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Review Article

Ergonomic Evaluation of Biomechanical Hand Function

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ABSTRACT

The human hand is a complex structure that performs various functions for activities of daily living and occupations. This paper presents a literature review on the methodologies used to evaluate hand functions from a biomechanics standpoint, including anthropometry, kinematics, kinetics, and electromyography (EMG). Anthropometry describes the dimensions and measurements of the hand. Kinematics includes hand movements and the range of motion of finger joints. Kinetics includes hand models for tendon and joint force analysis. EMG is used on hand muscles associated with hand functions and with signal-processing technology.

1. Introduction

The human hand is composed of a thumb, index finger, middle finger, ring finger, little finger, and palm, which includes the thenar eminence, the hypo thenar eminence, and creases. The fingers contain 19 bones of distal phalanges, middle phalanges, and proximal phalanges, and metacarpal bones. Thus, the fingers have metacarpophalangeal (MCP), proximal interphalangeal (PIP), and distal interphalangeal (DIP) joints, whereas the thumb has carpometacarpal (CMC), MCP, and interphalangeal (IP) joints. The wrist contains the following eight bones: the hamate, pisiform, triquetral, capitate, lunate, trapezoid, trapezium, and scaphoid [1]. In total, the hand has 27 bones and 28 muscles [2]. These numerous bones and muscles enable the hand to perform various functions.

The hand is frequently used in activities of daily living and industrial fields because of its many functions. This can cause numerous musculoskeletal disorders (MSDs) in the hand relative to the lower limbs, such as De Quervain's tenosynovitis, trigger finger, ganglionic cysts, hand–arm vibration syndrome, and BlackBerry thumb [3]. Hand disorders account for one third of all injuries at work, one fourth of lost work time, and one fifth of permanent disabilities [4]. Hand discomfort and injuries occur when a task requires a hand strength that exceeds the worker's capability, an awkward posture, and/or repetitive motion. Individuals with hand MSDs are limited in their activities due to their reduced grip strength and ability [5–8].

The handgrip is an important and basic function for various movements. Object manipulation with a stable handgrip is one of the most frequent movements performed in activities of daily living and occupational fields. A reduction in the grip strength and control ability can be attributed to physical and psychosocial factors. Physical factors can include a reduction in the number of contracting muscle fingers, reduction in the firing rate of motor units, and change in the muscle fiber type. Psychosocial factors can include pain, a fear of pain, and a fear of reinjury [8]. Pain can reduce the grip force, which decreases voluntary muscle activity. This manifests as decreases in the force generation, electromyographic (EMG) activity [9–11], motor unit discharge rate [12], and ability to maintain a grip force [13,14]. MSDs can cause a person's physical and psychological capacities to deteriorate.

Many researchers in the ergonomics field have been trying to understand how humans use their hands and which factors affect the hand-function capacity. In particular, the physical capacity of the hand has typically been evaluated by biomechanical methodologies. Biomechanical analysis of the human hand can be divided into anthropometry, kinematics, kinetics, and EMG [15].The

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application of biomechanical principles is important for preventing MSDs in order to improve working conditions and performance. In ergonomics, safety, and health, the hand is mainly evaluated to reduce the risk of MSDs. In product development, the hand is actively studied for the design of hand tools and cell phones. In rehabilitation, the hand is studied to evaluate the difference between patients and healthy individuals. Studying the hand is important for the development of hand-related simulations and robots in the digital manufacturing simulation and intelligence robot fields.

Detailed information on the technologies and methodologies used for hand analysis is required for nonexperts in the field of biomechanics such as hand-tool designers and safety supervisors to understand and choose easy and suitable methods. Hand anthropometry is simply the basis of biomechanical analysis. The range of motion (ROM) is the most commonly used functional measurement variable. Anatomical measurements and the ROM are usually used to design hand products and rehabilitation. The three-dimensional (3D) motion analysis system is currently the most commonly used technique to measure kinematic variables such as the trajectory, angle, velocity, and acceleration. This system needs marker sets and kinematic models for analysis. Several kinds of marker sets and kinematic models have been developed based on the purposes of different studies, and the accuracy of the system has been improved. Thus, it can provide important information for researchers to choose a suitable method. Kinetic hand models have been developed for analyzing the internal load (force and moment) of tendons and muscles during static and dynamic motions. These kinetic hand models have advantages and disadvantages with regard to the measurement method and complexity. Information from kinetic hand models can help a researcher design an experiment design. EMG is most commonly used in various research fields to evaluate the muscle activity, fatigue, and conduction velocity. For accurate analysis, understanding the use of the EMG equipment, electrode placement, muscle position, and signal-processing methods is important.

