additional studies have been conducted in which upper extremity joint angles were measured in (simulated) ADL tasks. In 2015, Korp, Richard, and Hawkins (2015) conducted a systematic review on functional ROMs in ADL for all upper and three lower extremity joints in the context of rehabilitation after burn injury. Per joint, they reported the tasks of upper and lower impairments of ROM with corresponding angles. Although this is valuable information, it does not provide full insight into the used ROMs of each specific ADL task and, therefore, does not allow individualized choices for required ROM based on function. Moreover, there is an impression that, for at least shoulder and elbow, additional data could have been discovered by conducting a literature search more specifically focusing on these joints. Therefore, the present review aimed to compile and synthesize data from literature on shoulder and elbow angles used by unimpaired participants performing ADL tasks.

Method

For this systematic review, the process described in 'Preferred Reporting Items for Systematic Reviews & Meta-Analysis (PRISMA)' was used (Moher, Liberati, Tetzlaff, and Altman, 2009). Ethics Committee(s) approval is 'Not Applicable' as the present study is a systematic review.

Databases and search strategy

A computerized literature search was conducted including the databases of PubMed, Cochrane, Scopus, CINAHL, and PEDro. Combinations of the following keywords and free text words were used: ADL; upper extremity; and ROM. Additionally, the words function, shoulder, and elbow were searched. The searches in the different databases were conducted from December 2014 to February 2015 (Appendix 1 for MeSH terms and number of retrieved studies per database). Furthermore, references of the retrieved studies were manually screened by two authors (AMO, LJM) and experts in the field were consulted.

Inclusion criteria and process of selection

The title and abstract were screened independently by two authors (AMO, LJM) focusing on unimpaired participants (investigated as the primary study group or control group of a randomized controlled trial (RCT)) performing ADL tasks in which shoulder and elbow angles were measured. Discrepancies were resolved with a discussion between the two reviewers and, in the event of uncertainty, the study was included for full text screening. The full text of potentially relevant studies was screened based on the more specific predefined inclusion criteria: 1) unimpaired participants performed ADL tasks without restriction of brace or splint; and 2) shoulder (thoracohumeral) and/or elbow angles were measured continuously and the maximal angles per joint and per movement direction were reported per task.

Assessment of quality of reviewed studies

The present review concerned cross-sectional observational studies. For this type of study, unlike RCTs or other clinical studies, no standard scales or checklists to assess quality or control for confounding variables were available (Sanderson, Tatt, and Higgins, 2007; Zeng et al., 2015). To be able to include quality assessment of studies, the recommendations of Sanderson, Tatt, and Higgins (2007) were followed to assess the risk of bias (ROB) using a selfdeveloped checklist covering the three most fundamental domains (i.e. participants, measurements of variables, and control of confounding). The categories included were: 1) representativeness of the study population; 2) hand dominance and prescription of the movement strategy; and 3) reliability of the methods used and definitions of measured angles. Methodological quality was appraised independently by two authors (AMO, LJM).

Data extraction

Data was extracted by one reviewer (AMO) regarding participant characteristics (number of participants, gender, age), methods (tracking system, number of ADL tasks that could be analyzed in this review, upper limb assessment), and the means (and standard deviations if reported in table or text) of joint angles of shoulder flexion, extension, abduction and adduction, and elbow flexion and extension. Graphically reported joint angles were extracted as accurately as possible and, if necessary, by enlarging the graph. A second reviewer (LJM) verified the extracted data.

Extraction of angles of shoulder motions

Although the unambiguous method to describe shoulder movements in 3D is in terms of plane of elevation (PoE) and angle of elevation (Doorenbosch, Harlaar, and Veeger, 2003; Wu et al., 2005), many studies described them in terms of flexion and extension as well as abduction and adduction. As in clinical practice this continues to be the most used description, therefore, in the present review, all reported shoulder movements were translated into the latter terminology. Angles of elevation in a PoE ≤ −45° were translated in terms of shoulder extension. Similarly, angles of elevation in a PoE between 45° and 135°, between −45° and 45°, and >135° were translated in terms of shoulder flexion, abduction, or adduction, respectively (Figure 1A-C).

Extraction of angles of elbow motions

In the literature, elbow movements are described in terms of flexion and extension. However, discrepancies exist on the definition of 0°. In the present review, 0° was established according to the anatomical posture (Figure 2).

In the event of doubt regarding the reported movement direction, decisions on the translations were made

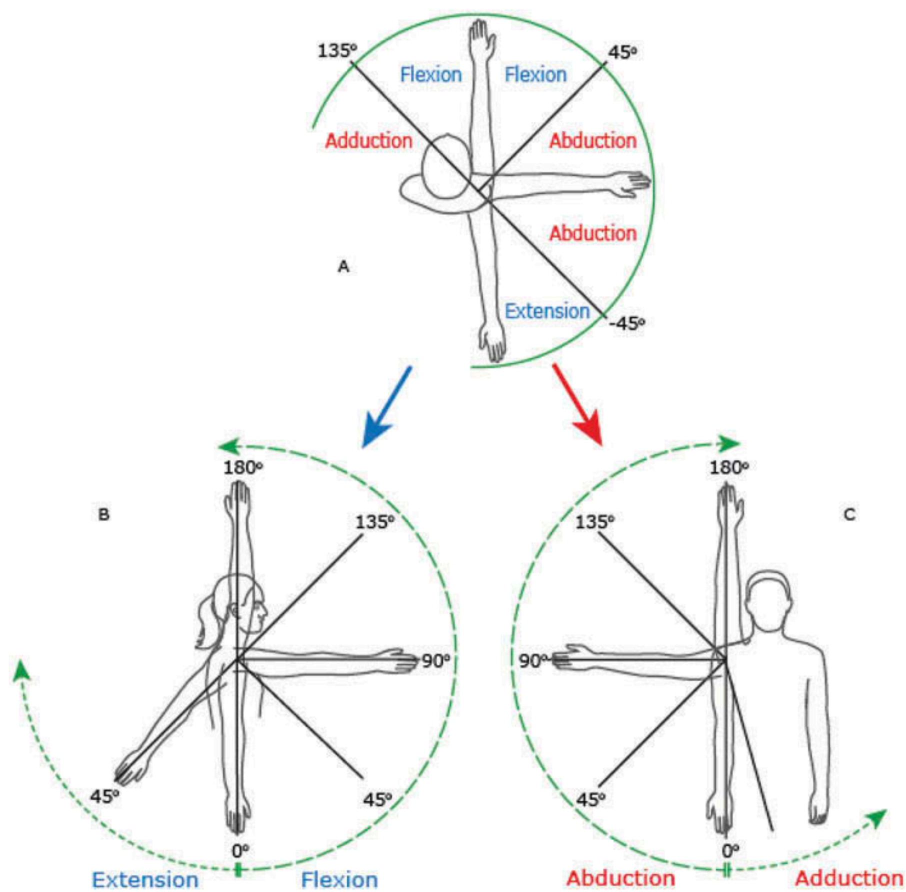

Figure 1. Movement directions of the shoulder. A: Transformation of planes of elevation (PoE) in shoulder extension (PoE≤-45°), flexion (45°<PoE≤135°), abduction (−45°<PoE≤45°) and adduction (PoE>135°). B: Angles of extension and flexion (sagittal view). C: Angles of abduction and adduction (frontal view).

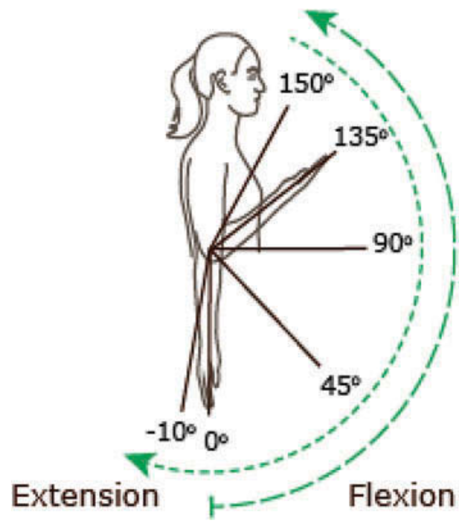

Figure 2. Movement directions of the elbow: angles of flexion and extension.

after the execution of the task and discussion between two researchers (AMO, LJM).

Outcomes

The primary outcome of interest was the required shoulder and/or elbow angle per movement direction while performing a specific ADL task. For all movement directions, this signified the largest measured angle per task except for elbow extension in which the smallest measured angle per task was the primary outcome of interest.

Data analysis and synthesis

For data analysis, tables organized per joint per movement direction were made, presenting an overview of all of the studies that measured required angles in ADL. Measured ADL tasks were clustered into two categories: 1) personal care and feeding tasks; or 2) daily, leisure, and work activities. If ADL tasks were simulated (i.e. merely touching a body part instead of performing the actual task) the tasks were listed under the most adequate category. Data synthesis was employed in order to generate an overview in figures showing the required angles per joint per movement direction per ADL task.

Results

The search strategy in the different databases resulted in a total of 583 potentially relevant studies (Figure 3). After screening the titles and abstracts, 543 were excluded. Full text screening of the remaining 40 studies meant that 27 studies could be included. Screening the reference lists of these revealed a further nine, thus a total of 36 studies were included in the present review (Tables 1 and 2).

From the 36 included studies, three (Cooper et al., 1993; Lee et al., 2007; Muller-Rath et al., 2009) reported data of two participant groups (differing in either age or gender). Three other studies (Kasten et al., 2009; Raiss et al., 2007, 2010) described data of the same participants, therefore, these studies were considered as one study group. The same applied for both studies of Maier et al. (2014a) and Maier et al. (2014b). Hence, in total, the present review yielded data on 36 study groups (Tables 1 and 2).

Risk of bias

The outcomes of the ROB assessment (Table 1) indicated that the representability of participants in four study groups was good (i.e. low ROB). In 28 study groups, this ROB was considered moderate either due to a small number of participants (<20) and/or the age and/or gender was not representative for the conclusions that were drawn. For instance, a conclusion was drawn for ‘adults’ even though the (vast) majority of participants were male and/or the range of ages indicated only young adults. For four study groups, the ROB on representability of participants was high. The ROB on study confounders (i.e. the performance of the ADL task with the dominant hand using a self-selected movement strategy) was low in approximately 16 of the study groups and moderate in 18. In two study groups, this ROB was considered high as tasks were performed with the non-dominant hand, and the movement strategy was instructed for parts of the ADL tasks or they needed to be performed as quickly as possible. In almost all of the study groups, reliability of the methods used and definitions of measured angles were judged to be good (i.e. low ROB).

