Published in final edited form as:

Gait Posture. 2018 February ; 60: 41–47. doi:10.1016/j.gaitpost.2017.11.001.

Reliability of upper limb and trunk joint angles in healthy adults during activities of daily living

Susannah M. Engdahl^a and Deanna H. Gates^{a,b}

^aDepartment of Biomedical Engineering, University of Michigan, Ann Arbor, MI, USA

^bSchool of Kinesiology, University of Michigan, Ann Arbor, MI, USA

Abstract

Assessments of upper limb performance should require participants to perform tasks that challenge the limits of their ability. In order to select appropriate tasks, it is important to know which joints are used to perform the movement and how reliably those movements can be measured. The purpose of this work was to quantify the reliability of upper limb and trunk joint angles in healthy adults during common activities of daily living (ADLs). Nineteen participants performed six ADLs with the right arm (applying deodorant, turning a doorknob, answering a desk telephone, placing a pushpin in a bulletin board, wiping a plate with a towel, and pouring water from a pitcher) during two separate sessions. Within- and between-session reliability was quantified using intraclass correlation coefficients (ICCs) and minimum detectable change values (MDCs). Reliability was generally better within-session than between sessions. The ICCs exceeded 0.75 for 88% of the joint angles and exceeded 0.90 for 32% of the angles. All MDCs were less than 25° and 61% were also less than 10°. The MDCs represented a larger percent of the average angles for the trunk (61%) and wrist (62%) compared to the shoulder (18%) and elbow (26%). Although these results show that most angles can be measured reliably for these six activities of daily living, reliability varied considerably between joints. It is therefore important to select tasks for assessing of upper limb performance based on which specific joints need to be evaluated.

Keywords

test-retest reliability; repeatability; upper limb; kinematics; activities of daily living

Corresponding Author: Deanna H. Gates, Ph.D. 401 Washtenaw Ave. Ann Arbor, MI 48109-2214, Phone: 734-647-2698, gatesd@umich.edu.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Conflicts of Interest
None.

Introduction

Kinematic analysis of upper limb movement can be used to identify performance deficits in individuals affected by pathologies such as cerebral palsy [1], amputation [2], or stroke [3], and to evaluate progress following an intervention. These assessments should require participants to perform activities that engage the specific joints of concern [4]. However, it can be difficult to choose appropriate activities because the kinematic redundancy of the upper limb makes it possible to accomplish any task using a variety of movement strategies [5]. When selecting tasks, it is helpful to know which joints are most important for performing each movement and the expected magnitude of variation across repeated measurements of those joints. Otherwise, insignificant trends in the data may be misinterpreted as meaningful or significant trends may be overlooked [6].

Measurement reliability can be affected by intrinsic and extrinsic errors [7]. Intrinsic errors are related to the inherent variation between repetitions of a movement or between different individuals. Extrinsic errors come from procedural sources, especially for data collected during different sessions. Notably, kinematic error can be introduced from small differences in the experimental setup between sessions, inconsistent identification of anatomical landmarks and application of markers, or limitations in the equipment used to track the markers. Soft tissue movement induced by the large range of motion of the upper limb can also reduce the measurement accuracy [5, 8]. Thus, measurement reliability depends on properties of both the task performance and the techniques used to assess the performance.

Reliability of upper limb angles has been quantified in patient populations such as children with cerebral palsy [1, 9–13], adults with stroke [14] and prosthesis users [2], as well as in healthy adults [3, 15–17]. Although satisfactory between-session [3, 16, 17] and within-subject [15] reliability has been reported for healthy adults, only a few types of movements have been studied. These include active range of motion tasks [15], typing [16], and forward reaching and hand-to-mouth movements [3, 17]. Furthermore, it is difficult to generalize these results because reliability was quantified using different metrics (Pearson correlations and intraclass correlation coefficients (ICCs)) and varying definitions of what constitutes a reliable measurement. Correlations and ICCs alone have limited utility in determining whether changes in a measurement represent meaningful changes in performance. As indicators of relative reliability, these metrics describe how consistently individual measurements are ranked within a group [18] but do not quantify the precision of a measurement. Metrics of absolute reliability, such as the standard error of measurement (SEM) or minimum detectable change (MDC), are better suited for this purpose [18–20]. However, MDCs have not been reported for upper limb joint angles in healthy individuals during activities of daily living.

