Gait & Posture 60 (2018) 41–47

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

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

Susannah M. Engdahl[a], Deanna H. Gates[a,b,*]

[a] Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI, USA
[b] School of Kinesiology, University of Michigan, Ann Arbor, MI, USA

ARTICLE INFO

Keywords:
Test-retest reliability
Repeatability
Upper limb
Kinematics
Activities of daily living

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-session. 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 ADLs, 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.

1. 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

---

* Corresponding author at: 401 Washtenaw Ave., Ann Arbor, MI, 48109-2214, USA.
E-mail address: gatesd@umich.edu (D.H. Gates).

https://doi.org/10.1016/j.gaitpost.2017.11.001
Received 16 May 2017; Received in revised form 14 September 2017; Accepted 5 November 2017

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.

2. Methods

2.1. 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/m^2.

2.2. 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 returned 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).

2.3. 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 x 19 participants x 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. Upper limb 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 to 95% of the movement cycle. Shoulder angles for standing tasks were selected from 10 to 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 in supplementary material. Because forearm supination and wrist angles were excluded for many tasks, we also calculated the reliability of the total range of motion as a supplementary measure.

2.4. Statistics

Statistical analyses were performed using SPSS 22 (IBM, Armonk,