Study and participant characteristics

The number of participants per study group varied between three and 59 with less than 20 participants in 25 study groups. The majority of the study groups consisted of adults (Table 2). The measurement of angles was performed with optical 3D tracking systems in all of the studies except for Morrey, Askew, and Chao (1981) who measured with an electro-goniometer. The number of analyzed ADL tasks per study group that could be included ranged from 1 to 18. In 26 study groups, upper extremity kinematics were measured while the ADL tasks were performed with the dominant upper limb, primarily the right upper limb. For eight groups, no information on dominance was

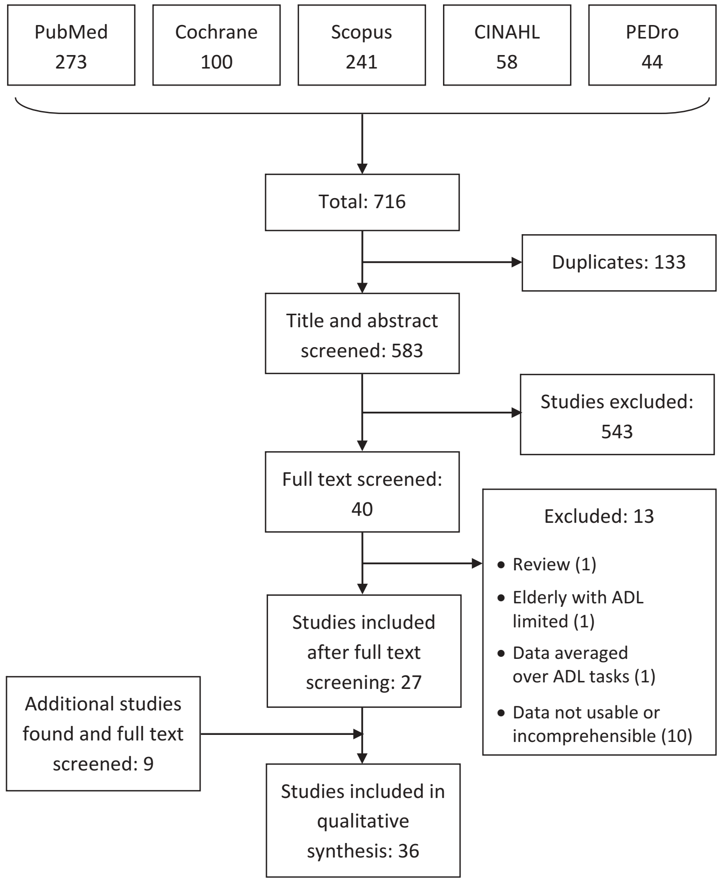

Figure 3. Flowchart of search strategy showing databases searched and number of papers retrieved from each database, papers rejected and papers reviewed.

provided and either left, right, or both upper limbs were studied (Table 2).

ADL tasks analyzed

Shoulder and elbow angles were analyzed for 66 different (simulated) ADL tasks of which 40 focused on personal care, seven on feeding, and 26 on a wide variety of daily, leisure, and work activities. Only 16 out of the 66 (24%) ADL tasks were analyzed in four or more study groups. The remaining tasks were studied in only one, two, or three study groups.

Concerning tasks studied in four or more study groups, the results of tasks performed in different study groups were generally quite similar (Appendix 2A-F). However, a number of significant differences were also determined. If outlier angles were not likely while performing that specific task, the ROB was used to decide whether or not these data points could be influenced by a confounder and, therefore, excluded for further analysis. This was the case for eight data points (see footnote of Appendix 2C, E, F).

Not all tasks were analyzed for all shoulder and elbow movement directions. For the shoulder, the required angles of flexion, extension, abduction, and adduction were analyzed in 30, 10, 23, and 4 study groups, respectively (Appendix 2A–D). Concerning the elbow, required flexion angles were analyzed in 26 study groups and extension in 21 (Appendix 2E-F).

Joint angles required in ADL

Shoulder and elbow angles per (simulated) ADL task used by unimpaired participants are exhibited in Figure 4 A–D.

Shoulder angles

Shoulder flexion angles <25° were not found for any of the ADL tasks, and angles of >45° were extracted in 34 of the 39 ADL tasks (Figure 4A). For nine tasks, angles between 90° and 135° were determined. The latter primarily involved tasks of personal care whereby the participant’s hand needed to be placed on the upper body or head but also comprised typing on a keyboard, turning a key, and turning a page. A maximal flexion angle of 142° was measured for ‘reaching above shoulder level to a shelf’. Shoulder extension angles

Table 1. Quality assessment (i.e. risk of bias) of the 36 included studies.

Year	Authors	Study group	A) ROB representability of participants	B) ROB study confounders	C) ROB measurements
1981	Morrey et al.	Adults + Elderly	+/-	+	+/-
1990	Safaee-Rad et al.	Male	+/-	+	+
1993	Cooper et al.	Male	+/-	+	+
		Female	+/-	+	+
2003	King et al.	Female	+	+/-	+
2003	Palmieri et al.	Children	+/-	+/-	+
2004	Mosqueda et al.	Children	+/-	+/-	+
2005	Magermans et al.	Female	+	+/-	+
2006	Henmi et al.	Adults	+/-	+/-	+
2007	Lee et al.	Adults	+/-	+	+
		Elderly	+/-	+	+
2007	Petuskey et al.	Children	+/-	+/-	+
2007/9/10	Raiss et al./Kasten et al./ Raiss et al.	Children + Adults	-	+	+
2008	van Andel et al.	Adults	+/-	+/-	+/-
2008	Carey et al.	Adults	+/-	+/-	+
2008	Sheikhzadeh et al.	Adults	+/-	+/-	+
2009	Muller Rath et al.	Male	+/-	+	+
		Female	+/-	+	+
2010	Aizawa et al.	Adults	+/-	+	+
2010	Murgia et al.	Adults	+/-	+	+
2010	Raminez-Garcia et al.	Adults	+/-	+	+
2010	Reid et al.	Children	+/-	+	+
2010	Sinha et al.	Adults	+	+/-	+
2011	Hall et al.	Elderly	+/-	+	+/-
2011	Masjedi et al.	Adults	+/-	+/-	+/-
2011	Murphy et al.	Adults + Elderly	+/-	+	+
2011	Sardelli et al.	Adults	+/-	+/-	+
2012	Karner et al.	Adults	-	+/-	+
2012	Namdari et al.	Adults	+/-	+/-	+
2014	Artiheiro et al.	Adults	-	+/-	+
2014	Bergsma et al.	Adults	+/-	+	+
2014	Kim et al.	Adults	+	+/-	+
2014	Klotz et al.	Children	-	-	+
2014	Lobo-Prat et al.	Male	+/-	+/-	+
2014a/14b	Maier et al./Maier et al.	Adults + Elderly	+/-	+/-	+
2014	Major et al.	Adults	+/-	-	+

ROB: Risk of Bias; +: Risk of Bias is low; +/-: Risk of Bias is moderate; -: Risk of Bias is high. A) Risk of Bias representability of participants. Low: ≥20 participants and good representability on both age and gender. Moderate: ≥20 participants and no representability on age and/or gender/<20 participants and no representability on age or gender; High: <20 participants and no representability on both age and gender. B) Risk of Bias study confounders. Low: dominant hand used and self-chosen movement strategy. Moderate: data dominant and non-dominant mixed or dominance not mentioned or prescription of movement strategy. High: data dominant and non-dominant mixed, or hand(s) and/or dominance not mentioned and prescription on movement strategy. C) Risk of Bias measurements. Low: reliability 3D measures good and definition of all measured angles given. Moderate: reliability 3D measures unknown or definition of (part of the) measured angles unclear. High: reliability 3D measures unknown and definition of all measured angles unclear.

were extracted for only 11 different ADL tasks. In eight of these tasks involving personal care, angles >40° were found (Figure 4A). Abduction angles >45° were ascertained in 15 of the 28 ADL tasks that included this movement direction (Figure 4B) while participants were able to perform all eating and drinking tasks with <45°. The greatest abduction angles of approximately 125° were required for 'placing the hand behind the head' and 'combing hair'. Adduction was only measured in four ADL tasks. The largest reported angle was for 'washing the contralateral axilla' (116°) (Figure 4B).

Elbow angles

The performance of many ADL tasks required a high degree of elbow flexion (Figure 4C). From the 45 tasks studied, only two tasks required a flexion angle <45°, and six required an angle between 45° and 90°. From the remaining 37 tasks, 16 needed a flexion angle of ≥135°. These latter mainly comprised tasks needed for personal care and feeding, though the largest angle was determined for 'using a telephone'. For 28 tasks, elbow extension was performed. During task performance, an angle of <20° was required for completing reaching tasks, touching one's own shoes or toes, opening a door, and turning a steering wheel (Figure 4D). Hyperextension of the elbow was not measured during any task.

Discussion

This systematic review presents the shoulder and elbow joint angles that are used by unimpaired participants to perform a total of 66 different ADL tasks and demonstrates that, in order to be able to perform ADL full ROM is critical in the elbow but is less significant in the shoulder.

The results for elbow flexion clearly indicated that many ADL tasks required angles from 130° up to 150°. It should be noted that these maximal angles were needed in basic ADL tasks of personal care, for instance, hair care

Table 2. Study and participant characteristics of the 36 studies reviewed.

