

## Distinctions in Weight Perception between Constrained and Unconstrained Lifting of Objects

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**Keywords:** Human, Weight Perception, Object Lifting, Constrained Lifting, Unconstrained Lifting, Psychophysics, Assistive Robotics, Safe Human-Robot Interaction

**Abstract.** We made two objects (hollow metal cylinders) with identical appearance. One was called the constrained object; another was called the unconstrained object. Human subjects lifted the constrained and unconstrained objects separately for various experiment conditions. We compared human's weight perception between the two types of objects. Results showed that weight perception between constrained and unconstrained lifting was almost the same. In our previous research, we developed a power assist system for lifting objects and determined a psychophysical relationship between actual and perceived weights for the objects lifted with the system [1]. The perceived weights were 40% of actual weights. However, the objects lifted with the system were constrained objects (as they were tied to the force sensor) that might affect the accuracy of the relationship. The results of this paper confirm that the constraint does not affect weight perception too much, which reconfirms that the psychophysical relationship between actual and perceived weights derived in our previous research was correct [1].

### Introduction

Power assist robots are mainly used for rehabilitation and health care purposes [2], [3]. We tried to bring novelty in the application of the power assist robots in [1]. In [1], we argued that power assist systems could be used to handle heavy objects in various industries. There are few models of power assist robots for objects manipulation [4], [5]. However, these models do not include human features such as human's weight perception in their controls and thus these models are not so human-friendly. We proposed a weight-perception-based model of power assist robot system for lifting heavy objects in various industries in [1].

In [1], we determined a psychophysical relationship between the actual weights and the perceived weights for lifting objects with a power assist robot system. Subjects lifted the power-assisted objects with the power assist robot and then compared the perceived weights to the reference weights and then determined the psychophysical relationship. However, the power-assisted object was a constrained object because it was tied to a force sensor. On the other hand, the actual object (reference weight object) was lifted manually and was not tied to any force sensor, and hence it was an unconstrained object. We assumed that the difference in constrained and unconstrained lifting conditions might affect the accuracy of the psychophysical relationship. This paper aims to investigate whether there is any difference in human's weight perception between constrained and unconstrained lifting of the same objects.

In this paper, we made two objects (hollow metal cylinders) with identical appearance. One was called the constrained object; another was called the unconstrained object. Human subjects lifted the constrained and unconstrained objects separately for various experiment conditions. We compared human's weight perception between the two types of objects. Results showed that weight perception between constrained and unconstrained lifting was almost the same, which reconfirms that the psychophysical relationship between actual and perceived weights derived in [1] was correct.

## Materials

We made two objects (hollow metal cylinders, hollow cylinder 1 and hollow cylinder 2) with identical appearance. The cylinders are shown in Fig.1(a) and details are presented in Table 1. A solid metal stick (height: 13cm, diameter: 2cm) was also made and vertically fixed on a table as

