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Distal upper limb kinematics during functional everyday tasks

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ABSTRACT

Quantitative characterisation of upper limb motion allows the evaluation of the effect of pathology on functional task performance, potentially directing rehabilitation strategies. Movement patterns of the distal upper limb in healthy adults during functional tasks have not been extensively characterised. During five loaded functional tasks (drinking from a glass, pouring from a kettle, turning a handle, lifting a bag to a shelf, turning a key) the movement patterns were characterised using three-dimensional motion analysis with a minimal marker set in 16 healthy adults (10 M,6F, 27 (IQR:25–43)years). Joint angles reported include flexion/extension at the elbow and wrist, forearm supination/pronation and digits 2–5 metacarpophalangeal (MCP) joint flexion/extension. Additionally for the thumb the angle between the metacarpal of the thumb and the 2nd digit (Thumb base), the thumb MCP (Thumb MCP) and interphalangeal (Thumb IP) joint angles are presented. Durations of activities performed at self-selected comfortable speeds (3.36 (IQR:3.07,3.66)s turning a key to 6.20 (IQR:5.44,6.38)s drinking from a glass) are reported. The maximum joint angles used (median of participants' maxima) were 141° of elbow flexion, 116° forearm supination, 36° wrist extension, 56° Thumb base, 14° Thumb MCP flexion, 18° Thumb IP flexion, 85° MCP2-5 flexion. The tasks of drinking from a glass, lifting a bag to a shelf and turning a key appeared to have the least variation in performance, suggesting that these activities are better suited to be selected as standardized tasks for assessing the impact of pathology on movement than pouring from a kettle and turning a handle.

1. Introduction

Three-dimensional motion analysis can be used to characterise movement patterns of the upper limb during the execution of everyday tasks [1]. This information provides normative reference patterns that can be used to compare with the performance of these activities by those with pathology [2–5]. Deviations from the patterns of movement seen in persons without pathology may be used to inform rehabilitation strategies.

In the upper limb three-dimensional motion analysis has been used extensively to characterise movement of the shoulder, elbow and wrist [1,6,7]. The movements of the thumb and other digits are less well characterised, pointing to a need for further investigation to understand normative movement patterns and therefore evaluate deviations due to pathology. It is possible that compensation in one joint of the upper limb may occur due to deficit in movement range in another joint in the kinematic chain, meaning that is it important to have a clear understanding of normal movement patterns throughout the limb.

Tracking of the movements of the digits can be accomplished using a number of different methods. Invasive scanning techniques have been used to monitor digit kinematics [8,9], but these cannot be implemented as a routine procedure. Also electrogoniometers have been used across the metacarpophalangeal joints[10], but the attachment of these presents a considerable burden to participants and may affect movement patterns. Alternatively optoelectronic motion analysis systems can be used where markers attached to the skin are used to track movements of the underlying bones. Due to the difficulty of tracking complex movements (marker occlusion), full digit motion analysis has been restricted to simple tasks, often of little everyday relevance [11]. Motion of the metacarpophalangeal joints can, however, be monitored with a limited marker set extending only to the proximal interphalangeal joint [12,13]. Such a marker set is suitable for use in a range of functional tasks allowing the collection of reference data for normative movements.

In this work the motion of the distal upper-limb (including elbow, wrist, thumb and metacarpophalangeal (MCP) joints) was characterised to enhance understanding of movements (joint angles and timings) in a selection of standardised everyday tasks. The joint movements used by a group for healthy adults were characterised as well as the variation of these movement patterns across the sample. This information can be

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used to evaluate the performance of these activities by those with pathology.

2. Methods

2.1. Participants

Participants were recruited from staff and students at a UK higher education establishment. All volunteers gave written informed consent with procedures approved by the institutional ethical review body. Only healthy participants with no current impairment of the upper limbs or neurological condition or uncorrected visual impairments were recruited. Previous impairment of upper limb function was not considered. Within the context of this report we use the term ‘upper limb’ to refer to all elements of the upper limb from shoulder to fingers. Participants age, gender, height, arm (from acromium process to fingertip arm outstretched), elbow to fingertip (from proximal elbow to fingertip elbow 90°) and hand (distal wrist crease to fingertip, hand supinated wrist neutral) lengths were recorded. Only the results from participants who were right hand dominant are reported.

2.2. Motion analysis

All activities were tracked with a camera (Panasonic SDR-H85) synchronised with a motion analysis system (13 camera Qualisys, 120 Hz) (Qualisys AB, Goteborg, Sweden). A marker set was used to allow determination of the joint angles of the upper limb including the elbow (flexion/extension and pronation/supination), wrist (flexion/extension), thumb (metacarpal 1 with respect to metacarpal 2 (Thumb base), metacarpophalangeal joint (Thumb MCP) and interphalangeal joint (Thumb IP)), and the other metacarpophalangeal joints (MCP2-5). This marker set was based on those previously proposed using a minimal marker set [14,15]. All markers (Table 1) were put in place for an initial static trial with the participant sitting at a table with palms placed on the table. For all subsequent trials the medial and lateral epicondyle markers (MEPI, LEPI) and the superior acromion marker (ACRM) were removed and the upper arm cluster used to identify their locations based on the STATIC trial.