Reference			Participant characteristics					Method		
					Age (years)					
Year	Authors	State, Country	*N*	Gender: %male	Mean	SD	Range	Tracking system	Number of ADL tasks*	Upper Limb
1981	Morrey et al.	Minnesota, USA	33	45			21–75	Triaxial electrogonio meter	15	D-L,R
1990	Safaee-Rad et al.	Canada	10	100			20–29	n.m.	3	D-R
1993	Cooper et al.	Canada	10	100			18–50	UM^2AS	3	D-R
			9	0			18–50	UM^2AS	3	D-R
2003	King et al.	Ohio, USA	59	0	27.5	9.9	20–50	M.A.C.	2	D-R
2003	Palmieri et al.	California, USA	49	n.m.			5–18	ExpertVision	2	L,R
2004	Mosqueda et al.	California, USA	51	n.m.	11.3		5–18	ExpertVision	3	L,R
2005	Magermans et al.	The Netherlands	24	0	36.8	11.8		Flock of Birds	6	R
2006	Henmi et al.	Japan	5	40	23		20–28	Vicon	3	L,R
2007	Lee et al.	Korea	16	100	26.9	2.6		M.A.C.	3	D
			12	50	67.9	4.8		M.A.C.	3	D
2007	Petuskey et al.	California, USA	28	n.m.			9–12	M.A.C.	5	L,R
2007/2009/2010	Raiss et al./ Kasten et al./ Raiss et al.	Germany	7	n.m.	25	15	13–54	Vicon	10	D-R
2008	van Andel et al.	The Netherlands	10	60	28.5	5.7		Optotrak	4	D-R
2008	Carey et al.	Florida, USA	10	60	28	7.4		Vicon	3 out of 4	D-R
2008	Sheikhzadeh et al.	New York, USA	8	75	32		25–40	Motion Monitor	8	D
2009	Muller Rath et al.	Germany	8	100	25.5	2.9		Vicon	2	D-L,R
			8	0	26.8	2.7		Vicon	2	D-L,R
2010	Aizawa et al.	Japan	20	50	23	5	18–34	FASTRAK	16	D-R
2010	Murgia et al.	UK	6	n.m.	32.5	10.7		Vicon	1	D
2010	Ramirez-Garcia et al.	Mexico	5	40			24–32	APAS	5	D-R
2010	Reid et al.	Perth, Australia	10	50	10.5	1.2		n.m.	3	D
2010	Sinha et al.	UK	20	50	33.3		17–60	Polemus 3 Space Fastrak	18	n.m.
2011	Hall et al.	Canada	13	69			66–93†	Vicon	6	D-R
2011	Masjedi et al.	UK	12	83	43	15.8		Vicon	12	R
2011	Murphy et al.	Sweden	19	57	53		41–78	M.A.C.	1	D-R
2011	Sardelli et al.	Salt Lake City, USA	25	56	34	10		Vicon	17	D
2012	Karner et al.	Austria	15	73	24.1	1.5		Lukotronic	3 out of 4	D-R
2012	Namdari et al.	Pennsylvania, USA	20	90	29.2	1.9	26–34	FASTRAK	6 out of 10	D-L,R
2014	Artilheiro et al.	Brazil	11	18	24.1	3.7		Vicon	1	D-R
2014	Bergsma et al.	Netherlands	8	63	49.9	9.8		Vicon	2 out of 4	D-R
2014	Kim et al.	Korea	32	53	25.3	2.4		Vicon	1	D-L,R
2014	Klotz et al.	Germany	17	65	13		9–17	Vicon	5 out of 6	ND
2014	Lobo-Prat et al.	Spain	3	100	n.m.			BTS SMART-D	1	L
2014a/2014b	Maier et al./ Maier et al.	Germany	10	50	64.2	7		Vicon	4	D-R
2014	Major et al.	Chicago, USA	6	50	35	11		M.A.C.	1 out of 5	ND

*: Number of ADL tasks that could be analyzed in this review; †: Age range of patients and control participants; n.m.: not mentioned; M.A.C.: Motion Analysis Corporation; L: Left; R: Right; D: Dominant; ND: Non Dominant.

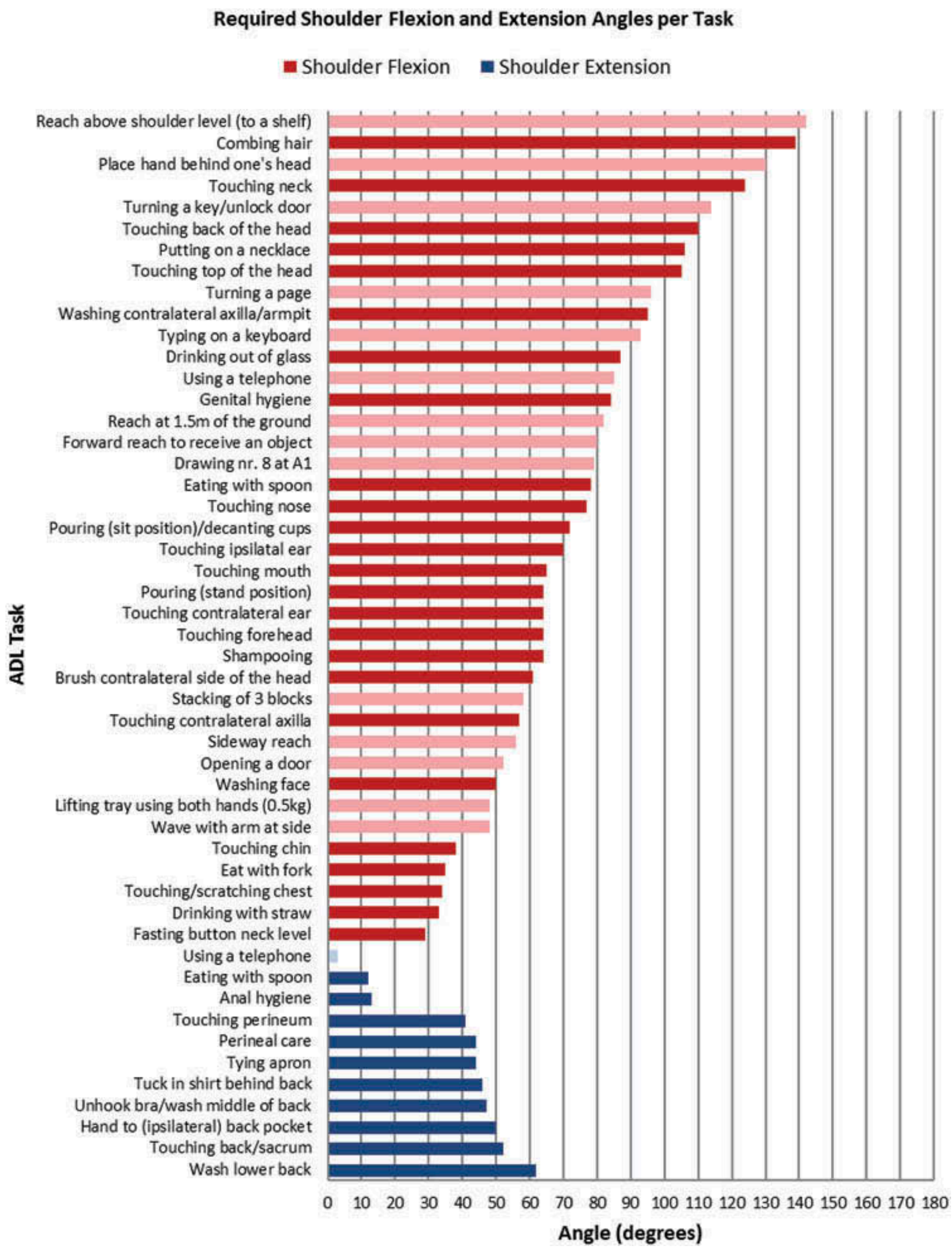

Figure 4(A). Shoulder and elbow angles per (simulated) ADL task used by unimpaired participants. Dark red and dark blue bars represent personal care and feeding tasks. Light red and light blue bars represent daily, leisure, and work activities. A: Shoulder flexion and extension. B: Shoulder abduction and adduction. C: Elbow flexion. D: Elbow extension.

and washing the face as well as in eating or drinking. The finding of the necessity of full elbow flexion in personal care and feeding tasks is in accordance with the conclusion of Ramanathan et al. (2000) and Klotz et al. (2013). However, in those studies, the maximal angles per separate task were not reported. Maximal elbow extension was not often necessary, although angles of 0–20° were required for tasks such as reaching and touching one's own toe, which represents putting on shoes and socks. Therefore, from our function-oriented synthesis, it can be concluded that elbow motion from 0° to 150° is required for ADL which is more than the generally used reference of 30°–130° (Morrey, Askew, and Chao, 1981). A comparison with the results concerning elbow motion presented in the function-oriented review of Korp, Richard, and Hawkins (2015) in the context of burn contractures is severely impaired as only a minimal number of studies on elbow motion were included, and no overview of results per task was provided.

Results of the shoulder were different compared to the elbow as, in order to perform ADL tasks, full shoulder motion proved to only be necessary in some

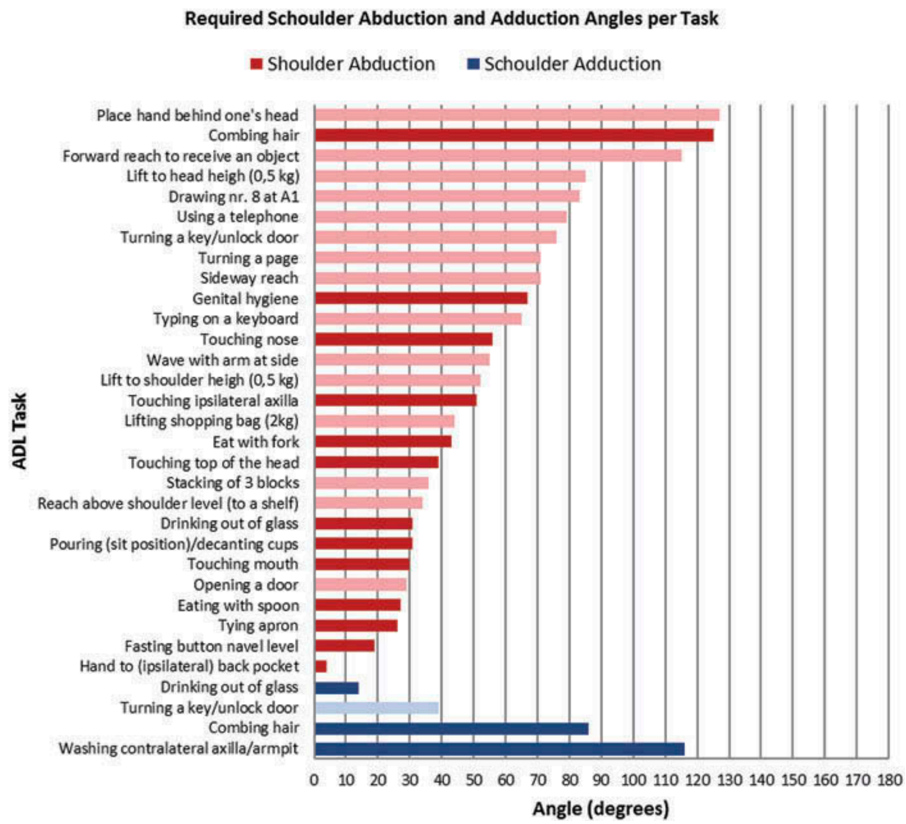

Figure 4(B). Continued.

of the movement directions. For both shoulder flexion and abduction, unimpaired participants only used approximately 130° of the maximally possible 180°. The only reported exception was a shoulder flexion angle of 142° in reaching toward a high shelf. On the contrary, up to 62° shoulder extension, which is considered full ROM (Magee, 2008), was found in tasks comprising personal care activities such as perineal hygiene and washing the lower back. Full shoulder adduction ROM was also needed in ADL, however, this movement direction was only minimally represented in the evaluated tasks. Korp, Richard, and Hawkins (2015) concluded that upper limits of 150° and 90° were needed in ADL for shoulder flexion and abduction, respectively. However, both values referred to the study of Koch et al. (1994), and it was uncertain how these values were determined.

