

CONTRIBUTION OF VISUALLY PERCEIVED SIZE TO THE SCALING OF FINGERTIP FORCES WHEN LIFTING A 'SMALL' OBJECT^{1,2}

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Summary.—The effects of visually perceived size of an object on the scaling of fingertip forces during lifting tasks were investigated using a small and lightweight object. A grip apparatus was attached to the top surface of three different size boxes of equal weight. 15 healthy adults were asked to grasp the grip apparatus with the thumb and index finger, lift it to a height of 5 cm, hold it for 8 sec., and then put it down. Force transducers embedded in the grip apparatus measured grip and load forces. When subjects lifted the same size object repeatedly, there were no size effects on the grip and load forces used by each subject. When the size was pseudorandomly varied, however, the grip and load forces exerted by 7 subjects significantly increased with increased size, while there were no size effects for the remaining subjects ($n=8$). These results suggest a smaller contribution of information on size to the force programming when lifting a small object than when lifting a larger and heavier object as used in previous studies.

In daily life, various kind of tools, containers, and other objects can be easily grasped, lifted, and manipulated one after another without any particular attention being given to them. Especially with regard to object weight, the true weight cannot be recognized until the object is lifted from the surface on which it rests. However, optimal grip and load forces are, in fact, prepared before being applied to the object (Westling & Johansson, 1984; Johansson & Westling, 1988; Gordon, Forssberg, Johansson, & Westling, 1991a, 1991b; Gordon, Westling, Cole, & Johansson, 1993). The literature cited plainly demonstrates that visually perceived information regarding the properties of the object is used in force programming during a lifting task.

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In other words, visual cues about the object acquired prior to picking it up may be integrated with the internal representation of the object and tactile or proprioceptive information acquired in previous lifts (Westling & Johansson, 1984; Johansson & Westling, 1988).

There have been few reports, however, concerning the role of visual information in the force programming during a lifting or holding task, although its importance has been clearly established in the programming of reaching and grasping movements prior to hand-object contact (e.g., Jeannerod, 1984; Marteniuk, Leavitt, MacKenzie, & Athenes, 1990). Gordon, *et al.* (1993) obtained evidence that visual cues are used in the programming of grip and load force. They reported that, when subjects lifted a variety of commonly handled objects, e.g., a soft drink can, a candle holder, and a telephone book, the force output was in proportion to the object's appearance and weight of the object from the first lift. Gordon, *et al.* (1991b) reported that information about perceived size was used to plan the physical force a subject applied to lift the object such that the grip force increased with the object's size even when its weight remained constant. In contrast, the subjects relied preferentially on tactile information if they were blindfolded (Gordon, *et al.*, 1991a).

The contribution of visual information to force programming, however, has remained less clear than those of weight-related or surface-frictional information, since the visual effect seems relatively small compared with weight-related or tactile information (Westling & Johansson, 1984; Kawai, Kinoshita, & Ikuta, 1994; Kawai, Kinoshita, Ikuta, & Yamamoto, 1995). Furthermore, little attention has been given to the manipulation of a 'tiny' object, such as may be manipulated within the palm of the hand or by the fingertips (cf. Gordon, *et al.*, 1991a, 1991b).

The present study was designed to examine the contribution of size information acquired prior to picking up an object to the programming of precision grip forces during lifting of a small lightweight object. The investigation was conceptually similar to those of Gordon, *et al.* (1991a, 1991b); however, the effects of size on the control of fine force will be clearer since the weight-related information was minimized.

METHOD

Subjects

Fifteen healthy adults (8 women and 7 men), aged 19 to 41 years ($M = 26.1$ yr., $SD = 7.6$), served as subjects after providing informed consent. All subjects had normal or corrected-to-normal vision. None of the subjects had previous experience with the experimental task, and they were not familiar with the hypothesis being tested.

Apparatus

A cube-like transducer-equipped grip apparatus ($30 \times 30 \times 30$ mm, 25 g), as shown in Fig. 1, was used in the experiment. The grip forces of the thumb and index finger and the load force (vertical lifting force) were measured independently by force transducers (KFG-02-120-C1, Kyowa, Tokyo, Japan) located in the parallel gripping plates and the bottom surface of the grip apparatus, respectively. Only the grip force of the index finger was used for the present study. An infrared light emitting diode (LED) was placed on the top surface of the grip apparatus to measure its vertical displacement. Three different sized plastic boxes of equal mass (30 g) were used: a small $10 \times 10 \times 60$ -mm box, a medium $30 \times 30 \times 60$ -mm box, and a large $60 \times 60 \times 60$ -mm box. The volume ratio among the boxes was 1:9:36. The total mass of the grip apparatus (25 g) and a given box (30 g) was 55 g. The grip apparatus and boxes were covered with smooth black vinyl (Tye-tac,