Therefore, the purpose of this study was to quantify the within-session and between-session reliability of upper limb and trunk joint angles in healthy adults for a set of common activities of daily living (ADLs) using both ICCs and MDCs. Knowledge of reliability metrics for upper limb joint angles will ultimately improve the interpretation of data from both healthy and patient populations, and will also aid in the selection of appropriate tasks for assessments.

Methods

Subjects

Twenty healthy adults (ages 18 – 35) provided written informed consent for this institutionally approved study. Individuals with a history of serious musculoskeletal, cardiovascular, neurological, respiratory, or visual problems were excluded. Handedness was determined using a modified version of the Edinburgh Inventory [21]. The only left-handed participant was omitted from analysis for consistency. The remaining 19 right-handed participants (9 male) had a mean age of 22 ± 4 years and BMI of 24.0 ± 3.6 kg/m².

Experimental Protocol

Participants completed two identical experimental sessions, at least one day apart (mean: 12 ± 10 days). During each session, participants performed six ADLs that were chosen for their clinical relevance. Many of these ADLs have been used in functional prosthesis training [22] or evaluating recovery from stroke [23].

Each ADL was performed 12 times at a comfortable pace. To enable comparison across participants, we designated the posture from which participants initiated and ended each movement (standing tasks: arms loosely down at the sides; seated tasks: arms resting flat on the table, spaced shoulder width apart). We also placed objects at a fixed distance with respect to their anthropometry and the table was aligned to the bottom of the ribcage while seated. The tasks were:

1. *Apply deodorant* (DEO): Participants stood 75% of arm's length from a stick of deodorant placed on the table along the midline of the body. They lifted the deodorant with the right hand, removed the cap with the left hand, simulated three swipes on the left axilla, replaced the cap, and replaced the deodorant.
2. *Turn a doorknob* (DOOR): Participants stood 75% of arm's length from a doorknob placed at waist height along the midline of the body. They turned the knob clockwise until its latch was fully retracted (approximately 90°).
3. *Answer a telephone* (PHONE): Participants sat at the table with a desk telephone placed between the arms at the distance of the hands from the near edge of the table. The phone's handset was oriented parallel to the near edge of the table. Participants lifted the phone, simulated answering it, and returned it to the cradle.
4. *Place a pushpin* (PIN): Participants stood at 75% of arm's length from a corkboard. They placed a pushpin into the board, aiming for a 1 inch diameter circle placed at eye level along the midline of the body.
5. *Wipe a plate with a towel* (PLATE): Participants stood with a plastic plate in the left hand and a dish towel in the right hand. They used the towel to wipe the surface of the plate three times, using circular motions.
6. *Pour water* (WATER): Participants sat at the table with a 2.3 L plastic pitcher and a plastic cup placed between the arms at the distance of the hands from the near edge of the table. The pitcher's handle was oriented parallel to the near edge of

the table. The pitcher contained 575 mL of water, and participants used their right arm to pour 150 mL of water into the cup.

Participants were not given practice time or any explicit instructions on how to complete the tasks, except to ensure that they return to the specified postures between repetitions.

The motions of seven body segments were tracked at 120 Hz using a 19 camera motion capture system (Motion Analysis Corporation, Santa Rosa, CA) and 24 reflective markers. Anatomical markers were placed on the acromion processes, medial and lateral humeral epicondyles, and radial and ulnar styloids for a static trial. Upper arm and forearm motion was subsequently tracked using clusters of four and three markers, respectively. Four markers were placed on the trunk (7th cervical vertebra, 8th thoracic vertebra, sternal notch, and xiphoid process) and three on the hands (3rd and 5th metacarpal heads and base of the 3rd metacarpal).

Data Analysis

Marker position data were filtered in Visual 3D (C-Motion, Germantown, MA) using a fourth-order low-pass Butterworth filter with a 6 Hz cutoff frequency. A model containing hand, forearm, upper arm, and trunk segments was created using the joint centers and local coordinate systems defined in [24]. Trunk-room, shoulder, elbow, and wrist joint angles for the right arm were calculated using Euler angle decomposition according to rotation sequences recommended by the International Society of Biomechanics [25]. For bilateral tasks (DEO and PLATE), joint angles were calculated for both arms.