Joint axes systems were defined (Table 1) and subsequently joint angles calculated (Visual 3D Professional V4.00.14, C-Motion, Germantown, MD, USA). Joint angles for elbow, wrist and digits 2 to 5 were calculated using a sequence of rotations from the proximal to the distal coordinate system (flexion/extension, then ulnar/radial deviation and then supination/pronation). As the definition of the thumb is more difficult than the other digits a specific method of determining joint angles was used as detailed in Table 1. Note that only selected outcomes are presented within this report.

2.3. Activities

The function of the upper limb can be categorised into three main object related actions, i.e. reach, grasp, and manipulation of objects [16]. Currently therapy assessment tools or intervention methods typically integrate all three actions of reach, grasp and manipulation of objects into one whole action. Therefore the five tasks selected for this study (Table 2) incorporated a variety of basic activities of daily living (ADL) tasks where the three object related hand actions could be described and categorised. Most ADL activities are bimanual and involve the use of both upper limbs. In spite of this, unimanual tasks were selected because clinicians and therapist typically assess and treat upper limb dysfunction on the affected upper limb or hand only.

2.4. Test set up

A table (height 72 cm) was used with a black none-reflective cloth covering it. An armless chair with wheels with height self-selected by the participant to allow comfortable performance of activities was used. Set locations were marked on the cloth for placement of equipment during the activities (F 40 cm, H 60 cm straight in front and E 40 cm in front and 16 cm to the right) (See Supplementary material Fig. S1).

2.5. Test procedure

Each activity was repeated 3 times with the dominant arm. At the start and finish of each activity repetition the participants placed their hands, palm down on the table surface at a distance approximately 16 cm from the centre line. All activities were performed at a self-selected speed. Before each activity the participant was given oral description of the action required and then allowed to perform one or two practices of the action to ensure they understood the requirements. For the kettle pour and drinking from a glass the participants were instructed to mimic the actions (Table 2).

2.6. Segmentation of activities

Two time points were chosen for identification in each activity (Table 2). All time points were identified manually by observation of the movement of the motion markers within the motion analysis software (Qualisys AB, Goteborg, Sweden) and accompanying video images.

2.7. Data analysis

Data were tested for normality of distribution (Shapiro-Wilk test, SPSS v23: SPSS Inc, Chicago, IL). Absolute and percentage timings of task components were determined based on the mean of each participant’s data. The standardised starting point joint angles were characterised. For each activity 100% was defined as the time from initiation to completion. The median and interquartile ranges of joint angles from 0 to 100% of the activity were calculated based on all repetitions of all participants. Joint angles are presented graphically and maxima and minima are characterised with range.

3. Results

For consistency of data presentation median and interquartile range (IQR) are used for all outcomes as there was a mix of normal and non-normal distributions within the data. Sixteen right hand dominant participants were recruited (10 M, 6F), age 27 (IQR:25,43) years, height 176.0 (IQR:169.5,183.0)cm, arm length 77.0 (IQR:74.0–78.9)cm, elbow to fingertip 46.1 (IQR:44.9,49.6)cm and hand length 19.3 (IQR:17.7,20.0)cm.

All participants successfully completed each activity 3 times giving 48 repetitions of each activity. The activities took between 3.36 (IQR:3.07,3.66)s (turn key in lock) and 6.20 (IQR:5.44,6.38)s (drinking from a glass) to complete (Table 3). In general the activity lift bag to shelf was performed with a lower variation in time than the other activities, although to time point 2 in each activity the maximum interquartile range of timing was 0.55 s for pouring from a kettle. Time point 2 was achieved on average between 43.5 (IQR:39.7,46.6)% (key turn) and 57.8 (IQR:55.7,62.1)% (lift bag to shelf) of the total time.

Graphical representation of joint angles demonstrates the movement patterns required (Fig. 1). The maxima and minima of joint angles are given in Table 4. As can be seen in Fig. 1, the maxima and minima for numerous joint angles occurred across a range of time points. This was due to the participants maintaining one joint at a particular angle whilst making adjustments at other joints. Participants used the highest level of elbow flexion for drinking from a glass (141 (IQR:138,143)°), with very consistent maximum flexion (106–108°) for all other activities, although with varying minimum levels of flexion. Forearm supination in the key turn activity reached 116 (IQR:103,134)° with a range of 96 (IQR:87,101)°. Wrist flexion was slightly higher in the lift a bag to