The selection of ADL tasks varied among studies. Several explicitly motivated their choice of tasks, referring to: function assessment scales or tests (Aizawa et al., 2010; Lobo-Prat et al., 2014; Magermans, Chadwick, Veeger, and van der Helm, 2005; Major et al., 2014; Murgia, Kyberd, and Barnhill, 2010; Namdari et al., 2012; Reid et al., 2010; van Andel et al., 2008); surveys of patient groups (Carey, Jason Highsmith, Maitland, and Dubey, 2008; Karner, Reichenfelser, and Gfoehler, 2014); consultation with the clinical staff (Karner, Reichenfelser, and Gfoehler, 2014; Magermans, Chadwick, Veeger, and van der Helm, 2005); and/or on (some) task(s) selected in earlier studies or pilot testing (Aizawa et al., 2010; Kim et al., 2014; King, Thomas, and Rice, 2003; Masjedi, Lovell, and Johnson, 2011; Murphy, Willén, and Sunnerhagen, 2011; Ramirez-Garcia, Leija, and Munoz, 2010; Sardelli, Tashjian, and MacWilliams, 2011). Others did not justify their choices.

In the current review, all reported tasks were clustered into two categories (i.e. basic daily activities involving personal care and feeding, as well as other activities involving housework, communication, and transportation). Being able to perform basic daily activities is essential for independent living and should, therefore, receive special attention in research and also be a primary therapeutic aim. The use of more categories might be beneficial, however, deciding on how many and which categories would be optimal was beyond the scope of this study.

The results showed that, although the required angles during basic ADL were often measured, dressing tasks were not systematically studied. The possible

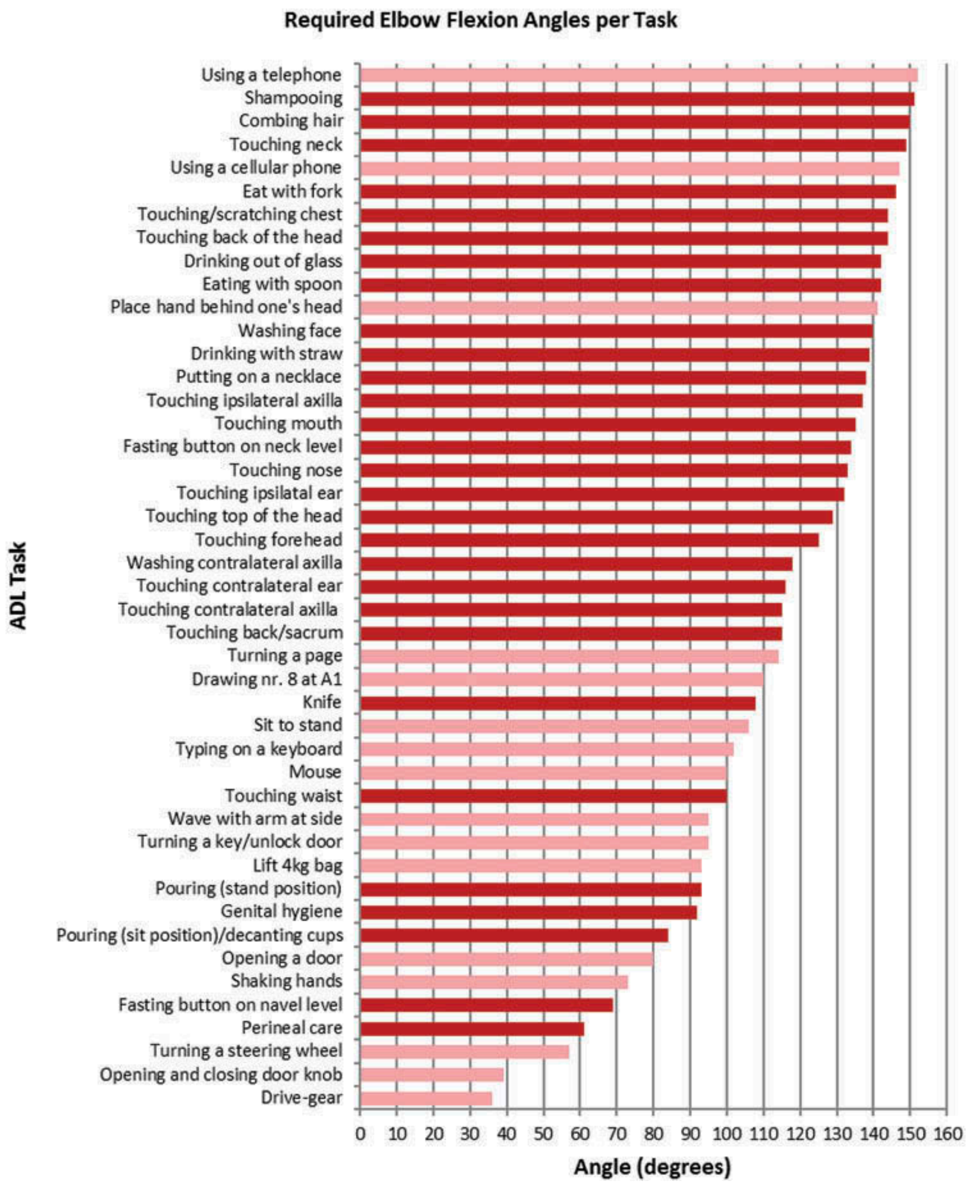

Figure 4(C). Continued.

reason for this is that angles are not detectable with 3D markers during dressing. Measurement systems independent of 3D markers can provide additional insight into dressing tasks as, for instance, 'putting on a coat' was shown to require large shoulder angles in community-dwelling seniors (Green, Boger, and Mihailidis, 2011). For other ADL tasks involving shoulder and elbow motion, more tasks could be included as well. For example, housekeeping was not measured at all. Transportation was examined solely by Anglin and Wyss (2000), however, these results could not be included in this review as only angles corresponding to the peak external moment were reported and not the angles needed to complete tasks. The development of an extensive list of basic ADL tasks and a list of ADL tasks based on a clinical perspective as well as from a patient perspective is strongly recommended.

In the present review, separate analyses were not feasible per age group, gender, or hand dominance of the participants. However, task execution can be influenced by these factors (Barnes, Van Steyn, and Fischer, 2001). Regarding age, only one study (Lee et al., 2007) included adults and the elderly. Results indicated similar elbow flexion angles in both groups but lower shoulder flexion angles in the elderly. Unfortunately, the male-female ratio also differed significantly between the age groups thereby limiting conclusions based solely on age. Concerning gender, separate male and female groups were present in two studies (Cooper et al., 1993; Muller-Rath et al., 2009) which concluded that differences between genders should be taken

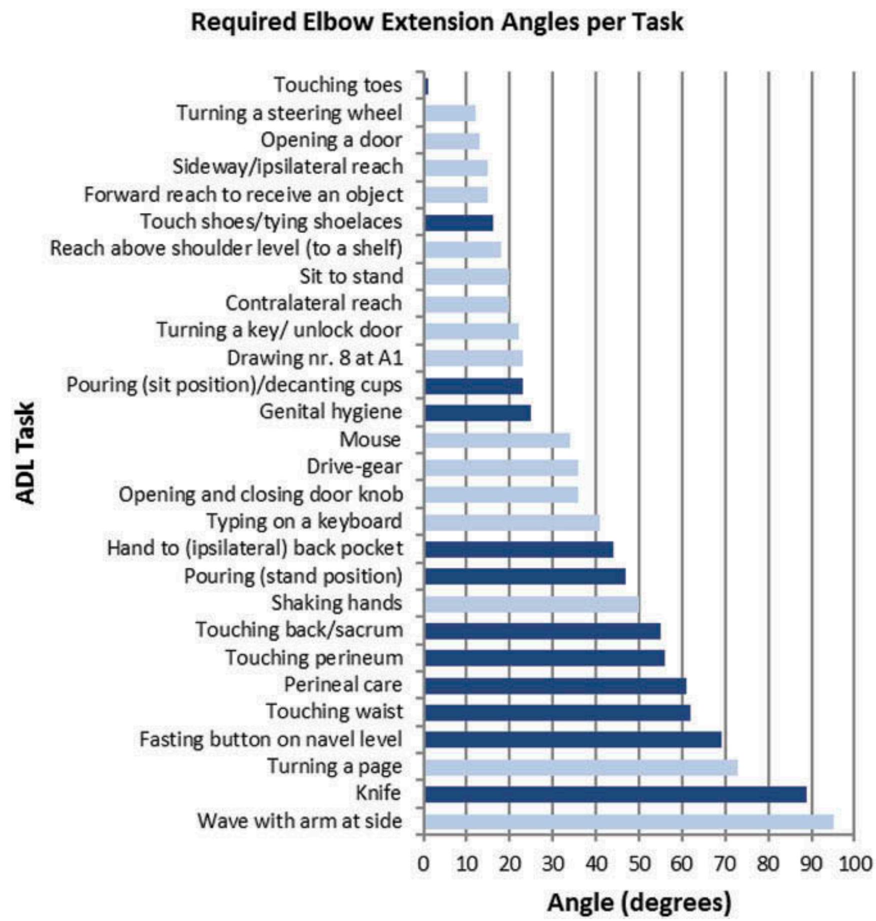

Figure 4(D). Continued.

into account as the averaged movement performance differed during the tasks. Whether these differences could be attributed to gender alone was uncertain as both groups involved fewer than ten participants, no standard deviations per group were provided, and no statistical analyses were conducted. Regarding hand dominance, in four studies (Henmi, Yonenobu, Masatomi, and Oda, 2006; Mosqueda et al., 2004; Palmieri et al., 2003; Petuskey et al., 2007), participants simultaneously performed tasks with both hands or in succession, however, none of the studies systematically compared the results. Therefore, although extensive attention is paid in the literature to age or gender differences regarding required shoulder and elbow ROM (Barnes, Van Steyn, and Fischer, 2001; Doriot and Wang, 2006; Medeiros, de Araujo, and de Araujo, 2013; Stathokostas, McDonald, Little, and Paterson, 2013), reliable information on differences in task execution is insufficient.