A 5 cm/s velocity threshold for the right hand was used to define the beginning and end times of each repetition, which were also verified visually. Joint angle waveforms were then time-normalized to 100% of task completion. Peak joint angles were determined for the upper limb. Peak-to-peak range of motion was determined for the trunk, since most tasks required minimal trunk motion. The following angles were included: trunk lateral lean, flexion, and rotation, humeral plane of elevation (similar to horizontal abduction/adduction), humeral elevation, humeral internal (+) and external (−) rotation, elbow flexion (+), forearm pronation (+) and supination (−), ulnar (+) and radial (−) deviation, and wrist flexion (+) and extension (−).

Participants did not necessarily need to use all available degrees of freedom to complete each task. Additionally, the peak upper limb angles did not always occur at the same point during task completion. To ensure that reliability was quantified only for relevant joint angles, distributions of the timing and magnitude of all 380 peaks (2 sessions × 19 participants × 10 repetitions) were examined. If the distribution revealed that a peak consistently depended on the participant's posture at rest rather than the requirements of the task (e.g., internal rotation for PIN (Fig. 1)), that angle was excluded. Arm angles that were never used (e.g., supination for PIN) or inconsistently used across participants (e.g., wrist flexion for PIN) were also excluded. To reduce dependence of the peaks on the participants' posture at rest (e.g., radial deviation for PIN), peaks were selected from 5–95% of the movement cycle. Shoulder angles for standing tasks were selected from 10–90% of the movement cycle because gimbal lock occurs when humeral elevation is near 0° [26], causing

extreme plane of elevation and rotation angles. Complete descriptions of the selected angles are included in Appendix 1. Because forearm supination and wrist angles for excluded for many tasks, we also calculated the reliability of the total range of motion as a supplementary measure.

Statistics

Statistical analyses were performed using SPSS 22 (IBM, Armonk, NY). Within-session reliability metrics were calculated using the 10 individual repetitions from the first session. Between-session reliability metrics were calculated using the averages of the 10 repetitions from each session. ICCs were calculated as a measure of *relative* within- and between-session reliability for each angle using (2, 1) and (2, k) models for absolute agreement, respectively. ICCs were considered valid only when significant F-tests ($p < 0.05$) indicated sufficient heterogeneity [27]. For wrist extension during PIN, an invalid between-session ICC was caused by outlying data from one participant (> 3 standard deviations from the mean), who was subsequently excluded for this calculation only. The following thresholds were used for assessing ICC magnitudes [27]: ICCs > 0.90 indicated reasonable reliability for clinical measures, ICCs > 0.75 indicated good reliability, and ICCs < 0.75 indicated poor to moderate reliability. MDCs were calculated as a measure of *absolute* within- and between-session reliability for each angle according to, where 1.96 corresponds to a 95% confidence interval and SEM is the square root of the mean square error term from the two-way ANOVA [18]. MDCs were also expressed as a percentage of the average angle achieved during session 1.

Results

Relative Reliability (ICCs)

The relative reliability was generally good (Fig. 2; Appendix 1). According to the thresholds suggested by [27], 88% of all angles had good reliability (ICC > 0.75) and 32% had reasonable reliability for clinical measures (ICC > 0.90).

For the trunk range of motion, the average within-session ICC was 0.76 (range: 0.52 – 0.91) and the average between-session ICC was 0.88 (range: 0.68 – 0.96). Within-session ICCs were less than 0.75 for lateral lean and flexion for DOOR, flexion for PHONE and PIN, and all angles for PLATE. Between-session ICCs were less than 0.75 only for flexion for DOOR.

For the peak upper limb angles, the average within-session ICC was 0.89 (range: 0.72 – 0.96) and the average between-session ICC was 0.83 (range: 0.67 – 0.97). Within-session ICCs were less than 0.75 for right wrist extension for DEO. Between-session ICCs were less than 0.75 for radial deviation and wrist extension for PIN, right wrist extension for DEO, ulnar deviation and wrist extension for WATER, and left elbow flexion, left wrist extension and right wrist extension for PLATE.

Absolute Reliability (MDCs)

In most cases, the trunk range of motion was small (Table 1). All trunk MDCs were less than 10° (Fig. 3; Appendix 1). The average within-session MDC was 3.6° (range: 1.5° – 9.8°) and

the average between-session MDC was 3.4° (range: $0.7^{\circ} - 8.9^{\circ}$). Trunk MDCs consistently represented a large percent of the peak angles (within-session: 64%, between-session: 58%; Fig. 4).