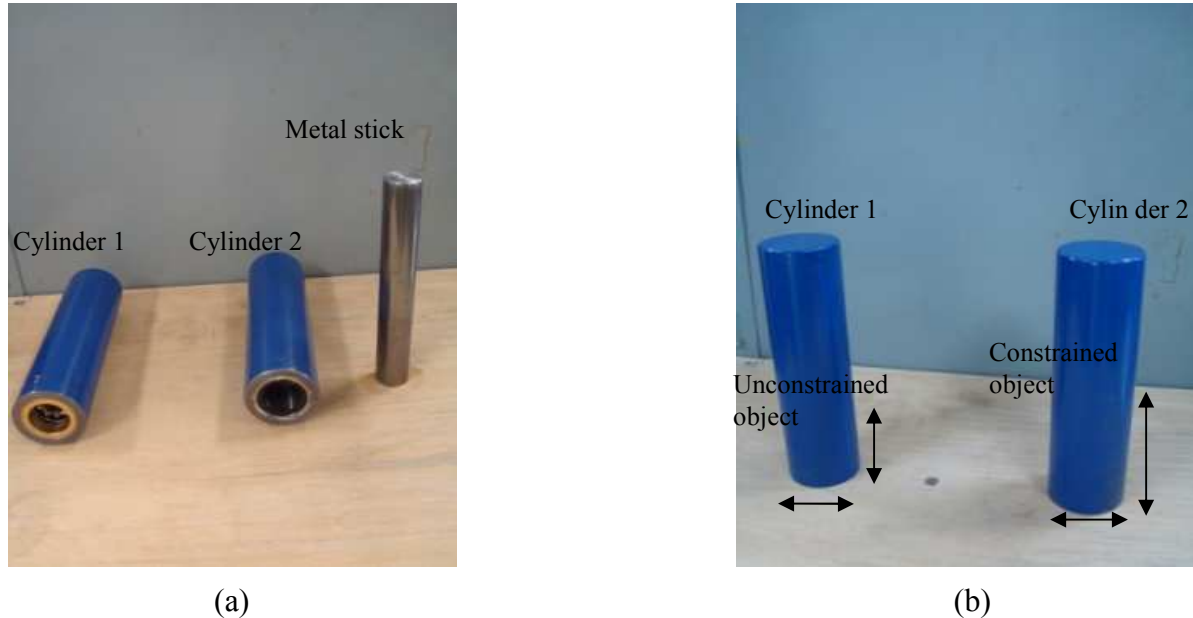


Fig.1 Configuration of constrained (cylinder 2 with metal stick inside) and unconstrained (cylinder 1) objects.

shown in Fig.1 (a). The hollow cylinder 2 was vertically placed on the table and the metal stick was inside the cylinder as shown in Fig.1(b). This arrangement restricted the movement of the cylinder 2 along the horizontal direction and thus made it a constrained object. The constrained object could be moved (lifted) only along the vertical direction. The hollow cylinder 1 was vertically placed on the table as shown in Fig.1(b) and there was nothing inside it. Hence, it was an unconstrained object and it could be moved along horizontal and vertical directions. The constrained and the unconstrained objects were put on the same table and were very close to each other.

Table 1 : Details of Cylinder 1 and Cylinder 2

Items	Cylinder 2	Cylinder 1
Weight	910g	910g
Height	15cm	15cm
Diameter (outer)	4cm	4cm
Diameter (inner)	2.2cm	2.2cm

## Methods

Eight mechanical engineering male students aged between 21 and 31 years performed as the subjects. The subjects were physically and mentally healthy. They did not have any prior experience of this experiment method. Experiment procedures were instructed to the subjects, but no formal training was arranged for them.

In each trial, the subject lifted the constrained object as shown in Fig.2 (a). The task required the subject to lift the object approximately 0.1 m, maintain the lift for 1-2 seconds and then release the object. The subject then lifted the unconstrained object following the same procedure as employed for the constrained object. See Fig.2 (b). The experiment was conducted by all subjects separately. In each trial, each subject grasped (and lifted) the object at three distinct positions separately as follows:

- (i) at the center of the object,
- (ii) at the upper end,
- (iii) at the lower end.

Again, for each position, the subject used:

- (i) power grip,
- (ii) 3-finger grip.

Thus the subject compared the perceived weight of the constrained object to that of the unconstrained object for each trial. The weight of the unconstrained object was considered as the reference weight and its weight was assumed as the 100%. The subject estimated the perceived weight of the constrained object comparing it to that of the reference weight. The subject was asked: If the reference weight (unconstrained object weight) is assumed as 100%, then what is the % for the perceived weight of the constrained object compared to the reference weight?

Subject's response regarding the perceived weight of the constrained object was recorded for each trial separately.

## Results

Responses of each subject regarding the perceived weight of the constrained object in comparison with that of the unconstrained object for different experiment protocols are shown in Table 2.

We see that the variation in the perceived weight of the constrained object with respect to the reference weight is not more than 10%. However, a subject needs more than a 10% difference in perceived weights to be able to discriminate between the weights of two objects [6]. The results show that human's weight perception for constrained lifting does not vary too much in comparison