This paper presents a literature review of some technologies and methodologies used for hand-function analysis based on a biomechanical approach and the results of previous studies related to hand functions. The following four categories of hand-function analysis are covered: (1) anthropometry, (2) kinematics, (3) kinetics, and (4) EMG.

2. Methods

For this review, a systematic search was conducted using PubMed, Elsevier Science, and ScienceDirect databases, and Google Scholar on studies published from 1960 to 2014. The search was restricted to papers published in English and containing the terms “hand biomechanics,” “hand function,” “hand anthropometry,” “hand kinematic,” “hand kinetic,” “EMG of hand,” “finger joint angle,” “finger tendon force,” or “biomechanical hand model” in the title, abstract, or keywords. The initial search of the database yielded about 450 results. After a review of the titles and abstracts to reject duplicated articles, 245 articles were selected. After applying inclusion and exclusion criteria, 19 articles related to hand anthropometry were selected, and 31 articles related to hand kinematics were identified from the manual targeted search. Eighteen articles or books related to hand kinetics, 10 articles related to hand EMG, and 26 articles related to hand anatomy, MSDs, posture, and functions were selected. In total, 104 articles were selected for inclusion in the current review (including 6 books and 6 reports). In the following sections, the term “reviewed articles” refers to the 104 selected articles.

3. Hand anthropometry

3.1. Technology for hand anthropometry evaluation

Hand anthropometry is important to the design of products for human hands. Examples include machine guards, hand tools, and luggage handles. Hand anthropometric parameters are categorized into anatomical measurement variables such as the length, width, and circumference [16–18]; functional measurement variables such as the handgrip span, flexion and extension ROMs of the fingers and wrist, and abduction/adduction and deviation ROMs of the wrist in engineering anthropometry [16,18–20].

Hand anthropometry can be directly measured using digital calipers, circumference tapes, and finger circumference gauges [16,21] and can also be measured from photographs [18,22] and scans [23,24]. Goniometers and 3D motion analysis systems are used to measure the width, flexion, and extension ROMs [25]. Direct measurement is easy and efficient, but skin movement and experimenter error can occur. Photography measurement requires less time than direct measurement, and the recorded information can be repeatedly used [26], but measuring the circumference is difficult. Although 3D scans can be used to measure diverse hand areas precisely, data can be distorted due to movements during the scan.

3.2. Anatomical measurement variables

In general, anthropometry for anatomical measurement variables is divided into general and application surveys. General surveys are used to explain the hand variation of large populations. Their main purpose is to describe populations. By contrast, application surveys are used to gather data for a specific product. Therefore, an application survey often uses few individuals but with strictly defined populations such as occupational groups [18].

Following the trend of general surveys for hand anthropometry, Vicinus [27] measured 44 dimensions of both hands in 253 males. The results for the left and right hands were significantly different. The left hand had a larger breadth than the right hand, whereas the right hand had a larger length than the left hand. Moreover, the correlation between the hand length and breadth dimensions was generally poor. Garrett [28,29] conducted a comprehensive general survey on 148 males and 211 females to measure 34 dimensions of the hand and 17 dimensions of engineering anthropometry [16]. This study showed a wider range of hand dimensions than previous studies. Gooderson et al [30] measured 62 dimensions of the left and right hands in 300 males and 187 females in the British army. Similar to Vicinus [27], they found a low correlation between the hand length and breadth dimensions. Greiner [18] measured 64 hand dimensions. Recently, Okunribido [31] measured 18 dimensions of the hand in 37 females from Ibadan and western Nigeria and compared them with those of other populations. The results showed that hand dimensions differed between populations. Similarly, Mandahawi et al [32] measured 24 hand dimensions in 115 males and 120 females and analyzed the difference between sexes and between Jordanians and other populations. Their results showed significant differences with regard to the sex and population.

With regard to examples of application surveys for hand anthropometry, Barter and Alexander [33] measured 18 hand dimensions in 100 individuals to develop a glove sizing system. In their study, hand dimensions were selected for developing the glove system, and these dimensions are not normally measured in most hand surveys. Rosenblad-Wallin [34] measured 33 hand dimensions for the development and design of army gloves.

Hand anthropometry data are used to design ergonomic tools or equipment and space. Thus, the measurement criteria and