Peak upper limb angle MDCs were all under 25° , and 47% were also less than 10° . The average within-session MDC was 8.7° (range: $3.9^{\circ} - 16.9^{\circ}$). Average within-session MDCs were similar across joints (shoulder: 8.0° , elbow: 8.6° , wrist: 9.6°). However, wrist MDCs represented a larger percent of the peak angles than elbow or shoulder MDCs (shoulder: 14%, elbow: 20%, wrist: 53%). On average, between-session MDCs for the peak upper limb angles were about 1.5 times greater than within-session MDCs (average: 13.1° , range: $6.1^{\circ} - 24.6^{\circ}$). Between-session MDCs were similar across joints (shoulder: 13.0° , elbow: 12.9° , wrist: 13.3°) and wrist MDCs represented the largest percent of the peak angles (shoulder: 23%, elbow: 33%, wrist: 71%). All MDCs, ICCs, and SEMs are included in Appendix 1, along with graphs of the kinematic patterns for each task.

Upper Limb Range of Motion Reliability

Compared to the peak angles, ICCs were generally lower and MDCs were higher for the upper limb range of motion (Appendix 2).

Discussion

The purpose of this study was to quantify the within-session and between-session reliability of upper limb and trunk joint angles in healthy adults during ADLs. Reliability was affected by both the participants' task performance and the measurement system. Accordingly, reliability was generally better within-session than between-session. Within-session reliability is primarily influenced by variation between repetitions (i.e., intrinsic error), while between-session reliability is also influenced by variation in experimental set-up and marker placement (i.e., extrinsic error). Efforts were made to reduce this procedural error by standardizing the participants' location with respect to the objects and having the same experimenter apply markers for both sessions. However, it is impossible to completely eliminate this variability.

The high ICCs suggest the relative reliability of the upper limb and trunk angles was "good". However, this terminology is debatable as there is no consensus on thresholds for ICC interpretation [18] and different disciplines may follow different guidelines [19]. ICCs are also sensitive to variability in the data such that low between-subject variability can skew the ICC towards smaller values, and vice versa [18]. This might explain why within-session ICCs tended to be lower than between-session ICCs for the trunk. Since the trunk range of motion (and corresponding between-subject variability) was small, the ICCs could be small as a result. Kinematic redundancy in the upper limb permits the use of numerous movement patterns to accomplish the same task, so high ICCs could simply indicate that different individuals use different strategies. Nonetheless, the ICCs are consistent with previously reported values (range: 0.63 – 0.97), although the choice of tasks, ICC models, and kinematic models varied among these studies [15, 16].

MDCs were used to assess the absolute reliability of the joint angles. Although MDCs for upper limb joint angles have not been widely reported, our results are consistent with those of Wagner et al. [14] for shoulder and elbow MDCs during forward reaching tasks in individuals with hemiparesis after stroke (range: 23% – 57% of average angle). In contrast, smaller MDCs (i.e., $< 5^\circ$) have been reported for many lower limb joint angles in healthy adults during gait [20, 28]. However, one study also reported much larger MDCs for transverse plane kinematics [28]. Similar between-plane differences were reported in other studies that used ICCs as the primary outcome measure [7]. Since gait primarily occurs in the sagittal plane, transverse plane joint angles may be comparatively smaller and more variable. Upper limb movement is not restricted to one primary plane, so poorer reliability compared to lower limb movement is perhaps unsurprising.

From a clinical perspective, the minimum clinically importance difference (MDIC) may be the most meaningful way to interpret changes. However, there is no consensus on the best way to determine this value. While it seems reasonable that the MDIC should be at least as large as the MDC, some (e.g., [29]) have suggested that the MDIC could be defined as 1 or 2 times the SEM. Since the MDC is a constant multiple of the SEM (accounting for an arbitrary confidence interval), the SEMs are necessarily much smaller. Here, all SEMs were $< 9^\circ$ and 84% were $< 5^\circ$. As there is no standard for choosing between these two metrics, we have followed the example of prior studies [13, 14] and reported both.

