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DEVELOPMENT OF A COMPLETE UPPER EXTREMITY MODEL FOR ASSESSMENT OF SHOULDER, ELBOW, WRIST, AND FINGER MOTION

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INTRODUCTION

People with disabilities due to neurological disorders and diseases including muscular dystrophy, spinal cord injury, and stroke represent a significant percentage of the global population. Stroke, for instance, is a major cause of adult long-term disability. According to a report published by the Public Health Agency of Canada in 2013, about 741,800 Canadian adults aged 20+ live with the effects of a stroke [1]. Upper extremity movement limitations can have a significant impact on the ability to perform activities of daily living (ADL), an individual's independence, and quality of life. Previous research has shown that the improvement of hand function post-trauma have high priority compared with other impairments such as bladder and bowel function [2]. For this reason, several studies have been aiming for the improvement of treatments and better ways to assist this population. Motion capture systems, for instance, can accurately quantify joint and body segment motion using mathematical models of the human body.

Previous biomechanical research in this area has shown that a kinematic analysis of the patient leads to a better understanding of human movement which helps the physiotherapist better analyze treatment effectiveness [3], [4]. The stereo-photogrammetry motion capture technology has been used extensively and several studies have sought to improve the tools and the methodology used to quantify human movement [5]–[9]. However, upper extremity biomechanics presents numerous challenges including increased complexity in dynamic situations and a lack of standardized models. Most of the existing upper extremity models do not include fingers because of the relatively complex high degree of freedom located in a very small space. To be able to collect kinematic data from the hand, small markers have to be used, such as 4mm size, and the cameras of the motion capture system usually have to be placed very close to the subject's hand to be able to track these small markers. For this reason, authors have been focusing on developing models only for hand and fingers, not taking into account the movements of the arm, or, conversely, only arm, not taking into account hand and fingers.

In the context of rehabilitation, the improvement of hand function also affects how a patient moves their trunk, upper-arm and forearm. Based on this information, in this research we reviewed more than 55 papers that were published from 1996 to 2017, in which research groups proposed and tested different techniques to measure the required inputs for biomechanical models. The majority of previous research focused on either upper extremity models or hand (alone) models. Based on this previous research we developed and tested the reliability of a complete kinematic upper extremity model that may be used in clinical-based research to analyze detailed information of the movement of the upper extremity, including upper arm, forearm, hand and fingers, during activities of daily living.

METHODOLOGY

Kinematic model and set up

A motion capture system, (Vicon, Oxford, UK), 12-camera (T160) movement analysis system sampling at 100 Hz was used to capture the kinematic data. This system is placed in the Human Performance Laboratory at the

University of New Brunswick. The cameras were positioned close enough to capture the trajectory of the small markers placed on the fingers and hand, and also to capture the trajectory of the larger markers placed on the arm, and forearm.

The comprehensive rigid-body upper extremity model developed in this research included the segments, upper-arm, forearm, hand, fingers, and thumb. Segments were connected by a three degree-of-freedom shoulder joint, a two degree-of-freedom elbow, wrist, thumb, carpometacarpal joint, and one degree-of-freedom finger metacarpophalangeal, distal and proximal interphalangeal joints.

Two sets of information are needed to reconstruct an instantaneous position of an anatomical landmark (LA) in a marker-based stereo-photogrammetry. One is the technical frame, that will generate relevant information regarding position and orientation based on marker cluster positioned on a rigid body (segment), and the other is the time invariant position of the anatomical landmark with respect to this technical frame [9]. The LA can be easily palpable (bony prominence) or non-palpable (internal), as example, the shoulder, which makes it easier to misplace it and increase the error in the motion capture analysis.

Marker location

The marker location is an integration of a well-known upper extremity model (which does not include fingers) used in clinical research, and a hand model (which does not include upper arm and forearm). The upper extremity model developed in this paper is similar to the model developed by Schmidt *et al.*[4], and Hingtgen *et al.*[10]. The hand and fingers model is similar to the model developed and used by Metcalf *et al.*[11], Miyata *et al*.[12].

