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Validity and reliability of upper extremity three-dimensional kinematics during a typing task

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ABSTRACT

Computer use continues to be considered a risk factor for work-related musculoskeletal disorders despite a greater awareness of the risk associated with excessive use, the implementation of safety features and the introduction of extensive interventional programs. Better understanding of risk factors in movement patterns is needed. This study identified the most suitable variable for work-related upper extremity motion analysis as being peak-to-peak range of motion. Assessment was by three-dimensional motion analysis for upper extremity ergonomics. The study was designed to validate and examine the reliability of these parameters in the setting of keyboarding. Sixty-two right-hand dominant participants (non-skilled typists) were recruited. Motion analysis was performed using the Cartesian Optoelectronic Dynamic Anthropometric CX-1 (CODA) system with markers which were attached to the right hand, elbow, wrist and fingers. Range of motion and angular velocity were recorded while the subjects repeatedly typed a predetermined sentence five times. The re-test examination was repeated after an interval of one week. The findings clearly demonstrated discriminative validity in wrist range of motion ($p < .01$), test–re-test, reliability ($.83 > \text{ICC} > .70$) and inter-rater reliability ($.95 > \text{ICC} > .70$) for most variables. The CODA system has considerable potential for understanding movement patterns in the upper extremities. These findings can provide the basis for future studies on the efficacy of ergonomic intervention programs.

1. Introduction

Epidemiological studies have shown an increase in upper extremity musculoskeletal disorders (UE-MSD) among typists who spend more than 4 h a day working on a computer [1–3]. As many as one-half of the people who used computers extensively reportedly complain of pain [4]. An activity analysis of computer settings pointed to a number of risk factors for UE-MSD, including fast typing, awkward posture [1,5–7], hyperextension of the little digit metacarpophalangeal joint (MPJ) and isolation of the thumb and little digit [8], maintaining static hand positions [10,11], mechanical pressure on the distal forearm [2,6,12], and exerting force while typing [13,14]. Identifying specific kinematic patterns that differentiate between workers who suffer from UE-MSD from those who do not is essential, and understanding the mechanism underlying UE-MSD disorder is vital for designing preventive programs. Evaluation of UE-MSD is usually based on questionnaires and observations [2,7], which can be meaningful, accessible, and inexpensive, but they are subjective measures.

Significant progress has been made in the development and use of two- and three-dimensional (3D) computerized motion analyses systems as a kinematic measuring tool. They are routinely used in gait analysis research and clinical practice, and have has recently been applied in evaluating upper extremities [15,16]. The possibility of analyzing movement with the 3D system is highly attractive for diagnosing motion disorders, but knowledge about the use of 3D systems for evaluating the upper extremity in an ergonomic context is sparse. Kontaxis et al. [17] reviewed the main research publications on 3D motion analysis of the upper extremities and were first to describe guidelines and recommendations for building a 3D upper extension motion analysis protocol. Most of the studies conducted on the upper extremities provide descriptive data, such as range of motion (ROM), segmental movement, reaching or performance of activities of day living (e.g., combing hair, drinking) [18–20]. Few studies utilized 3D motion analysis to describe the kinematics of the upper extremities during typing [8,9,21]. Sommerich et al. [22] described the overall joint posture, velocities, accelerations and the metacaparpophalangeal (MCP) and proximal interphalangeal

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(PIP) kinematics with a two-dimension electrogoniometer. Baker et al. [8] analyzed 3D kinematics of the upper extremities during typing, focusing on descriptive statistics of the ROM in both hands (fingers and wrist displacement). Baker et al. [9,21] recently reported a motion analysis of the wrist and fingers during typing in which they compared the hand and digit kinematics between an ergonomic and a non-ergonomic keyboard. The same group [21] also used the 3D motion analysis system to validate an ergonomic observational instrument.

To the best of our knowledge, test–re-test reliability of 3D kinematics of the upper extremities during task performance has not been studied before with the exception of two studies on the repeatability of a reaching test in children with cerebral palsy [23,24]. Both of those investigations used a passive motion analysis system, as did most other studies, but none looked into the reliability and validity of an active motion analysis system, either in general or in relation to computer use. We used the Cartesian Optoelectronic Dynamic Anthropometric CX-1 (CODA) motion analysis system [25] in the current study. Our aim was to identify the most suitable variables for motion analysis of the upper extremities and to test the validity and reliability of these analyses. We hypothesized that there would be significant differences in motion parameters of the wrist between wrist-injured and non-injured participants as well as significant Interclass correlation between repeated measurements taken at one-week interval. We also hypothesized that there would be a high intra-class correlation (ICC) between repeated measures taken by two raters.

2. Methods

2.1. Participants

The study was approved by the Institutional Review Board of the hospital in which the research was conducted. Each participant signed a consent form before enrollment. For discriminative validity, a total of 14 subjects with wrist injuries who were being treated in the outpatient hand clinic (ten males and four females, mean age 37 ± 11.7 years) were recruited. Three non-injured participants per patient were matched for age (mean 33 ± 12 years), gender and hand dominancy. Four non-injured participants dropped out due to CODA's camera reception error, leaving 38 non-injured participants (21 males and 17 females), of whom 19 were re-tested by a second rater (12 females and eight males, mean age 30.2 ± 11.7 years) for evaluating inter-rater reliability. Ten non-injured volunteers (seven females and three males, mean age 29 ± 12.4 years) were recruited for test–re-test reliability assessment.