Regardless of which reliability metric is used, it is clear from this work that the choice of tasks used for assessing upper limb performance depends on which joint angles need to be included. For example, PHONE had a low within-session MDC for elbow flexion (3.9°) compared to other tasks, but a comparatively high within-session MDC for wrist extension (15.5°). PHONE might be a good choice if elbow flexion is important to the assessment, but not if wrist extension is important. In that case, it would be advisable to include another task that had a lower MDC for wrist extension (such as DOOR).

Knowledge of reliability metrics for upper limb joint angles can be used to determine appropriate tasks for assessing specific joint angles. As an example, we have provided recommendations using one set of possible thresholds (ICC > 0.75 , MDC $< 10^\circ$; Table 2). These thresholds are not standard and should be altered depending on the requirements of any proposed assessment. Although the results of this study may serve as a guide, they include only a limited number of the potential tasks that can be performed with the upper limb and cannot be directly applied to every population. Prior work has shown that patient populations (e.g., individual with upper limb loss or stroke) have increased variability compared to healthy populations [2, 30]. Thus, it is likely that the reliability will also differ for patient populations [20]. Future work should quantify reliability of relevant tasks separately for specific patient populations of interest.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

D.H. Gates is supported by the Eunice Kennedy Shriver National Institute of Child Health & Human Development of the National Institutes of Health under Award Number K12HD073945. S.M. Engdahl is supported by the National Science Foundation Graduate Research Fellowship Program under Award Number DGE 1256260. The authors thank Kelsey White, Jacob Lynn, Nicole Johns, Mingxian Tian, Yoonjoo Kim, and Zachary Conley for their help with data collection and processing.

References

1. Fitoussi F, Diop A, Maurel N, Laassel el M, Pennecot GF. Kinematic analysis of the upper limb: a useful tool in children with cerebral palsy. *J Pediatr Orthop B*. 2006; 15:247–56. [PubMed: 16751732]
2. Major MJ, Stine RL, Heckathorne CW, Fatone S, Gard SA. Comparison of range-of-motion and variability in upper body movements between transradial prosthesis users and able-bodied controls when executing goal-oriented tasks. *J Neuroeng Rehabil*. 2014; 11
3. Caimmi M, Carda S, Giovanzana C, Maini ES, Sabatini AM, Smania N, et al. Using kinematic analysis to evaluate constraint-induced movement therapy in chronic stroke patients. *Neurorehabil Neural Repair*. 2008; 22:31–9. [PubMed: 17595381]
4. Kontaxis A, Cutti AG, Johnson GR, Veeger HEJ. A framework for the definition of standardized protocols for measuring upper-extremity kinematics. *Clin Biomech*. 2009; 24:246–53.
5. van Andel CJ, Wolterbeek N, Doorenbosch CA, Veeger DH, Harlaar J. Complete 3D kinematics of upper extremity functional tasks. *Gait Posture*. 2008; 27:120–7. [PubMed: 17459709]
6. Schwartz MH, Trost JP, Wervey RA. Measurement and management of errors in quantitative gait data. *Gait Posture*. 2004; 20:196–203. [PubMed: 15336291]
7. McGinley JL, Baker R, Wolfe R, Morris ME. The reliability of three-dimensional kinematic gait measurements: A systematic review. *Gait Posture*. 2009; 29:360–9. [PubMed: 19013070]
8. Rau G, Disselhorst-Klug C, Schmidt R. Movement biomechanics goes upwards: from the leg to the arm. *J Biomech*. 2000; 33:1207–16. [PubMed: 10899329]
9. Lempereur M, Brochard S, Mao L, Rémy-Néris O. Validity and reliability of shoulder kinematics in typically developing children and children with hemiplegic cerebral palsy. *J Biomech*. 2012; 45:2028–34. [PubMed: 22658078]
10. Jaspers E, Feys H, Bruyninckx H, Cutti A, Harlaar J, Molenaers G, et al. The reliability of upper limb kinematics in children with hemiplegic cerebral palsy. *Gait Posture*. 2011; 33:568–75. [PubMed: 21334208]
11. Mackey AH, Walt SE, Lobb GA, Stott NS. Reliability of upper and lower limb three-dimensional kinematics in children with hemiplegia. *Gait Posture*. 2005; 22:1–9. [PubMed: 15996586]
12. Reid S, Elliott C, Alderson J, Lloyd D, Elliott B. Repeatability of upper limb kinematics for children with and without cerebral palsy. *Gait Posture*. 2010; 32:10–7. [PubMed: 20430623]
13. Schneiberg S, McKinley P, Gisel E, Sveistrup H, Levin MF. Reliability of kinematic measures of functional reaching in children with cerebral palsy. *Dev Med Child Neurol*. 2010; 52:e167–e73. [PubMed: 20187878]
14. Wagner JM, Rhodes JA, Patten C. Reproducibility and minimal detectable change of three-dimensional kinematic analysis of reaching tasks in people with hemiparesis after stroke. *Phys Ther*. 2008; 88:652–63. [PubMed: 18326055]
15. Aizawa J, Masuda T, Hyodo K, Jinno T, Yagishita K, Nakamaru K, et al. Ranges of active joint motion for the shoulder, elbow, and wrist in healthy adults. *Disabil Rehabil*. 2013; 35:1342–9. [PubMed: 23826904]
16. Levanon Y, Gefen A, Lerman Y, Givon U, Ratzon NZ. Validity and reliability of upper extremity three-dimensional kinematics during a typing task. *Gait Posture*. 2010; 32:469–74. [PubMed: 20678936]
17. Caimmi M, Guanziroli E, Malosio M, Pedrocchi N, Vicentini F, Tosatti LM, et al. Normative Data for an Instrumental Assessment of the Upper-Limb Functionality. *Biomed Res Int*. 2015; 35:36.