A total of 37 passive reflective markers were placed on the participant. Markers were placed, on the right and left acromion, one on spinous process C7, and on the sternal notch. Four markers in a rigid plate were attached to the arm and forearm, and twenty-one 4 mm markers were directly attached to the skin of the participant's hand as shown in Figure 1.

Joint Center

The joint center and joint axes were determined based on the anatomical markers. The elbow and wrist joint centers were calculated at the midpoint between medial and lateral epicondyle and the midpoint between radial and ulnar styloids, respectively. The shoulder joint center was determined based on the circumference of the shoulder that was measured around the acromion and axilla to approximately calculate the radius of the shoulder. The location of the joint center was then inferiorly from the acromion, at the measured radius [10].

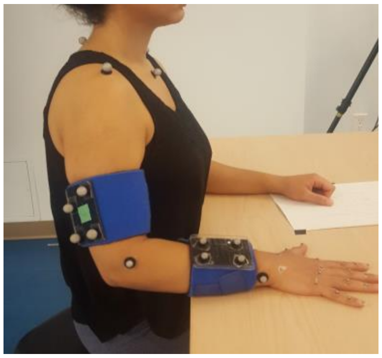

Figure 1: Marker arrangement for the upper extremity, hand, and fingers

Experiment

For the data collection, one participant was seated in an adjustable chair, with their elbow in approximately 90 degrees and the hand comfortably positioned on a flat table centered on the motion capture volume area.

An object was placed directly in front of the subject during the tasks. The subject was verbally instructed to perform 2 tasks based on simple activities of daily living. All of the movements started and ended at a predetermined position. The first task required that the participant reach a rounded bottle, grasp it, bring it to their mouth, and return it to its original position. The second task was identical to the first task however the procedure was performed with a narrowed bottle for a different grasp.

The 3D marker position data acquired from the Vicon system was used to calculate elbow and finger joint position, joint angles, and range of motion throughout the grasping cycle.

Additionally, to assess how much the skin motion artifact is affecting the data measured on the fingers, a correlation coefficient between angle and distance of the marker on the finger was calculated.

RESULTS

To evaluate the skin motion effect of having 4 mm markers placed on each phalangeal joint, a mean of the correlation coefficient between angle and distance of all fours fingers was calculated. The results show that there is less skin motion artifact between the metacarpophangeal (MCP) and the proximal interphalangeal (PIP) r=0.719±0.012 than between the proximal interphalangeal and the distal interphalangeal (DIP) joints r=0.939±0.024. However, this model has been tested and proved to be reliable for clinical research giving angles with a mean repeatable accuracy of 5.1°, as shown by Metcalf *et al*. [13].

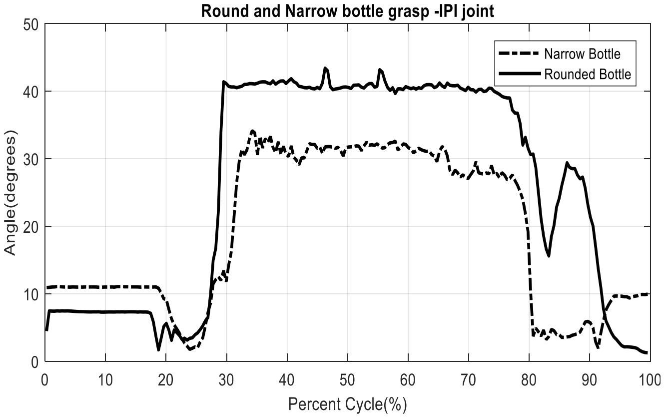

Figure 2: Graph of the IPI joint angle variation within a cycle when grasping a narrow (dashed line) and rounded (solid line) bottle.

