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Short communication

Kinematic performance of a six degree-of-freedom hand model (6DHand) for use in occupational biomechanics☆

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ABSTRACT

Upper extremity musculoskeletal disorders represent an important health issue across all industry sectors; as such, the need exists to develop models of the hand that provide comprehensive biomechanics during occupational tasks. Previous optical motion capture studies used a single marker on the dorsal aspect of finger joints, allowing calculation of one and two degree-of-freedom (DOF) joint angles; additional algorithms were needed to define joint centers and the palmar surface of fingers. We developed a 6DOF model (6DHand) to obtain unconstrained kinematics of finger segments, modeled as frusta of right circular cones that approximate the palmar surface. To evaluate kinematic performance, twenty subjects gripped a cylindrical handle as a surrogate for a powered hand tool. We hypothesized that accessory motions (metacarpophalangeal pronation/supination; proximal and distal interphalangeal radial/ulnar deviation and pronation/supination; all joint translations) would be small (less than 5° rotations, less than 2 mm translations) if segment anatomical reference frames were aligned correctly, and skin movement artifacts were negligible. For the gripping task, 93 of 112 accessory motions were small by our definition, suggesting this 6DOF approach appropriately models joints of the fingers. Metacarpophalangeal supination was larger than expected (approximately 10°), and may be adjusted through local reference frame optimization procedures previously developed for knee kinematics in gait analysis. Proximal translations at the metacarpophalangeal joints (approximately 10 mm) were explained by skin movement across the metacarpals, but would not corrupt inverse dynamics calculated for the phalanges. We assessed performance in this study; a more rigorous validation would likely require medical imaging.

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1. Introduction

Upper extremity musculoskeletal disorders are recognized as an important occupational health issue across all industry sectors (Marras et al., 2009). Worker's compensation claims in 2006 included $12.4 billion for related over-exertions (Liberty-Mutual, 2008). In manufacturing, shoulder, wrist, hand, and finger disorders accounted for 33% of lost work day injuries (BLS, 2005). Carpal-tunnel-syndrome (CTS) and hand–arm-vibration-syndrome (HAVS) adversely affect workers who use powered hand tools or engage in manual assembly operations, where injury severity is related to gripping mechanics (NIOSH, 1997). The need exists to develop hand models that provide comprehensive biomechanics during occupational tasks.

The metacarpophalangeal joint (MCP) of the index, middle, ring, and little fingers (F2, F3, F4 and F5, respectively) primarily allows flexion/extension and radial/ulnar deviation; the proximal and distal interphalangeal joints (PIP, DIP) primarily allow flexion/extension (Netter, 1991). Clinically defined accessory motions include rotations and translations other than these primary rotations, and are small for normal joints (Kuczynski, 1975). Accessory rotations at the MCP joint include pronation/supination; those at the PIP and DIP joints include radial/ulnar deviation and pronation/supination. Detailed studies of these motions, free from skin movement artifact, are rare. Using a radiographic technique to obtain bone-to-bone motions for two human subjects, Chao et al. (1989, p. 89) reported accessory motions for pinching and grasping tasks (Table 1). Using an electromagnetic tracking system, Minamikawa et al. (1993) reported PIP joint motion for 12 cadaver index fingers. Using a similar technique Uchiyama et al. (2000) reported PIP joint motion for nine cadaver middle fingers, with externally applied moments. Using circular bone wires fixed to each phalange and metacarpal, Degeorges and Oberlin (2003) reported means and standard deviations for

☆*Disclaimer*: The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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