Limitations of the study

Although the results of the present review are noteworthy, caution is necessary when applying them to clinical practice. First, even though 66 ADL tasks were analyzed, still not all daily activities were assessed. Therefore, there may be tasks that require larger angles than those shown in this review.

Second, the synthesis of results focussed on the maximal angle per task. This angle may not be representative for each individual during the execution of tasks due to postural variabilities and variations such as body or upper limb length. Hence, some individuals will need larger joint angles in ADL and some may be able to perform daily tasks with somewhat smaller angles compared to the average. Despite such individual variabilities, the conclusion remains that many personal care and feeding tasks require extensive elbow flexion.

Third, the methodological quality was not optimal for all of the included studies but, overall, a low to moderate ROB was determined. Therefore, it is not believed that this has had consequences for the overall outcome of this review.

Fourth, for tasks that were studied in more than one reviewed study group, it was decided to use the highest value for Figure 4A–D as it was opined that this maximal value gave an indication of the joint angle required to complete tasks in all potential movement patterns as measured by the different individual studies. However, it could be argued that this choice led to a skewing of the results. The possibility of a full synthesis with forest plots was discussed as well but, due to the limited available data (group means plus SD) per movement direction per task (Appendix 2A-F), this was not possible.

Finally, in the present review, all shoulder movement data were translated from ISB terms to terms of flexion, extension, abduction, and adduction as it was suggested that this yielded the most beneficial information for the physical and occupational therapy practice. Consequently, for daily activities in which the plane of elevation angle was approximately 45°, the movement direction of that specific task would change from flexion to abduction or vice versa if this angle was a few degrees less or more. For instance, a PoE of 46° for pouring water into a glass (Aizawa et al., 2010) was described as flexion but would be described as abduction if this angle was 44°. However, as it involved only a few tasks, there is confidence that this translation has not influenced the primary conclusions. In addition, it was initially planned to include shoulder rotation movements in this review, however, it became apparent that results would be incomparable due to the different methods used to analyze rotation. A number of studies employed the ISB axial rotation definition (Doorenbosch, Harlaar, and Veeger, 2003; Wu et al., 2005) while others used the definition of the non-singular axial rotation (Masuda, Ishida, Cao, and Morita, 2008) or reported rotation data without mentioning the used method. Furthermore, the amount of humeral rotation needed to complete tasks depends on the position of the arm in space (Namdari et al., 2012). The current recommendation is that the method of 3D measuring for rotation must be described in detail in future research.

Future directions

First, for use in physical and occupational therapy practice, tables or figures with functional ROM should be developed per ADL category, age group, and eventually gender and hand dominance. Therefore, further research should focus on expanding the amount and diversity of tasks and being aware of the differences of the participants' characteristics. Second, additional research is required on how often and for how long especially large angles are used by unimpaired participants in ADL tasks during the day. As mentioned in the introduction, when functional ROM cannot be recovered, compensatory movements in other components of the coordinated joint system will be indispensable for accomplishing ADL tasks (de Groot et al., 2011; Mell, Childress, and Hughes, 2005; Trehan et al., 2015; Veeger et al., 2006). Such movements pose a risk for overuse problems. The magnitude of this risk depends on how often, for how long, and at which angle these compensatory movements are necessary during the day. Third, an impaired ROM cannot only hamper ADL but can also have an impact on patients' perceived (social) participation (Bartoszek et al., 2015; Fischer et al., 2014). To optimize and tailor mobility interventions, more research is needed on the correlation between ROM impairment, functioning, participation, and quality of life. Furthermore, inclusion and evaluation of patients' goals of treatment is crucial.

Implications for physiotherapy practice

Shoulder and elbow angles needed to perform daily activities by unimpaired participants have been investigated in many well-performed studies. Full ROM was critical in the elbow to be able to perform ADL but was less important in the shoulder when performing 66 (simulated) tasks. These data should be used to assess impairments on the individual level and to establish goals in physical and occupational therapy both in terms of function and prevention of secondary conditions due to overuse of compensatory movements.

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the article.

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References

Adams BD, Grosland NM, Murphy DM, McCullough M 2003 Impact of impaired wrist motion on hand and upper-extremity performance. Journal of Hand Surgery America 28: 898–903.

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. Journal of Biomechanics 43: 2915–2922.

Anglin C, Wyss UP 2000 Arm motion and load analysis of sit-to-stand, stand-to-sit, cane walking and lifting. Clinical Biomechanics 15: 441–448.

Artilheiro MC, Correa JC, Cimolin V, Lima MO, Galli M, de Godoy W, Lucareli PR 2014 Three-dimensional analysis of performance of an upper limb functional task among adults with dyskinetic cerebral palsy. Gait Posture 39: 875–881.

Barnes CJ, Van Steyn SJ, Fischer RA 2001 The effects of age, sex, and shoulder dominance on range of motion of the shoulder. Journal of Shoulder and Elbow Surgery 10: 242–246.

Bartoszek G, Fischer U, Grill E, Muller M, Nadolny S, Meyer G 2015 Impact of joint contracture on older persons in a geriatric setting: A cross-sectional study. Zeitschrift Für Gerontologie Und Geriatie 48: 625–632.

Bergsma A, Murgia A, Cup EH, Verstegen PP, Meijer K, de Groot IJ 2014 Upper extremity kinematics and muscle activation patterns in subjects with facioscapulohumeral dystrophy. Archives of Physical Medicine and Rehabilitation 95: 1731–1741.

Bland MD, Beebe JA, Hardwick DD, Lang CE 2008 Restricted active range of motion at the elbow, forearm, wrist, or fingers decreases hand function. Journal of Hand Therapy 21: 268–274.

Carey SL, Jason Highsmith M, Maitland ME, Dubey RV 2008 Compensatory movements of transradial prosthesis users during common tasks. Clinical Biomechanics 23: 1128–1135.

Cooper JE, Shwedyk E, Quanbury AO, Miller J, Hildebrand D 1993 Elbow joint restriction: Effect on functional upper limb motion during performance of three feeding activities. Archives of Physical Medicine and Rehabilitation 74: 805–809.

de Groot JH, Angulo SM, Meskers CG, van der Heijden-Maessen HC, Arendzen JH 2011 Reduced elbow mobility affects the flexion or extension domain in activities of daily living. Clinical Biomechanics 26: 713–717.

Doorenbosch CA, Harlaar J, Veeger DH 2003 The globe system: an unambiguous description of shoulder positions in daily life movements. Journal of Rehabilitation Research and Development 40: 147–155.

Doriot N, Wang X 2006 Effects of age and gender on maximum voluntary range of motion of the upper body joints. Ergonomics 49: 269–281.

Fergusson D, Hutton B, Drodge A 2007 The epidemiology of major joint contractures: A systematic review of the literature. Clinical Orthopaedics and Related Research 456: 22–29.

Fischer U, Bartoszek G, Muller M, Strobl R, Meyer G, Grill E 2014 Patients' view on health-related aspects of functioning and disability of joint contractures: A qualitative interview study based on the international classification of functioning, disability and health (ICF). Disability and Rehabilitation 36: 2225–2232.

Fradet L, Liefhold B, Rettig O, Bruckner T, Akbar M, Wolf SI 2015 Proposition of a protocol to evaluate upper-extremity functional deficits and compensation mechanisms: Application to elbow contracture. Journal of Orthopaedic Science 20: 321–330.

Green SL, Boger JN, Mihailidis A 2011 Toward enabling winter occupations: Testing a winter coat designed for older adults. Canadian Journal of Occupational Therapy 78: 57–64.

Hall LC, Middlebrook EE, Dickerson CR 2011 Analysis of the influence of rotator cuff impingements on upper limb kinematics in an elderly population during activities of daily living. Clinical Biomechanics 26: 579–584.

Henmi S, Yonenobu K, Masatomi T, Oda K 2006 A biomechanical study of activities of daily living using neck and upper limbs with an optical three-dimensional motion analysis system. Modern Rheumatology 16: 289–293.

Karner J, Reichenfelser W, Gfoehler M 2014 Kinematic and kinetic analysis of human motion as design input for an upper extremity bracing system. Proceedings of the 9th IASTED International Conference on Biomedical Engineering. Biomedical Engineering 2012: 376–383.

Kasten P, Maier M, Wendy P, Rettig O, Raiss P, Wolf S, Loew M 2010 Can shoulder arthroplasty restore the range of motion in activities of daily living? A prospective 3D video motion analysis study. Journal of Shoulder and Elbow Surgery 19: 59–65.

Kasten P, Rettig O, Loew M, Wolf S, Raiss P 2009 Three-dimensional motion analysis of compensatory movements in patients with radioulnar synostosis performing activities of daily living. Journal of Orthopaedic Science 14: 307–312.

Kim K, Park DS, Ko BW, Lee J, Yang SN, Kim J, Song WK 2011 Arm motion analysis of stroke patients in activities of daily living tasks: A preliminary study. Conference Proceedings: IEEE Engineering in Medicine and Biology Society 2011: 1287–1291.

Kim K, Song WK, Lee J, Lee HY, Park DS, Ko BW, Kim J 2014 Kinematic analysis of upper extremity movement during drinking in hemiplegic subjects. Clinical Biomechanics 29: 248–256.

King S, Thomas JJ, Rice MS 2003 The immediate and short-term effects of a wrist extension orthosis on upper-extremity kinematics and range of shoulder motion. American Journal of Occupational Therapy 57: 517–524.

Klotz MC, Kost L, Braatz F, Ewerbeck V, Heitzmann D, Gantz S, Dreher T, Wolf SI 2013 Motion capture of the upper extremity during activities of daily living in patients with spastic hemiplegic cerebral palsy. Gait Posture 38: 148–152.

Klotz MC, van Drongelen S, Rettig O, Wenger P, Gantz S, Dreher T, Wolf SI 2014 Motion analysis of the upper extremity in children with unilateral cerebral palsy-An assessment of six daily tasks. Research in Developmental Disabilities 35: 2950–2957.