The grasping cycle for the fingers and elbow for both tasks are shown in Figures 2 and 3 respectively. A complete grasping cycle defined in five steps can be seen in these figures. The cycle begins with elbow flexion and finger extension and then moves to elbow extension and finger flexion, when the subject grasp the bottle. After that, there is an elbow flexion with fingers flexed (midpoint), when the subject brings the bottle to their mouth, followed by an elbow extension and finger extension, when releasing the bottle, and ending with elbow flexion and finger extended (back to the initial position). Figure 2 shows the PIP joint angle of the subject grasping a narrowed and a rounded bottle. It can be seen that for the narrowed bottle the subject flexed the PIP joint less than when grasping the rounded bottle.

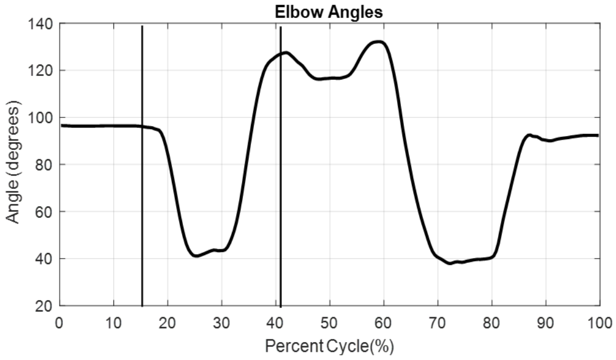

Figure 3: Graph of the elbow angle variation within a cycle.

DISCUSSION

When choosing the best kinematic measurement technique, selecting the appropriate marker topology and the joint coordinate system will depend on the requirements of each study and protocol. More complex models may not be useful for clinical purposes but might be important for a biomechanical analysis.

The results presented here are comparable to common and well-known models used in clinical research. A model very similar to the hand model presented in this paper, for instance, has been actively used in ongoing clinical trials to assess functional movements of chronic stroke patients and a splinting intervention for hyperextension of the PIP joint in rheumatoid arthritis [11]. Moreover, an upper extremity model very similar to the model presented in this paper was used to compare unaffected and affected motion patterns in a patient post stroke [10]. The tasks performed on the study with post stroke patient and the task performed in this study are also similar which make it possible to make a comparison between results. In their experiment, the subject started with their hand against their sternum, reached an object placed directly in front of them and ended the cycle with their hand back in front of their sternum.

Hintgen et al. [10] found similar results with respect to elbow angle measurement pattern within a cycle (Figure 4). The solid line in Figure 4 represents the subject's unaffected arm and the dashed line represents the subject's affected arm. A similarity can be seen in Figure 3 between 15 and 40% of the cycle (represented by the two vertical lines on the graph) when the subject reached and grasped the bottle and brought it to their mouth. Remembering that the start and end position within this interval is not the same for the subject in our study.

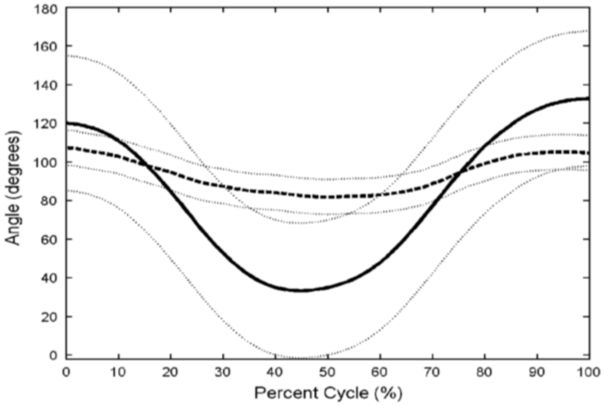

Figure 4:Graph from Hingtgen *et al.*[10] of the elbow angle variation within a cycle in post stroke patients.

CONCLUSION

In this study we developed and tested a complete model with a three degree-of-freedom shoulder (glenohumeral) joint, two degree-of-freedom elbow and wrist, and one degree-of-freedom fingers (phanangeal) joint that is suitable for clinical research. This is the first time an integration of upper extremity and hand model in a passive marker-based system have been accomplished and tested. Using this model, research can assess feasible and clinically meaningful information regarding shoulder, elbow, wrist and fingers joint angles, range of motion and angular velocity which are important variables for patient evaluation and treatment.

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