18. Weir JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J Strength Cond Res.* 2005; 19:231–40. [PubMed: 15705040]
19. Vaz S, Falkmer T, Passmore AE, Parsons R, Andreou P. The Case for Using the Repeatability Coefficient When Calculating Test–Retest Reliability. *PLoS One.* 2013; 8:e73990. [PubMed: 24040139]
20. Wilken JM, Rodriguez KM, Brawner M, Darter BJ. Reliability and minimal detectable change values for gait kinematics and kinetics in healthy adults. *Gait Posture.* 2012; 35:301–7. [PubMed: 22041096]
21. Oldfield RC. The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia.* 1971; 9:97–113. [PubMed: 5146491]
22. Management of Upper Extremity Amputation Rehabilitation Working Group. VA/DoD Clinical Practice Guideline for the Management of Upper Extremity Amputation Rehabilitation. 2014. <http://www.healthquality.va.gov/guidelines/Rehab/UEAR/VADoDCPGManagementofUEAR121614Corrected508.pdf>
23. Barreca SR, Stratford PW, Lambert CL, Masters LM, Streiner DL. Test-Retest Reliability, Validity, and Sensitivity of the Chedoke Arm and Hand Activity Inventory: A New Measure of Upper-Limb Function for Survivors of Stroke. *Arch Phys Med Rehabil.* 2005; 86:1616–22. [PubMed: 16084816]
24. Gates DH, Walters LS, Cowley J, Wilken JM, Resnik L. Range of Motion Requirements for Upper-Limb Activities of Daily Living. *Am J Occup Ther.* 2016; 70
25. Wu G, van der Helm FC, Veeger HE, Makhsous M, Van Roy P, Anglin C, et al. 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.* 2005; 38:981–92. [PubMed: 15844264]
26. Doorenbosch CA, Harlaar J, Veeger DH. The globe system: an unambiguous description of shoulder positions in daily life movements. *J Rehabil Res Dev.* 2003; 40:147–55. [PubMed: 15077640]
27. Portney, LG., Watkins, MP. *Foundations of Clinical Research: Applications to Clinical Practice.* 3rd. Prentice Hall; 2009.
28. Meldrum D, Shouldice C, Conroy R, Jones K, Forward M. Test–retest reliability of three dimensional gait analysis: Including a novel approach to visualising agreement of gait cycle waveforms with Bland and Altman plots. *Gait Posture.* 2014; 39:265–71. [PubMed: 24139682]
29. Copay AG, Subach BR, Glassman SD, Polly DW, Schuler TC. Understanding the minimum clinically important difference: a review of concepts and methods. *Spine J.* 2007; 7:541–6. [PubMed: 17448732]
30. Cirstea MC, Levin MF. Compensatory strategies for reaching in stroke. *Brain.* 2000; 123:940–53. [PubMed: 10775539]

Highlights

- Reliability of upper limb and trunk joint angles was assessed in healthy adults.
- Intraclass correlation coefficients and minimum detectable changes were calculated.
- Overall reliability was good and was better within-session than between-session.
- Reliability varied considerably between joints and tasks.