Koch M, Gottschalk M, Baker DI, Palumbo S, Tinetti ME 1994 An impairment and disability assessment and treatment protocol for community-living elderly persons. Physical Therapy 74: 286–298.

Korp K, Richard R, Hawkins D 2015 Refining the idiom "functional range of motion" related to burn recovery. Journal Burn Care and Research 36: e136–145.

Lee JH, Chun MH, Jang DH, Ahn JS, Yoo JY 2007 A comparison of young and old using three-dimensional motion analyses of gait, sit-to-stand and upper extremity performance. Aging Clinical and Experimental Research 19: 451–456.

Lobo-Prat J, Font-Llagunes JM, Gomez-Perez C, Medina-Casanovas J, Angulo-Barroso RM 2014 New biomechanical model for clinical evaluation of the upper extremity motion in subjects with neurological disorders: an application case. Computer Methods in Biomechanics and Biomedical Engineering 17: 1144–1156.

Magee DJ 2008 Orthopedic Physical Assessment, 5thedn. St. Louis, Saunders Elsevier.

Magermans DJ, Chadwick EK, Veeger HE, van der Helm FC 2005 Requirements for upper extremity motions during activities of daily living. Clinical Biomechanics 20: 591–599.

Maier MW, Kasten P, Niklasch M, Dreher T, Zeifang F, Rettig O, Wolf SI 2014a 3D motion capture using the HUX model for monitoring functional changes with arthroplasty in patients with degenerative osteoarthritis. Gait Posture 39: 7–11.

Maier MW, Niklasch M, Dreher T, Zeifang F, Rettig O, Klotz MC, Wolf SI, Kasten P 2014b Motion patterns in activities of daily living: 3-year longitudinal follow-up after total shoulder arthroplasty using an optical 3D motion analysis system. BMC Musculoskeletal Disorders 15: 244.

Major MJ, Stine RL, Heckathome CW, Fatone S, Gart SA 2014 Comparison of range-of-motion and variability in upper body movements between transradial prosthesis users and able-bodied controls when executing goal-oriented tasks. Journal of Neuro Engineering and Rehabilitation 11: 132.

Masjedi M, Lovell C, Johnson GR 2011 Comparison of range of motion and function of subjects with reverse anatomy bayley-walker shoulder replacement with those of normal subjects. Human Movement Science 30: 1062–1071.

Masuda T, Ishida A, Cao L, Morita S 2008 A proposal for a new definition of the axial rotation angle of the shoulder joint. Journal of Electromyography and Kinesiology 18: 154–159.

Medeiros HB, de Araujo DS, de Araujo CG 2013 Age-related mobility loss is joint-specific: An analysis from 6,000 flexitest results. Age 35: 2399–2407.

Mell AG, Childress BL, Hughes RE 2005 The effect of wearing a wrist splint on shoulder kinematics during object manipulation. Archives of Physical Medicine and Rehabilitation 86: 1661–1664.

Metzger AJ, Dromerick AW, Holley RJ, Lum PS 2012 Characterization of compensatory trunk movements during prosthetic upper limb reaching tasks. Archives of Physical Medicine and Rehabilitation 93: 2029–2034.

Moher D, Liberati A, Tetzlaff J, Altman DG, Group PRISMA 2009 Reprint–preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. Physical Therapy 89: 873–880.

Morrey BF, Askew LJ, Chao EY 1981 A biomechanical study of normal functional elbow motion. Journal of Bone and Joint Surgery (Am) 63: 872–877.

Mosqueda T, James MA, Petuskey K, Bagley A, Abdala E, Rab G 2004 Kinematic assessment of the upper extremity in brachial plexus birth palsy. Journal of Pediatric Orthopedics 24: 695–699.

Muller-Rath R, Disselhorst-Klug C, Williams S, Braun C, Miltner O 2009 Influence of sex and side dominance on the results of quantitative, three-dimensional motion analysis of the upper extremities. Zeitschrift Für Orthopädie Und Unfallchirurgie 147: 463–471.

Murgia A, Kyberd PJ, Barnhill TA 2010 The use of kinematic and parametric information to highlight lack of movement and compensation in the upper extremities during activities of daily living. Gait Posture 31: 300–306.

Murphy MA, Willén C, Sunnerhagen KS 2011 Kinematic variables quantifying upper-extremity performance after stroke during reaching and drinking from a glass. Neurorehabilitation and Neural Repair 25: 71–80.

Namdari S, Yagnik G, Ebaugh DD, Nagda S, Ramsey ML, Williams GR, Mehta S 2012 Defining functional shoulder range of motion for activities of daily living. Journal of Shoulder and Elbow Surgery 21: 1177–1183.

Palmieri TL, Petuskey K, Bagley A, Takashiba S, Greenhalgh DG, Rab GT 2003 Alterations in functional movement after axillary burn scar contracture: A motion analysis study. Journal Burn Care and Rehabilitation 24: 104–108.

Pereira BP, Thambyah A, Lee T 2012 Limited forearm motion compensated by thoracohumeral kinematics when performing tasks requiring pronation and supination. Journal of Applied Biomechanics 28: 127–138.

Petuskey K, Bagley A, Abdala E, James MA, Rab G 2007 Upper extremity kinematics during functional activities: Three-dimensional studies in a normal pediatric population. Gait Posture 25: 573–579.

Pieniazek M, Chwala W, Szczechowicz J, Pelczar-Pieniazek M 2007 Upper limb joint mobility ranges during activities of daily living determined by three-dimensional motion analysis–preliminary report. Ortopedia, Traumatologia, Rehabiltacja 9: 413–422.

Raiss P, Maier MW, Wolf SI, Rettig O, Loew M, Kasten P 2010 3D motion analysis of the upper extremities and its application in shoulder arthroplasty. Obere Extremität 5: 27–36.

Raiss P, Rettig O, Wolf SI, Loew M, Kasten P 2007 Range of motion of shoulder and elbow in activities of daily life in 3D motion analysis. Zeitschrift Für Orthopädie Und Unfallchirurgie 145: 493–498.

Ramanathan R, Eberhardt SP, Rahman T, Sample W, Seliktar R, Alexander M 2000 Analysis of arm trajectories of everyday tasks for the development of an upper-limb orthosis. IEEE Transactions on Rehabilitation Engineering 8: 60–70.

Ramirez-Garcia A, Leija L, Munoz R 2010 Active upper limb prosthesis based on natural movement trajectories. Prosthetics and Orthotics International 34: 58–72.

Reid S, Elliott C, Alderson J, Lloyd D, Elliott B 2010 Repeatability of upper limb kinematics for children with and without cerebral palsy. Gait Posture 32: 10–17.

Safaee-Rad R, Shwedyk E, Quanbury AO, Cooper JE 1990 Normal functional range of motion of upper limb joints during performance of three feeding activities. Archives of Physical Medicine and Rehabilitation 71: 505–509.

Sanderson S, Tatt ID, Higgins JPT 2007 Tools for assessing quality and susceptibility to bias in observational studies in epidemiology: A systematic review and annotated bibliography. International Journal of Epidemiology 36: 666–676.

Sardelli M, Tashjian RZ, MacWilliams BA 2011 Functional elbow range of motion for contemporary tasks. Journal of Bone and Joint Surgery (Am) 93: 471–477.

Sheikzadeh A, Yoon J, Pinto VJ, Kwon YW 2008 Three-dimensional motion of the scapula and shoulder during activities of daily living. Journal of Shoulder and Elbow Surgery 17: 936–942.

Sinha A, Nazar MA, Moorehead J, Bhalaik V, Brownson P 2010 A kinematic assessment of normal elbow movement in activities of modern day living. Shoulder Elbow 2: 118–123.
Skalsky AJ, McDonald CM 2012 Prevention and management of limb contractures in neuromuscular diseases. Physical Medicine and Rehabilitation Clinics of North America 23: 675–687.
Stathokostas L, McDonald MW, Little RM, Paterson DH 2013 Flexibility of older adults aged 55-86 years and the influence of physical activity. Journal of Aging Research 2013: 743843.
Trehan SK, Wolff AL, Gibbons M, Hillstrom HJ, Daluiski A 2015 The effect of simulated elbow contracture on temporal and distance gait parameters. Gait Posture 41: 791–794.
van Andel CJ, Wolterbeek N, Doorenbosch CA, Veeger DH, Harlaar J 2008 Complete 3D kinematics of upper extremity functional tasks. Gait Posture 27: 120–127.
Veeger HE, Magermans DJ, Nagels J, Chadwick EK, van der Helm FC 2006 A kinematical analysis of the shoulder after arthroplasty during a hair combing task. Clinical Biomechanics 21(Suppl 1): S39–44.
Willig TN, Bach JR, Rouffet MJ, Krivickas LS, Maquet C 1995 Correlation of flexion contractures with upper extremity function and pain for spinal muscular atrophy and congenital myopathy patients. American Journal of Physical Medicine and Rehabilitation 74: 33–38.
World Health Organization 2001 International Classification of Functioning, Disability and Health: ICF. Geneva: World Health Organization.
Wu G, van der Helm FC, Veeger HE, Makhsous M, Van Roy P, Anglin C, Nagels J, Karduna AR, McQuade K, Wang X, et al International society of biomechanics 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. Journal Biomechanics 38: 981–992.
Zeng X, Zhang Y, Kwong JS, Zhang C, Li S, Sun F, Niu Y, Du L 2015 The methodological quality assessment tools for preclinical and clinical studies, systematic review and meta-analysis, and clinical practice guideline: a systematic review. Journal of Evidence-Based Medicine 8: 2–10.

Appendix 1: MeSH terms and number of retrieved studies per database

PubMed:
Search: *("upper extremity"[MeSH Terms] OR "elbow"[Title] OR "shoulder"[Title]) AND ("range of motion"[MeSH Terms] OR "motion"[Title] OR "range of motion"[Title/abstract]) AND ("activities of daily living"[MeSH Terms] OR "activities of daily living"[Title/Abstract])*.
Search resulted in 273 studies.

Cochrane:
Advanced search on title, abstract and keywords: *Range of motion AND (activities of daily living) OR (daily activities) OR (daily living) AND (upper extremity) OR (elbow) OR (shoulder)*.
Search resulted in 100 studies.

Scopus:
Search: *TITLE-ABS-KEY ('Activities of Daily Living' AND 'Range of Motion' AND 'Upper Extremity')*.
Search resulted in 241 studies.

CINAHL:
Advanced search on: *'Activities of Daily Living' AND 'Range of Motion' AND 'Upper Extremity'* without selecting a field.
Search resulted in 58 studies.

