INFLUENCE OF OBJECT SIZE AND HAND POSTURE ON UPPER LIMB JOINT LOADS DURING ONE-HANDED LIFTING EXERTION

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INTRODUCTION

This work aims to collect new information and develop models for design of objects that are held or manipulated with the hand. Examples include, handles that are used to lift and hold containers or support the body, tools, parts and materials. Towards this end, this study examines the effect of object size and posture on upper limb joint loads.

We previously showed that self-selected hand posture used to grasp, hold (approximately eight seconds), and place cylindrical objects is influenced by weight of the object [1]. Subjects reached over and grasped light objects (<1.6 kg) from above using their finger tips more than 50% of the time; for heavier cylinders, reached under and lifted the object with their palm and base of the fingers. As subjects gained control over the cylinder, they shifted to hook grip posture at thigh height or palm grip posture at shoulder height to hold the object. These results are qualitatively consistent with previous findings that grasp posture selection is related to comfort or effort [2-4].

We hypothesize that people will assume posture that reduces relative loads produced on upper limb joints. We compute the moments on the wrist, elbow and shoulder from the load and moment arms. There is not a direct way to compute corresponding moments for the hand because it involves a complex combination of normal and friction forces. Therefore we assume that if the relative loads of wrist, elbow and shoulder all are less than 1, the hand strength is the limiting factor.

METHODS

Twenty right-handed healthy university students (10 males and 10 females, age between 19 and 32 years, mean age 22.0 ± 2.8) were asked to grasp and pull cylindrical handle (D = 3.2 cm and 7 cm) in vertical up direction using three postures (Figure 1), a) an overhand grip in which the load is supported with the tips of the fingers, b) an underhand grip in which the load is supported with the palm and base of the fingers, and c) a hook grip at the side of the body in which the load is supported by hooking the fingers under the handle. They gave written informed consent in accordance with our University IRB regulations. Subjects were asked to "pull the handle in vertical up direction as hard as they can" without jerking it [5] while maintaining the specified posture. There were two repetitions for each size and posture. The order of the trials was randomized for each subject. A break of at least two minutes was given between successive trials. Functional strength tests were then conducted to quantify isolated joint strengths for each subject.

The relative loads were computed as the ratio of the moments produced about the shoulder, elbow and wrist from the lifting test with the corresponding strengths and were expressed as decimal fractions. The moments were calculated as the lifting force multiplied by the moment arms from the handle to joint. The moment arms were computed from marker data obtained using an eight-camera Qualisys motion tracking system (Qualisys Inc., Sweden).

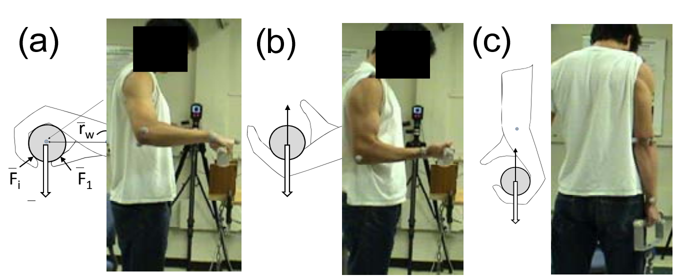

Figure 1: Grasp postures (a) overhand grasp; (b) underhand grasp; (c) hook grip.

Analysis of variance was performed to determine significant factors on the lifting strength data. Model included posture, object diameter, and gender as fixed variables, their second order interactions, and subject as a random variable. Post-hoc Tukey tests were performed on significant main effects and interactions to identify lifting strength differences among conditions.

RESULTS AND DISCUSSION

Maximum voluntary isometric lifting strengths for the three postures and two object sizes are summarized in Table 1. The lifting strength for males was, on average, 2.2 times of the one for females (object diameter and posture pooled, $p<0.01$). The lifting strength for hook grip was 2.2 times of the one for underhand grip (object diameter and gender pooled, $p<0.01$), and 4.3 times of the one for overhand grip (object diameter and gender pooled, $p<0.01$). The lifting strength for the object diameter 3.2 cm was, on average, 56% greater than that of the diameter 7 cm (posture and gender pooled, $p<0.01$). As object diameter increased from 3.2 cm to 7 cm, the lifting strength of overhand grip decreased 32% (gender pooled, $p<0.01$). The lifting strength of underhand grip decreased 9% but was not shown significant difference ($p>0.05$). The lifting strength of hook grip decreased 46% ($p<0.01$).

The relative wrist, elbow, and shoulder moments for the lifting test expressed as decimal fraction of isolated joint strengths are shown in Table 1. The results show that hand strength is the limiting factor for overhand grip because the relative loads for the wrist, elbow, and shoulder all are less than 1 (one-sample t test; $p<0.001$ for the joints and both sizes). Most of the object load is supported by the tips of the fingers and thumb using a complex combination of normal finger flexion forces and friction forces. For underhand grasp, wrist strength is the limiting factor (one-sample t test; $p>0.1$ for both sizes), indicating the finger strength does not limit lifting.

The results support several practical ergonomic applications as well as further research. If possible a 3.2 cm handle size is preferred over 7.0 cm for light weight objects for overhand grasp. Surfaces that enhance friction or geometries that enhance mechanical interference can be used to reduce the effort for overhand grasp. Clearance for underhand grasp should be provided for heavy objects. The results support further studies to develop models that describe grasping behavior and hand-object coupling.

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ACKNOWLEDGEMENTS

This work was supported by General Motors and by the partners of the Human Motion Simulation Laboratory at the University of Michigan.

Table 1: Lifting strengths for two cylindrical handle diameters (3.2 cm, 7 cm) and three grasp postures (overhand grasp, underhand grasp, and hookgrip at the side of body) by gender (mean ± SD). Wrist, elbow, and shoulder joint moments as decimal fraction of respective strengths during maximum voluntary isometric lifting exertions (gender pooled, mean ± SD).

Posture	Object Diameter (cm)	Lifting Strength (N)		Joint moment as fraction of joint strength in maximum lifting exertion (gender pooled)		
		Male	Female	Wrist	Elbow	Shoulder
Overhand grip	3.2	96.1 ± 17.8	48.8 ± 9.4	0.61 ± 0.19	0.58 ± 0.12	0.52 ± 0.09
	7	62.4 ± 12.1	35.7 ± 9.0	0.46 ± 0.16	0.40 ± 0.11	0.38 ± 0.11
Underhand grip	3.2	168.8 ± 49.4	74.9 ± 23.1	0.94 ± 0.20	0.91 ± 0.17	0.68 ± 0.17
	7	152.1 ± 62.1	69.4 ± 21.5	1.06 ± 0.25	0.85 ± 0.16	0.64 ± 0.17
Hook grip	3.2	466.5 ± 103.4	211.9 ± 59.3	-	-	-
	7	256.3 ± 64.8	111.4 ± 38.5	-	-	-