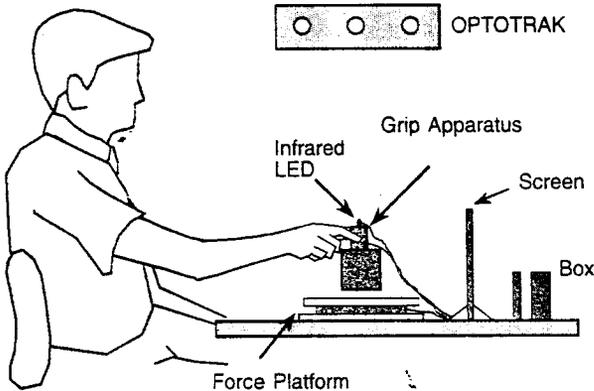


FIG. 1. Experimental arrangement

Vancouver, Canada). The three boxes were easily attached to or detached from the center of the bottom surface of the grip apparatus. A force platform as shown in Fig. 1 was used to measure the reaction force to detect the time of the lift of the object. A three-camera OPTOTRAK system (Northern Digital Inc., Waterloo, Canada) was used to record the vertical displacement of the object. The displacement and force signals from the grip apparatus and the force platform were recorded at a frequency of 200 Hz by the OPTOTRAK data acquisition unit.

Procedure

Subjects were seated in a height-adjustable chair facing an experimental

table. They were instructed to grasp the test object by placing the thumb and index finger pads of the right hand on the gripping surfaces to lift it at natural speed to a predetermined height (5 cm above the force platform) by flexing the elbow. After maintaining the lift for approximately 8 sec., the subjects were asked to replace the object upon the force platform and release it (Fig. 1). Following a demonstration by the experimenter, the subjects performed a few lifts of each box to practice the lifting height and speed. They then performed the tasks for 10 consecutive lifts for each of the three boxes. Following the constant condition, the boxes were pseudorandomly presented with the only restriction being that each block of three trials contained each box. Thirty trials, 10 trials for each box, were performed by all subjects. The time period between trials was 5 to 10 sec. Care was taken to minimize the effects of sweat on the pads of the thumb and index finger by keeping the laboratory cool and wiping the hand with a paper towel between trials. In the session of the repeated trials with the same size box, the presentation order of the three boxes was pseudorandomly performed between subjects.

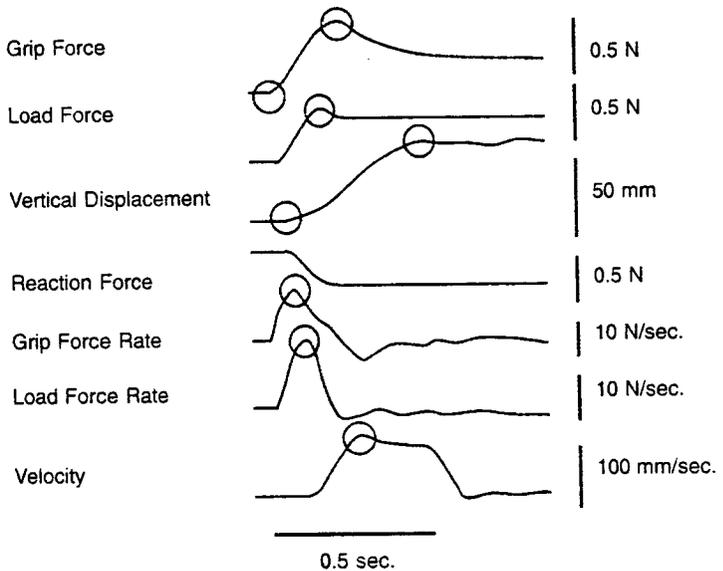


FIG. 2. Grip Force, Load Force, Vertical Displacement, Reaction Force, Grip Force Rate, Load Force Rate, and Velocity. Forces in Newtons (N)

Data Analysis

The force parameters analyzed were the peaks of the grip force generated by the index finger (Peak Grip Force), load force (Peak Load Force),

grip force rate (Peak Grip Force Rate), and load force rate (Peak Load Force Rate), as shown in Fig. 2.

Grip Force Rate and Load Force Rate were computed from the Grip Force and Load Force, respectively, using a 5-point numerical rating scale for differentiation. Similarly, the peak of the velocity of vertical movement of the object (Peak Velocity) was computed from the vertical displacement data (Vertical Displacement). Ten-trial records for each parameter for each size were averaged for each subject.