PEDro:
Simple search on: *'activities of daily living, range of motion'*.
Search resulted in 44 studies.

Appendix 2A: A-F: Shoulder and elbow angles per (simulated) ADL tasks used by unimpaired participants for A: shoulder flexion, B: shoulder extension, C: shoulder abduction, D: shoulder adduction, E: elbow flexion, F: elbow extension

	Required angle	Aizawa et al (2010)	Artilheiro et al (2014)	Carey et al (2008)	Cooper et al (1993) Female	Cooper et al (1993) Male	Hall et al (2011)	Henmi et al (2006)	Kasten et al (2009), Raiss et al (2007), Raiss et al (2010)	Kim et al (2014)	King et al (2003)	Klotz et al (2014)	Lee et al (2007) Adult	Lee et al (2007) Elderly	Lobo-Prat et al (2014)	Maier et al (2014a), Maier et al (2014b)
Combing hair	**139**	110 (14)					70		78 ‡							139
Brush contralateral side of the head	**61**															
Shampooing	**64**							64 (9)								
Washing face	**50**	44 (10)						50 (7)								
Putting on a necklace	**106**	106 (19)														
Fasting button neck level	**29**	29 (11)														
Washing contralateral axilla/armpit	**95**						18									75
Genital hygiene	**84**								84 ‡							
Touching top of the head	**105**												68 (26)	43 (19)		
Touching forehead	**64**	59 (10)														
Touching contralateral ear	**64**	64 (11)														
Touching ipsilatal ear	**70**	70 (12)														
Touching nose	**77**											77				
Touching chin	**38**															
Touching back of the head	**110**															
Touching neck	**124**															
Touching contralateral axilla	**57**	42 (13)														
Touching/scratching chest	**34**															
Eat with fork	**35**				29	28										
Eating with spoon	**78**	56 (11)			31	31			78			67				
Pouring (sit position)/decanting cups	**72**								72		60	68				
Pouring (stand position)	**64**	64 (20)														
Drinking out of glass	**87**	87 (12)	71†	70	31	36			87	86 (5)		86				
Drinking with straw	**33**															
Touching mouth	**65**	40 (10)											65 (35)	35 (10)		
Reach above shoulder level (to a shelf)	**142**															132
Reach at 1.5m of the ground	**82**						82									
Forward reach to receive an object	**80**						75						63 (14) §	47 (10) §	59 §	
Sideway reach	**56**															
Place hand behind one's head	**130**															
Using a telephone	**85**								85							
Turning a key/unlock door	**114**								114			83				
Turning a page	**96**								96							
Opening a door	**52**			52 (12)												
Wave with arm at side	**48**															
Drawing nr. 8 at A1	**79**								79							
Stacking of 3 blocks	**58**										58					
Lifting tray using both hands (0.5kg)	**48**															
Typing on a keyboard	**93**								93							
Needed range	**29-142**															

	Required angle	Major et al. (2014)	Masjedi et al (2011)	Mosqueda et al (2004)	Muller-Rath et al (2009) Female	Muller-Rath et al (2009) Male	Muragia et al (2010)	Murphy et al (2013)	Namdari et al (2012)	Palmieri et al (2003)	Petuskey et al (2007)	Reid et al (2010)	Safaee-Rad (1990)	Sheikhzadeh et al (2008) *	van Andel et al (2008)
Combing hair	**139**								108 (3)						
Brush contralateral side of the head	**61**		61												
Shampooing	**64**														
Washing face	**50**														
Putting on a necklace	**106**														
Fasting button neck level	**29**														
Washing contralateral axilla/armpit	**95**								95 (2)						
Genital hygiene	**84**														
Touching top of the head	**105**			83 (14)							85 (17)			105 (9)	
Touching forehead	**64**													64 (7)	
Touching contralateral ear	**64**													62 (3)	
Touching ipsilatal ear	**70**													65 (5)	
Touching nose	**77**														
Touching chin	**38**													38 (4)	
Touching back of the head	**110**													110 (10)	
Touching neck	**124**													124 (13)	
Touching contralateral axilla	**57**		44											54 (9)	57
Touching/scratching chest	**34**														
Eat with fork	**35**												35(12)		
Eating with spoon	**78**												36(14)		
Pouring (sit position)/decanting cups	**72**	67	57												
Pouring (stand position)	**64**		31												
Drinking out of glass	**87**		38					52 (5)					43 (16)		63
Drinking with straw	**33**														
Touching mouth	**65**											38			
Reach above shoulder level (to a shelf)	**142**			139 (11)					121 (2)	134 (28)	142 (10)				
Reach at 1.5m of the ground	**82**														
Forward reach to receive an object	**80**		80								32 (17)	66 ‖			
Sideway reach	**56**				20 §	56 §						28 §			
Place hand behind one's head	**130**				130	130									
Using a telephone	**85**		45												
Turning a key/unlock door	**114**														
Turning a page	**96**						42								
Opening a door	**52**														
Wave with arm at side	**48**										48 (27)				
Drawing nr. 8 at A1	**79**														
Stacking of 3 blocks	**58**														
Lifting tray using both hands (0.5kg)	**48**		48												
Typing on a keyboard	**93**														
Needed range	**29-142**														

*: data changed to positive values; †: at going phase mug to mouth; ‡: not reported in Kasten et al (2009); §: reaching at shoulder height; ||: reaching at table height; #: calculated out of dataset.

Appendix 2B. Shoulder extension angles (degrees) per (simulated) ADL tasks performed by unimpaired participants.

	Required angle	Aizawa et al (2010)	Hall et al (2011)	Kasten et al (2009), Raiss et al (2007), Raiss et al (2010)	Maier et al (2014a), Maier et al (2014b)	Masjedi et al (2011)	Mosqueda et al (2004)	Namdari et al (2012)	Palmieri et al (2003)	Petuskey et al (2007)	van Andel et al (2008)
Personal care and feeding											
Unhook bra/wash middle of back	**47**							47 (2)			
Tuck in shirt behind back	**46**							46 (2)			
Tying apron	**44**				44						
Wash lower back	**62**					62					
Perineal care	**44**		44								
Anal hygiene	**13**			13 *							
Hand to (ipsilateral) back pocket	**50**						49 (8)		50 (8)	47 (11)	48
Touching back/sacrum	**52**	52 (12)									
Touching perineum	**41**	41 (8)									
Eating with spoon	**12**			12							
Daily, leasure and work activities											
Using a telephone	**3**			3							
Needed range	**3 - 62**										

*: not reported in Kasten et al (2009).

Appendix 2C: Shoulder abduction angles (degrees) per (simulated) ADL tasks performed by unimpaired participants.

	Required angle	Aizawa et al (2010)	Carey et al (2008)	Cooper et al (1993) Female	Cooper et al (1993) Male	Hall et al (2011)	Henmi et al (2006)	Kasten et al (2009), Raiss et al (2007), Raiss et al (2010)	Kim et al (2014)	King et al (2003)	Klotz et al (2014)	Maier et al (2014a), Maier et al (2014b)	Major et al (2014)
Personal care and feeding													
Combing hair	**125**							125 *				74	
Fasting button navel level	**19**	19 (6)											
Tying apron	**26**											26	
Genital hygiene	**67**							67 *					
Hand to (ipsilateral) back pocket	**4**												
Touching top of the head	**39**												
Touching nose	**56**										56		
Touching ipsilateral axilla	**51**	51 (18)											
Eat with fork	**43**			23	17		43 (6)						
Eating with spoon	**27**			27	17	24		107 §			65 §		
Pouring (sit position)/decanting cups	**31**							86 §		31	50 §		30
Drinking out of glass	**31**		28	28	23			111 §	12 (4)		77 §		
Touching mouth	**30**												
Daily, leasure and work activities													
Reach above shoulder level (to a shelf)	**34**												
Forward reach to receive an object	**115**											115 ǁ	
Sideway reach	**71**												
Place hand behind one's head	**127**												
Using a telephone	**79**							79					
Turning a key/unlock door	**76**							76			56		
Turning a page	**71**							71					
Opening a door	**29**		29 (7)										
Wave with arm at side	**55**												
Drawing nr. 8 at A1	**83**							83					
Stacking of 3 blocks	**36**									36			
Lifting shopping bag (2kg)	**44**												
Lift to shoulder heigh (0,5 kg)	**52**												
Lift to head heigh (0,5 kg)	**85**												
Typing on a keyboard	**65**							65					
Needed range	**4 - 127**												

	Required angle	Masjedi et al (2011)	Mosqueda et al (2004)	Muller-Rath et al (2009) Female	Muller-Rath et al (2009) Male	Murphy et al (2011)	Namdari et al (2012)	Palmieri et al (2003)	Petuskey et al (2007)	Reid et al (2010)	Safaee-Rad (1990)	van Andel et al (2008)
Personal care and feeding												
Combing hair	**125**											100
Fasting button navel level	**19**											
Tying apron	**26**											
Genital hygiene	**67**											
Hand to (ipsilateral) back pocket	**4**		4 (8)					4 (8)	2 (5)			
Touching top of the head	**39**		39 (13)						36 (13)			
Touching nose	**56**											
Touching ipsilateral axilla	**51**											
Eat with fork	**43**										19(6)	
Eating with spoon	**27**										22(7)	
Pouring (sit position)/decanting cups	**31**											
Drinking out of glass	**31**					30 (10)					31 (9)	
Touching mouth	**30**									30		
Daily, leasure and work activities												
Reach above shoulder level (to a shelf)	**34**		32 (11)					32 (12)	34 (9)			
Forward reach to receive an object	**115**								5 (10)	49 ‡		
Sideway reach	**71**			68 †	68 †					71 †		
Place hand behind one's head	**127**			51	46		127 (2)					
Using a telephone	**79**											
Turning a key/unlock door	**76**											
Turning a page	**71**											
Opening a door	**29**											
Wave with arm at side	**55**								55 (10)			
Drawing nr. 8 at A1	**83**											
Stacking of 3 blocks	**36**											
Lifting shopping bag (2kg)	**44**	44										
Lift to shoulder heigh (0,5 kg)	**52**	52										
Lift to head heigh (0,5 kg)	**85**	85										
Typing on a keyboard	**65**											
Needed range	**4 - 127**											

*: not reported in Kasten et al (2009); †: reaching at shoulder height; ‡: reaching at table height; §: left out for further analysis; ||: taking book from shelf.

Appendix 2D. Shoulder adduction angles (degrees) per (simulated) ADL tasks performed by unimpaired participants.

