A PILOT STUDY OF BIOMECHANICAL FACTORS AFFECTING UPPER LIMB POSTURE DURING GRASPING, HOLDING, AND PLACING CYLINDRICAL OBJECT

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INTRODUCTION

A biomechanical analysis was performed to explain upper limb postures during grasping, holding, and placing cylindrical objects. This study is needed for ergonomic design of work equipment and methods to provide workers with sufficient control over objects in object transfer tasks.

We previously showed that self-selected postures used to grasp, hold (approximately eight seconds), and place cylindrical objects are influenced by object weight. Horizontal cylinders varying from 0.34 to 5.44 kg were presented to four males and four females at elbow height. The cylinders were supported at each end such that there was sufficient clearance for the hand to approach and grasp the object from above or beneath (overhand or underhand grips as described by Rosenbaum et al. [1]). We observed that 1) the probability of grasping with an overhand grip (Figure 1a) decreased, while that of an underhand grip (Figure 1b) increased with increasing weight; 2) after grasping, subjects re-positioned and held the object primarily using either a hook grip at the side of the body (Figure 1c), an underhand palm grip in front of the body, or a palm grip at shoulder height (Figure 1d); 3) the probability of holding the object using the hook grip decreased while that of the palm grips increased with increasing weight; and 4) the subject placed the object back onto stands using overhand or underhand grips in similar trends as in grasping.

These results are qualitatively consistent with Rosenbaum's theory that posture selection for grasping objects is related to end-state comfort [1]. We propose that comfort and posture behavior can be explained in terms of relative upper limb joint loads (% maximum voluntary joint strength). In this study we estimated and compared the relative loads that would be produced on the hands, wrists, elbows and shoulders for the postures observed in our previous study.

METHODS

Major external forces and moments of the upper limb during grasp, hold and place are shown in Figure 1. The load moments at the wrist, elbow, and shoulder joints were estimated using the University of Michigan 3D Static Strength Prediction Program™ (3DSSPP) version 6.0.4 [2] and were compared with the mean population strengths reported by 3DSSPP. The 3DSSPP also considered the contribution of static body weight to the joint load moment. Human figures were scaled by the heights and weights of the eight subjects. The postures (Figure 1) were entered based on estimation from videos.

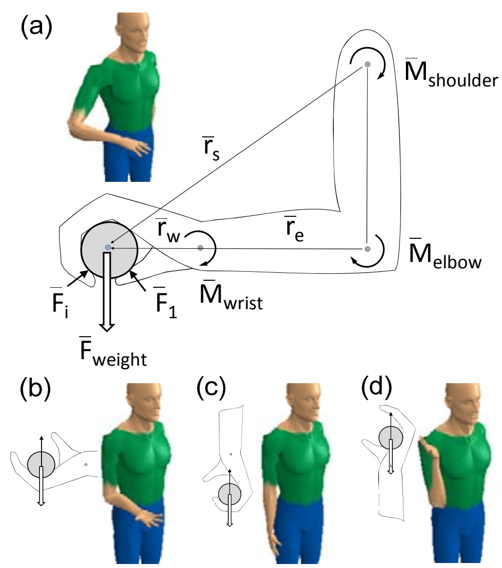

Figure 1: External forces and moments on upper limb joints in (a) overhand approach and finger grip; (b) underhand approach and palm grip; (c) holding cylinder at side of body using a hook grip (thigh height); and (d) holding cylinder with a vertical forearm using a palm grip at shoulder height.

The finger load for the overhand grip was estimated using a simplified biomechanical analysis (Figure 1a). The finger placements were computed using a kinematic model scaled for the subjects' hand size and a hand-object contact algorithm [3] for a 70 mm diameter cylinder used in the laboratory study. The contact forces were assumed to be vectors acting perpendicular on the distal phalanges. The weight of the cylinder was assumed to be distributed in proportion to relative finger strengths [4]. The force on the thumb required to achieve static equilibrium was computed. The loads on the fingers and thumb were compared with reported mean pulp pinch strengths [5]. The force exerted in hook grip (Figure 1c) was compared directly with mean strength data for a similar diameter cylindrical grip dynamometer [6]. The contact forces in Figure 1b and 1d were assumed to be vectors acting on the metacarpals; the forces on the fingers were assumed to be negligible compared with those acting on the palm.

RESULTS AND DISCUSSION

Subjects reached and grasped cylinders less than 1.6 kg using the overhand approach and finger grip (Figure 1a) more than 50% of the time. In this posture, a 1.6 kg load produced an average finger force of 17 N across the subjects, corresponding to 24% and 37% of mean male and female pulp pinch strength, respectively. The average load moments at the wrist, elbow, and shoulder were corresponding to 19%, 8%, and 13% of mean male joint strengths, and 25%, 15%, and 23% of mean female joint strengths, respectively. Subjects used an underhand palm grip for heavier objects (>1.6 kg) more than 50% of the time. As subjects gained control over the cylinder, they shifted to one of the grips shown in Figures 1b-d. The hook grip posture (Figure 1c) was observed more than 50% of the time for holding cylinders with mass less than 3 kg, which produced 29 N of finger load, corresponding to 24% and 40% of mean male and female cylindrical grip strength, respectively. Only traction forces are exerted on the wrist, elbow and shoulder in this posture, so the load moments are negligible. The underhand grip (Figure 1b) was observed from 30% to 40% of the time for holding cylinders more than 3 kg. The posture of palm grip at shoulder height (Figure 1d) was observed more than 50% of the time for cylinders more than 4.5 kg. In the underhand grip the load on the fingers is negligible. Average load moments at the wrist, elbow and shoulder joints corresponding to 35%, 21%, and 21% of mean male joint strength, and 44%, 41%, and 41% of mean female strength respectively, are computed for a 4.5 kg cylinder. In the palm grip at shoulder height the finger force is negligible, and the moments on the wrist, elbow and shoulder are all low (ranging from 2 to 11% of mean male and from 3 to 17% of mean female joint strength for a 4.5 kg cylinder). After holding the cylinders for about 8 seconds the overhand grip was used more than 50% of the time to return the cylinders with 1.7 kg or less to their starting location. The underhand grip was used more than 50% of the time for heavier cylinders (>1.7 kg).

Grasping objects with overhand and hook grips required the highest relative finger force and was observed only for the lightest objects (<24% mean finger strength of male or 40% of female). Holding objects at the shoulder height with a palm grip minimized relative finger, wrist, elbow, and shoulder loads and was observed for the heaviest objects (wrist, elbow, and shoulder load moments >21% male or 41% female strength).

These results are limited by a small number of subjects and conditions and the use of population strengths versus measured individual strengths. The results support further studies to develop models that use specified load thresholds for predicting work postures for ergonomic application.

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