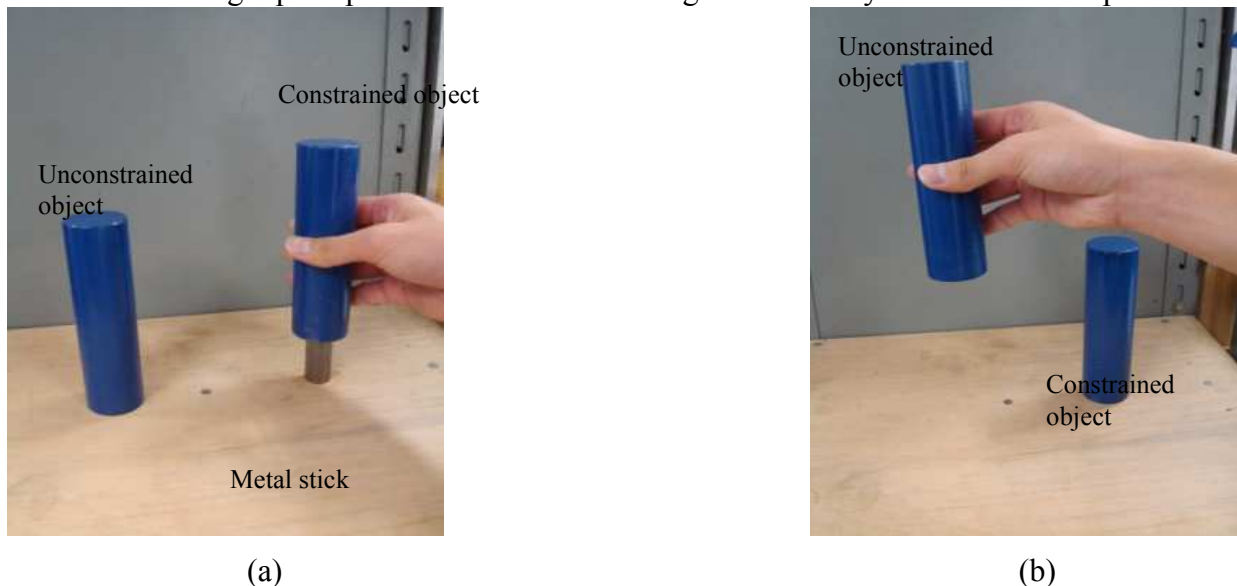


Fig.2 Lifting constrained and unconstrained objects by a human subject.

with that for the unconstrained lifting of the same object. The reasons may be that: (i) the total efforts for lifting the constrained object do not vary too much in comparison with that for the unconstrained object [7], (ii) object's visual cues were the same for both objects that resulted in similar weight perception, (iii) the inner metal stick did not touch the inner surface of the constrained object, hence the grip and the load force requirements did not vary between the constrained and the unconstrained lifting that resulted in similar weight perception, (iv) human's haptic cues, grasping method, posture, hand stiffness etc. did not vary between the constrained and the unconstrained lifting etc.[7].

Again, perceived weight for grasping at upper end or at lower end is more than that for grasping at the center of the object. The reason may be that gravity is sensed more intensely when grasped either at lower or at upper end than grasped at the centre. Similarly, the 3-finger grasp produced higher perceived weight than the power grip. The similar reason applies for this that the gravity is sensed more intensely when grasped with 3-fingers than when grasped with power grip.

Table 2: Estimated weight of the constrained object in comparison with the reference weight for different experiment protocols.

Subjects	Weight of unconstrained object (reference weight)	Estimated weight of constrained object					
		Grasped at centre		Grasped at upper end		Grasped at lower end	
		Power grip	3-finger grip	Power grip	3-finger grip	Power grip	3-finger grip
1	100%	95%	100%	105%	110%	105%	110%
2	100%	100%	105%	105%	110%	105%	110%
3	100%	95%	100%	105%	110%	105%	110%
4	100%	100%	100%	105%	105%	105%	105%
5	100%	100%	105%	110%	110%	110%	110%
6	100%	105%	110%	110%	110%	110%	110%
7	100%	95%	100%	105%	110%	105%	110%
8	100%	95%	105%	105%	105%	105%	105%

### Conclusions and Future Works

As presented in this paper, the human subjects lifted the constrained and the unconstrained objects separately for various experiment conditions and protocols. We compared human's weight perception between the two types of objects. Results showed that weight perception between the constrained and the unconstrained lifting did not vary too much, which reconfirms that the psychophysical relationship between actual and perceived weights for lifting objects with power-assist derived in our previous research in [1] was correct. In near future, we will develop appropriate control methods and strategies for power assist robots for manipulating heavy objects in industries based on the findings of this paper and of [1], [8]-[10].

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