	Required angle	Artilheiro et al (2014)	Klotz et al (2014)	Maier et al (2014a), Maier et al (2014b)	Namdari et al (2012)
Personal care and feeding					
Combing hair	**86**				86 (3)
Washing contralateral axilla/armpit	**116**			37	116 (2)
Drinking out of glass	**14**	14 *			
Daily, leasure and work activities					
Turning a key/unlock door	**39**		39		
Needed range	**14-116**				

*: at going phase mug to mouth.

Appendix 2E: Elbow flexion angles (degrees) per (simulated) ADL tasks performed by unimpaired participants.

	Required angle	Aizawa et al (2010)	Artilheiro et al (2014)	Carey et al (2008)	Cooper et al (1993) Female	Cooper et al (1993) Male	Henmi et al (2006)	Kasten et al (2009), Raiss et al (2007), Raiss et al (2010)	Karner et al (2012)	Kim et al (2014)	Klotz et al (2014)	Lee et al (2007) Adult	Lee et al (2007) Elderly	Magermans et al (2005)
Personal care and feeding														
Combing hair	**150**	119 (8)						150	141					136 (15)
Shampooing	**151**						151 (9)							
Washing face	**140**	128 (6)					140 (5)							
Putting on a necklace	**138**	138 (6)												
Fasting button on neck level	**134**	134 (7)												
Fasting button on navel level	**69**	69 (19)												
Washing contralateral axilla	**118**													118 (9) †
Perineal care	**61**													61 (20)
Genital hygiene	**92**							92						
Touching top of the head	**129**											121 (22)	129 (2)	
Touching forehead	**125**	124 (7)												
Touching contralateral ear	**116**	116 (8)												
Touching ipsilatal ear	**132**	132 (5)												
Touching back of the head	**144**													
Touching nose	**133**										133			
Touching neck	**149**													
Touching/scratching chest	**144**								132					
Touching back/sacrum	**115**	115 (9)												
Touching waist	**100**													
Touching ipsilateral axilla	**137**	137 (7)												
Touching contralateral axilla	**115**	100 (10)												
Eat with fork	**146**				122	114	146 (5)							
Eating with spoon	**142**	123 (8)			126	116		142			125			132 (8)
Knife	**108**													
Pouring (sit position)/decanting cups	**84**							68			79			
Pouring (stand position)	**93**	93 (7)												
Drinking out of glass	**142**	115 (5)	135 *	123	136	126		142		120 (4)	129			
Drinking with straw	**139**								139					
Touching mouth	**135**	130 (5)										103 (41)	130 (0)	

(*Continued*)

Appendix 2E: (Continued).

	Required angle	Aizawa et al (2010)	Artilheiro et al (2014)	Carey et al (2008)	Cooper et al (1993) Female	Cooper et al (1993) Male	Henmi et al (2006)	Kasten et al (2009), Raiss et al (2007), Raiss et al (2010)	Karner et al (2012)	Kim et al (2014)	Klotz et al (2014)	Lee et al (2007) Adult	Lee et al (2007) Elderly	Magermans et al (2005)
Daily, leasure and work activities														
Place hand behind one's head	**141**													
Using a telephone	**152**							152						
Using a cellular phone	**147**													
Opening a door	**80**			66 (14)										
Opening and closing door knob	**39**													
Turning a key/unlock door	**95**							95						
Sit to stand	**106**													
Turning a page	**114**							94						
Drive-gear	**36**													
Turning a steering wheel	**57**			40										
Shaking hands	**73**													
Wave with arm at side	**95**													
Drawing nr. 8 at A1	**110**							110						
Lift 4kg bag	**93**													93 (24)
Mouse	**100**													
Typing on a keyboard	**102**							102						
Needed range	**36 - 152**													

	Required angle	Major et al (2014)	Morrey et al (1981)	Mosqueda et al (2004)	Muller-Rath et al (2009) Female	Muller-Rath et al (2009) Male	Murgia et al (2010)	Petuskey et al (2007)	Raminez-Garcia et al (2010)	Reid et al (2010)	Safaee-Rad (1990)	Sardelli et al (2011)	Sinha et al (2010)	van Andel et al (2008)
Personal care and feeding														
Combing hair	**150**													122
Shampooing	**151**													
Washing face	**140**													
Putting on a necklace	**138**													
Fasting button on neck level	**134**													
Fasting button on navel level	**69**													
Washing contralateral axilla	**118**													
Perineal care	**61**													
Genital hygiene	**92**													
Touching top of the head	**129**		119 (6)	110 (9)				110 (7)				117	114 (20)	
Touching forehead	**125**												125 (19)	
Touching contralateral ear	**116**													
Touching ipsilatal ear	**132**													
Touching back of the head	**144**		144 (7)									143 (6)	137 (17)	
Touching nose	**133**													
Touching neck	**149**		135 (5)									149 (5)	147 (18)	
Touching/scratching chest	**144**		120 (8)									144 (5)	139 (24)	
Touching back/sacrum	**115**													
Touching waist	**100**		100 (13)										62 (15)	
Touching ipsilateral axilla	**137**													
Touching contralateral axilla	**115**													115
Eat with fork	**146**		128								122 (4)	128	110	
Eating with spoon	**142**										123 (5)			
Knife	**108**		107									108		
Pouring (sit position)/decanting cups	**84**	111‡	58									84	62	
Pouring (stand position)	**93**								76 (10)					
Drinking out of glass	**142**		130						135 (3)		129 (3)	131		126
Drinking with straw	**139**													
Touching mouth	**135**									135			132 (15)	

(*Continued*)

Appendix 2E: (Continued).

	Required angle	Major et al (2014)	Morrey et al (1981)	Mosqueda et al (2004)	Muller-Rath et al (2009) Female	Muller-Rath et al (2009) Male	Murgia et al (2010)	Petuskey et al (2007)	Raminez-Garcia et al (2010)	Reid et al (2010)	Safaee-Rad (1990)	Sardelli et al (2011)	Sinha et al (2010)	van Andel et al (2008)
Daily, leasure and work activities														
Place hand behind one's head	**141**				141	139								
Using a telephone	**152**		136						144 (4)			146 (3)	136	
Using a cellular phone	**147**											147 (3)		
Opening a door	**80**		57						80 (23)			63		
Opening and closing door knob	**39**												39	
Turning a key/unlock door	**95**													
Sit to stand	**106**		95									106		
Turning a page	**114**		104				96					114	81	
Drive-gear	**36**												36 (25)	
Turning a steering wheel	**57**												57	
Shaking hands	**73**								73 (12)					
Wave with arm at side	**95**							95 (16)						
Drawing nr. 8 at A1	**110**													
Lift 4kg bag	**93**													
Mouse	**100**											100	34 (15)	
Typing on a keyboard	**102**											102	41 (15)	
Needed range	**36 - 152**													

Appendix 2F: Elbow extension angles (degrees) per (simulated) ADL tasks performed by unimpaired participants.

	Required angle	Aizawa et al (2010)	Bergsma et al (2014)	Carey et al (2008)	Kasten et al (2009), Raiss et al (2007), Raiss et al (2010)	Klotz et al (2014)	Lee et al (2007) Adult	Lee et al (2007) Elderly	Lobo-Prat et al (2014)	Magermans et al (2005)	Morrey et al (1981)	Mosqueda et al (2004)
Personal care and feeding												
Fasting button on navel level	**69**	69 (19)										
Perineal care	**61**									61 (20)		
Genital hygiene	**25**				25							
Hand to (ipsilateral) back pocket	**44**											66 (17)
Touch shoes/tying shoelaces	**16**										16 (6)	
Touching waist	**62**										100 (13)	
Touching back/sacrum	**55**										70 (12)	
Touching perineum	**56**	56 (22)										
Touching toes	**1**											
Knife	**89**										89	
Pouring (sit position)/decanting cups	**23**				23	74					36	
Pouring (stand position)	**47**	93 (7)										
Daily, leasure and work activities												
Reach above shoulder level (to a shelf)	**18**									39 (18) *		22 (8)
Forward reach to receive an object	**15**						16 (10) †	15 (9) †	59 †			
Sideway/ipsilateral reach	**15**		24									
Contralateral reach	**20**		20									
Opening a door	**13**			13							24	
Opening and closing door knob	**36**											
Turning a key/unlock door	**22**				22	36						
Sit to stand	**20**										20	
Turning a page	**73**				20 §						78	
Drive-gear	**36**											
Turning a steering wheel	**12**			12								
Shaking hands	**50**											
Wave with arm at side	**95**											
Drawing nr. 8 at A1	**23**				23							
Mouse	**34**											
Typing on a keyboard	**41**				41							

	Required angle	Muller-Rath et al (2009) Female	Muller-Rath et al (2009) Male	Murgia et al (2010)	Palmieri et al (2003)	Petuskey et al (2007)	Raminez-Garcia et al (2010)	Reid et al (2010)	Sardelli et al (2011)	Sinha et al (2010)	van Andel et al (2008)
Personal care and feeding											
Fasting button on navel level	**69**										
Perineal care	**61**										
Genital hygiene	**25**										
Hand to (ipsilateral) back pocket	**44**				66 (19)	63 (21)					44
Touch shoes/tying shoelaces	**16**								27 (7)		
Touching waist	**62**									62 (15)	
Touching back/sacrum	**55**								102	55 (23)	
Touching perineum	**56**										
Touching toes	**1**									1 (11)	
Knife	**89**								99		
Pouring (sit position)/decanting cups	**23**								68	27	
Pouring (stand position)	**47**						47				
Daily, leasure and work activities											
Reach above shoulder level (to a shelf)	**18**				23 (10)	18 (6)					
Forward reach to receive an object	**15**					49 (25)		21 ‡			
Sideway/ipsilateral reach	**15**	26 †	26 †					15 †			
Contralateral reach	**20**										
Opening a door	**13**						28		29		
Opening and closing door knob	**36**									36	
Turning a key/unlock door	**22**										
Sit to stand	**20**								24		
Turning a page	**73**			84					86	73	
Drive-gear	**36**									36 (25)	
Turning a steering wheel	**12**									24	
Shaking hands	**50**						50				
Wave with arm at side	**95**					95 (16)					
Drawing nr. 8 at A1	**23**										
Mouse	**34**								67	34 (15)	
Typing on a keyboard	**41**								87	41 (15)	

*: performed by 8/24 participants; †: reaching at schoulder height; ‡: reaching at table height; §: left out for further analysis.