Fig. 1.

Joint angles for the right shoulder (left), elbow (middle), and wrist (right) are shown for placing a pin in a corkboard with the right arm (PIN). Data are normalized to 100% of task completion. Solid lines represent the average across subjects for session 1 (black) and session 2 (blue). Dotted lines represent the standard deviation across subjects within a session. Notations are provided to designate which angles are positive or negative.

Fig. 2.

Relative within-session (top) and between-session (bottom) reliability for the upper limb and trunk joint angles is shown using intraclass correlation coefficients (ICCs). For each activity of daily living, ICCs are presented only for the joint angles relevant to that task. Suggested thresholds for interpretation are designated by dashed lines (ICCs > 0.90 indicate reasonable reliability for clinical measures, ICCs > 0.75 indicate good reliability, and ICCs < 0.75 indicate poor to moderate reliability).

Fig. 3.

Absolute within-session (top) and between-session (bottom) reliability for the upper limb and trunk joint angles is shown using minimum detectable change values (MDCs). For each activity of daily living, MDCs are presented only for the joint angles relevant to that task.

Fig. 4. Within-session (top) and between-session (bottom) minimum detectable change values (MDCs) for the upper limb and trunk joint angles are presented as a percentage of the average angle achieved during session 1.

Table 1

Mean (SD) joint angles achieved during sessions 1 and 2. Trunk angles represent peak-to-peak range of motion, while arm angles represent peaks. For details on the excluded angles, see Appendix 1.

	Lateral Lean (°)		Rotation (°)		Flexion (°)	
	Session 1	Session 2	Session 1	Session 2	Session 1	Session 2
Trunk						
DEO	10.2 (4.2)	11.1 (4.8)	25.6 (9.0)	25.9 (8.4)	21.0 (8.9)	22.8 (10.9)
DOOR	1.7 (0.8)	2.1 (1.2)	9.5 (5.6)	11.2 (7.6)	2.2 (0.9)	2.8 (2.3)
PHONE	2.9 (1.5)	2.8 (1.7)	4.8 (2.8)	3.8 (2.4)	2.6 (1.2)	2.4 (1.0)
PIN	4.1 (2.1)	3.8 (1.9)	9.2 (5.0)	8.6 (4.0)	2.9 (1.0)	2.9 (1.0)
PLATE	1.7 (0.6)	1.7 (0.6)	4.0 (1.6)	4.1 (1.4)	3.1 (1.1)	3.2 (1.3)
WATER	8.5 (2.6)	9.4 (2.8)	7.7 (3.0)	7.4 (2.5)	4.2 (1.9)	4.1 (1.6)
Shoulder						
DEO - Left	64.6 (16.2)	67.9 (12.7)	110.1 (15.5)	114.7 (13.7)	-40.2 (17.9)	-39.5 (15.1)
DEO - Right	100.3 (7.4)	100.0 (6.6)	52.0 (10.3)	52.6 (9.9)	-46.5 (10.2)	-46.9 (9.5)
DOOR	95.8 (10.9)	95.6 (8.4)	29.6 (7.5)	30.4 (5.8)	-61.0 (14.5)	-60.3 (14.6)
PHONE	76.3 (9.9)	78.8 (9.1)	61.9 (8.9)	59.3 (9.1)	-59.0 (8.4)	-59.1 (7.9)
PIN	76.4 (7.1)	77.2 (5.6)	76.8 (6.5)	77.0 (6.5)	-53.9 (7.0)	-53.0 (8.1)
PLATE - Left	-	-	-	-	-	-
PLATE - Right	79.2 (13.0)	75.3 (14.8)	29.6 (7.1)	29.4 (7.4)	-42.8 (13.8)	-38.8 (16.3)
WATER	67.3 (9.0)	70.8 (8.7)	80.9 (9.3)	80.4 (8.8)	-53.9 (9.3)	-54.3 (9.2)
Elbow						
DEO - Left	33.0 (10.4)	31.2 (11.7)	-	-	112.2 (12.3)	111.1 (12.2)
DEO - Right	27.3 (7.5)	28.6 (10.8)	-	-	110.9 (8.3)	111.8 (5.2)
DOOR	-	-	-19.6 (15.4)	-19.8 (15.0)	51.4 (10.3)	52.2 (7.2)
PHONE	27.3 (6.7)	28.3 (9.7)	-	-	136.7 (5.3)	137.0 (5.0)
PIN	37.6 (7.4)	39.0 (9.2)	-	-	100.4 (9.5)	98.8 (8.1)
PLATE - Left	-	-	-	-	97.0 (7.1)	96.7 (6.9)