RESULTS

Fig. 3 illustrates the adaptive profiles of Peak Grip Force Rate (left) and Peak Load Force Rate (right) as a function of trial for the 10 repeated lifts in the constant condition. Group means and standard deviations shown in Fig. 3 were calculated for every two trials.

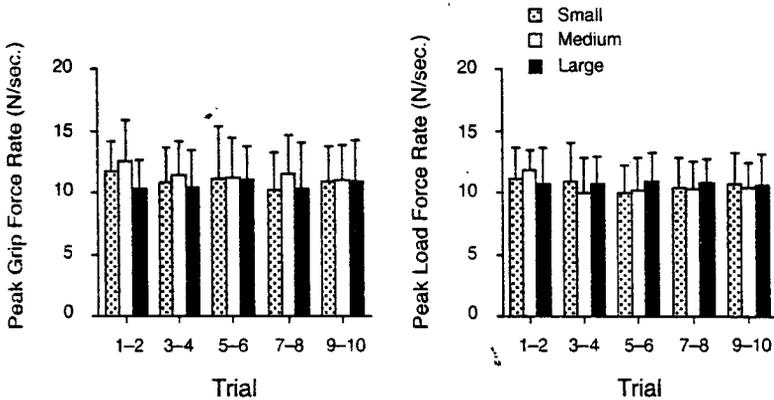


FIG. 3. Group means and standard deviations of Peak Grip Force Rate (left) and Peak Load Force Rate (right) as a function of trial in the repeated lifts with a box of a constant size

A 3×10 (size \times trial) analysis of variance indicated that the main effects for size and trial and the interaction of size \times trial were not significant. The other parameters were not significantly affected by size in the repeated sessions, indicating that the effect of size was not present in the repeated lifts with constant size, unlike the random lifts with different size as described below.

Fig. 4a and 4b show the influence of the size of the box on Average Grip Force and Force Rate as a function of time for two typical subjects in the pseudorandom session (Subjects 14 and 8 in Table 1, respectively). All 10 trials for the small box (dotted line), medium box (thick line), and the large box (thin line) were synchronized at the onset of grip force and aver-

aged. The subject in Fig. 4a was clearly affected by the box's size. That is, the patterns in grip force were characterized by increases in Peak Grip Force and Peak Grip Force Rate with the box's size. On the other hand, the subject in Fig. 4b was not significantly affected by the size, that is, the force profiles were almost constant across the boxes.

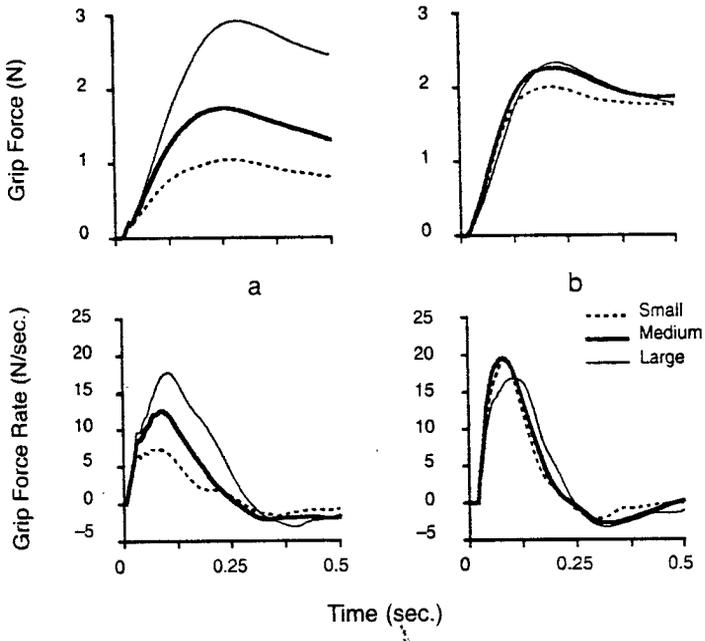


FIG. 4. Influence of box size on Average Grip Force and Grip Force Rate as a function of time. A subject from the group for whom the effect of size was statistically significant (a) and one from the group for whom size was not a significant effect (b).

Table 1 presents the results of individual analyses for each parameter. The main effect of size was observed in all or some parameters in seven of 15 subjects as shown by asterisks in Table 1 ($p < .05$). The significant differences by size on the *post hoc* analysis were also noted for each parameter for each subject in Table 1 ($p < .05$). On the other hand, there were no significant effects for size on any parameters for the eight remaining subjects (see Table 1). The group showing an effect of size included 4 men and 3 women, and the other group 3 men and 5 women. A 2×3 (sex and size) analysis of variance indicated neither the main effect for sex nor the interaction of sex \times size was significant for either parameter.