The inclusion criterion for participants in the discriminative validity subgroup was an injury of the wrist. The inclusion criteria for all participants were being generally in good health, and right-handed non-skilled computer users. Exclusion criteria were previous orthopedic injury or neurological deficit (with the exception of wrist injury for the injured subgroup), and medical conditions associated with swelling of the joints or hand numbness (pregnancy, diabetes, heart condition, arthritis).

2.2. Instruments

All participants filled in a biodemographics questionnaire. For the upper extremity kinematic model, kinematic data were collected using the Coda CX1 (CODA) [25], a 3D motion analysis system. The upper extremity setting was positioned around a computer workstation in a motion laboratory. Two cameras tracked the position of 14 active CODA markers (infrared light-emitting devices, LEDs) and seven drive boxes. The markers setup was attached to the anatomical frames of the forearm, arm and fingers, representing the segments and joints of interest that take part in typing. Five virtual markers were added and extrapolated from the real markers in order to place a point near the center of rotation and define the hand and arm axis (Table 1, Fig. 1). This setup was recommended by the CODA manufacturers, based on the International Society of Biomechanics (ISB) [16]. A sample rate of 200 Hz was recommended by the manufactures for sets including up to 28 markers. The system provided information on joint range of motion (wrist flexion, projected and non-projected, extension and radial-ulnar deviation), mean, standard deviation (SD), minimum (Min), maximum (Max), peak-to-peak (PTP) range in degrees, root mean square (RMS), area under the curve (AUC) and angular velocity (°) of movement. The peak-to-peak range and angular velocity were chosen for our purposes. Data were sampled, stored and exported to MATLAB for calculation of the kinematic variables. The system was calibrated with a standard hand goniometer, and the results demonstrated a significant correlation ($r = .999$; $p \leq .001$) between the CODA system and the goniometer.

2.3. Procedure

Biodemographic questionnaires were filled in and the markers and drive boxes were attached according to protocol (Table 1). The participants were instructed to be seated, adjust the station to a comfortable position, and start to type a predetermined sentence on a standard computer with flat keyboard position. The typing task was repeated five times. The joints kinematics were derived from the markers while the subject was sitting and typing. The participants with wrist injury were tested on the affected hand, even if that hand was not the dominant one. The subjects in the non-injured group were tested on the same hand as that of the matched subject with the injury. Ten participants were assigned to the test–re-test subgroup and there was a one-week interval between the first and second test.

Table 1
The CODA upper extremity marker setup.

Markers and location	Angle definitions
Marker 1: Index proximal interphalangeal joint (PIP2) Marker 2: Index metacarpophalangeal joint (MP2) Marker 3: Medial wrist, on radial styloid joint Marker 5: Glenohumeral joint: anterior upper arm Marker 6: Glenohumeral joint: posterior upper arm Marker 7: Lateral epicondyle of humerus: on elbow joint axis Marker 9: Lateral wrist on ulnar styloid Marker 11: Middle metacarpophalangeal joint (MP3) Marker 12: Middle proximal interphalangeal joint (PIP3) Marker 13: Ring metacarpophalangeal joint (MP4) Marker 14: Ring proximal interphalangeal joint (PIP4) Marker 15: Little metacarpophalangeal joint (MP 5) Marker 16: Little proximal interphalangeal joint (PIP5)	MP index-MP little flexion extension, the angles between: Vector 1: Markers 2,11,13, 15 matched to Markers 1,12,14,16, respectively and Vector 2: virtual Marker 1–virtual Marker 3 Extension taken as positive and flexion taken as negative
Virtual Marker 1: Wrist center. Midpoint of medial and lateral wrist. Markers 3 and 9 used as the distal end of the forearm Virtual Marker 2: Mid-hand. Mean point of all MP markers. A line between this point and the volar wrist center defines the forward axis of the hand Virtual Marker 3: Normal hand. A point on the normal hand, defined from the medial and lateral wrist markers and volar mid-hand. A line to this point from the volar wrist to center defines a second hand axis	Wrist (lateral) deviation, the angles between: Vector 1: Marker 7 and virtual Marker 1 and Vector2: virtual Marker 2 and virtual Marker 3. Projected onto the horizontal (x–y) plane Radial deviation taken as negative and ulnar deviation taken as positive
Virtual Marker 4: Proximal humerus. Midpoint of anterior humerus and posterior humerus (Markers 5 and 6) used as the proximal end of the upper arm	Wrist flexion–extension the angles between: Vector 1: virtual Marker 1. and virtual Marker 5 and Vector 2: virtual Marker 1 and virtual Marker 3 Extension taken as positive and flexion taken as negative
Virtual Marker 5: Normal lower arm. A point on the normal hand to the triangle formed between the wrist markers and the elbow marker. A line to this point from the volar wrist center defines a second lower-arm axis that is perpendicular to the long-axis (elbow ≥ virtual wrist center)	Elbow flexion-extension the angles between Vector 1: virtual Marker 4 and Marker 7 and Vector 2: Marker7 and virtual Marker 1 Flexion taken as positive and hyperextension taken as negative