	Lateral Lean (°)		Rotation (°)		Flexion (°)		Extension (°)	
	Session 1	Session 2	Session 1	Session 2	Session 1	Session 2	Session 1	Session 2
PLATE - Right	34.2 (8.4)	35.4 (9.6)	–	–	94.4 (8.5)	94.5 (8.0)	–	–
WATER	19.0 (8.4)	21.3 (10.8)	–	–	–	–	–	–
	Ulnar Deviation (°)		Radial Deviation (°)		Flexion (°)		Extension (°)	
	Session 1	Session 2	Session 1	Session 2	Session 1	Session 2	Session 1	Session 2
DEO - Left	–	–	–	–	–	–	–	–
DEO - Right	16.7 (8.6)	16.5 (8.6)	–17.0 (6.7)	–16.5 (4.6)	16.0 (11.8)	14.1 (10.9)	–26.5 (7.7)	–26.4 (6.3)
DOOR	18.3 (5.5)	19.1 (5.9)	–8.3 (5.2)	–8.6 (5.4)	–	–	–21.1 (9.3)	–21.6 (7.5)
PHONE	–	–	–13.9 (7.9)	–13.6 (5.8)	18.2 (7.4)	17.2 (7.0)	–29.8 (12.7)	–31.6 (11.5)
PIN	–	–	–13.1 (9.2)	–12.4 (7.1)	–	–	–31.0 (9.7)	–33.0 (7.7)
PLATE - Left	–	–	–	–	–	–	–30.6 (13.9)	–30.9 (12.2)
PLATE - Right	–	–	–11.0 (9.6)	–12.7 (8.2)	–	–	–27.1 (8.3)	–29.4 (10.4)
WATER	11.0 (6.1)	10.3 (4.5)	–	–	–	–	–32.1 (10.2)	–33.7 (7.8)

Table 2

Sample recommendations for peak upper limb joint angles with high reliability for each task. Angles were selected using thresholds of ICC > 0.75 and MDC < 10°. As these are not standard thresholds, the recommendations should be viewed as an example of how this data might be used. Potential reasons for lower reliability are also described.

Task	Sample Recommendations	Potential Protocol Limitations
DEO	Within-session: pronation (left arm), plane of elevation (right arm), elevation (right arm), external rotation (right arm), pronation (right arm), elbow flexion (right arm), ulnar deviation (right arm), radial deviation (right arm) Between-session: plane of elevation (right arm), elevation (right arm), ulnar deviation (right arm), radial deviation (right arm)	Lack of required position for left arm during deodorant application and allowing participants to simulate application may have contributed to poorer reliability. <i>Requiring participants to actually apply deodorant may improve reliability.</i>
DOOR	Within-session: plane of elevation, elevation, external rotation, ulnar deviation, radial deviation, wrist extension Between-session: elevation, ulnar deviation, radial deviation	Approaching a doorknob placed along midline of body and at 75% of arm's length may be different than how participants would choose to approach a door. <i>Placing doorknob in line with shoulder and at a smaller percentage of arm length may improve reliability.</i>
PHONE	Within-session: plane of elevation, elevation, external rotation, pronation, elbow flexion, radial deviation, wrist flexion Between-session: elbow flexion	
PIN	Within-session: plane of elevation, elevation, external rotation, pronation, radial deviation Between-session: plane of elevation, elevations	Approaching a corkboard at 75% of arm's length may be different than how participants would choose to approach a corkboard. <i>Placing corkboard at a smaller percentage of arm length may improve reliability.</i>
PLATE	Within-session: elbow flexion (left arm), elevation (right arm), external rotation (right arm), pronation (right arm), radial deviation (right arm) Between-session: elevation (right arm)	Lack of required position for plate during wiping may have contributed to poorer reliability.
WATER	Within-session: plane of elevation, elevation, external rotation, pronation, ulnar deviation Between-session: elevation	