Group means and standard deviations of the dependent measures are

TABLE 1
 SIZE OF BOX ON EACH DEPENDENT MEASURE FROM INDIVIDUAL ANALYSES OF VARIANCE

Subject	Sex	Group	Parameter					
			Peak Grip Force	Peak Load Force	Peak Grip Force Rate	Peak Load Force Rate	Peak Velocity	
1	m							
2	f	*	S<L	S<L	S<L	S<L		
3	m							
4	f							
5	f							
6	f	*	S<L, M<L	S<L, M<L	S<L	S<L	S<L	
7	f							
8	m							
9	f							
10	m	*	S<M<L	S<M<L				S<L
11	f							
12	m	*			S<L, M<L	S<L, M<L	S<L, M<L	S<L, M<L
13	m	*	S<M<L	S<L, M<L	S<M, S<L	S<M, S<L	S<M, S<L	S<M, S<L
14	f	*	S<M<L	S<L	S<L	S<L	S<M, S<L	S<M, S<L
15	m	*	S<M<L	S<L				

Note.—S=small box, M=medium box, L=large box; S<L indicates that the mean value for the large box is significantly larger than that for the small box ($p<.05$), for example. *Group for which the size effect was significant.

shown in Table 2. The group means for age were 27.9 yr. ($SD=8.6$) for the group showing an effect for size and 24.6 yr. ($SD=7.0$) for the other group. There was no significant mean age difference between two groups.

TABLE 2
 MEANS AND STANDARD DEVIATIONS OF DEPENDENT MEASURES AS A FUNCTION OF SIZE OF BOX FOR GROUPS FOR WHOM THE EFFECT OF SIZE WAS SIGNIFICANT OR NOT

Group		Measure				
		Peak Grip Force, N	Peak Load Force, N	Peak Grip Force Rate, N/sec.	Peak Load Force Rate, N/sec.	Peak Velocity, mm/sec.
Affected* ($n=7$)						
Small	M	1.15	0.68	12.23	10.90	85.89
	SD	0.35	0.04	5.21	3.19	28.80
Medium	M	1.57	0.71	16.97	12.38	97.30
	SD	0.57	0.03	5.83	3.03	28.45
Large	M	2.24	0.74	21.70	14.10	106.15
	SD	1.03	0.02	7.52	3.94	29.16
Other ($n=8$)						
Small	M	1.39	0.68	15.87	14.67	83.24
	SD	0.49	0.03	6.84	4.79	19.66
Medium	M	1.47	0.69	16.68	15.07	82.87
	SD	0.62	0.03	8.12	5.83	24.25
Large	M	1.50	0.69	15.80	15.36	86.63
	SD	0.54	0.03	7.49	6.29	16.20

*Group for whom size effect was significant.

DISCUSSION

When the size of the box was randomly varied, two types of strategies were observed in force programming. First, the grip force was applied in proportion to a prediction of weight based on the box's size. Second, a constant grip force was applied regardless of the box's size. The present results, therefore, indicate that the contribution of visual information about the size was smaller than may have been expected from the previous study of lifting of considerably larger and heavier objects (Gordon, *et al.*, 1991a, 1991b).

The reduced contribution of size information in the present results may have been because the force programming in the manipulation of a tiny object involves more information concerning constraints of 'precision' rather than for 'force output'. Generally speaking, with handled objects being smaller, finer control of force may be required for the manipulation, since the physical properties such as fragility, slipperiness, and softness take priority over weight (Hoff & Arbib, 1993). These properties are acquired from tactile information on contact with the object. Consequently, subjects whose grip responses were not affected by the information about size in the present study may have utilized their internal memory of the boxes acquired from tactile or proprioceptive information in previous lifts (Westling & Johansson, 1984; Johansson & Westling, 1988; Kawai, *et al.*, 1994, 1995).

The reduction of visual information is known to alter strategies of reaching and grasping. That is, as the size of target object is reduced, the approaching and contacting phases of reaching for the object are markedly affected, and the subjects preferentially rely on feedback control to gain more precise information (Marteniuk, *et al.*, 1990). When the visual information is not available, i.e., when lifting an object blindfolded, some of the subjects relied preferentially on the tactile feedback information (Gordon, *et al.*, 1991b). Our present results may support the alteration of lifting strategy on the basis of the effect of visual information.

In summary, visual information may not always have definitive priority in force programming in a lifting task compared to other sensory modalities, especially when manipulating a small and lightweight object. Rather, the subjects tend to rely on the other modalities, such as tactile or proprioceptive information. This is because knowing whether the object is fragile seems to be more important during the manipulation of a smaller object than knowing how much force is required to achieve the lift. Conclusively, the information on size may contribute mainly to the prediction of force output.

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