Effects of Object Characteristics on Female Grasp Patterns

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Key Words: environment • hand functions

Objective. This study determined which object characteristics had an effect on grasp when adult women took a drink from a cup.

Method. Thirty women aged 20 to 45 years (M = 27.6 years) were randomly assigned to a sequence for each of three experiments. The first experiment tested the grasp pattern used for cups of same height and weight but with different-sized handles. The second experiment tested the grasp pattern for cups of varied height but with same-sized handles and same weight. The third experiment tested the grasp pattern for cups of varied weight but with same-sized handles and same height. The grasp patterns were recorded by a videocamera placed across from the subjects.

Results. The number of fingers placed through the handle was found to be significantly greater for the cup with a larger handle than for the cups with the smaller handles when cup size and weight were held constant, $\chi^2(2) = 49.8$, $p < .001$. No significant difference was found in the number of supporting fingers for varying cup heights or weights.

Conclusion. The results support other research that has stated that handle size accounted for the change in grasp pattern. Because motor performance is affected by the object characteristics as well as personal abilities, adaptation of characteristics, such as handle size, for persons with limited hand use may provide an environment that evokes more optimal performance.

Grasping is a function critical to performance in daily living. Many patterns of grasp are needed to successfully interact with the environment. Certain aspects of the environment, such as object characteristics, may influence the choice of grasp pattern. The purpose of this study was to determine whether the object characteristics of handle size, object size, and object weight affect the grasp phase of prehension during the functional activity of drinking from a cup.

Object size has been found to have a significant effect on the transport component of prehension (Bootsma, Marteniuk, MacKenzie, & Zaal, 1994; von Hofsten & Ronnqvist, 1988). However, studies that determined the effect of object size on the grasp component were confounded by differences in object weight (Castiello, Bennett, & Mucignat, 1993; Castiello, Bennett, & Stemach, 1993). Studies that have taken object weight into consideration have compared weight with the perception of size (on weight) but did not study the natural pattern of grasp (Gordon, Forsberg, Johansson, Eliasson, & Westling, 1992; Harshfield & DeHardt, 1970). Studies
that have examined grasp pattern have used abstract shapes, such as cubes, rather than functional tools (e.g., Halverson, 1931).

In treatment, occupational therapists use tools and utensils that require goal-oriented grasp of handles. Kamakura, Matsuo, Ishii, Mitsuboshi, and Miura (1980) identified non-goal-oriented grasp patterns associated with 98 everyday objects used in Japanese culture. Although their study established a useful categorization of grasp patterns, the information does not apply to grasping objects for functional use. Arbib, Iberall, and Lyons (1985) stated that an object is “only perceived in terms of the task in which it is being used” (p. 111) and theorized that handle size affects grasp for a functional activity. Although this theory was successfully applied to a robotic hand, there have been no studies linking it to human subjects. Therefore, further research into persons without disabilities is needed in order to develop expectations of grasp pattern performance for objects used in everyday life. Occupational therapists who help retrain persons with hand abnormalities to perform activities of daily living efficiently will benefit from a knowledge of goal-oriented grasp patterns.

**Literature Review**

**Definition of Grasp**

Newell, Scully, Tenenbaum, and Hardiman (1989) defined prehension as the “act of grasping” (p. 1). Paulignan, MacKenzie, Marreuniuk, and Jeannerod (1990) stated that the “act of prehension requires the coordinated control of arm and fingers” (p. 431). Casanova and Grunert (1989) defined static prehension as “any form of prehension in which the object is not moved within the hand” and dynamic prehension as “prehension in which an object is manipulated within the hand” (p. 232). Bennett and Castiello (1994) described two components of prehension: (a) transport (reach) during which the hand moves toward the object and (b) manipulation (grasp) during which the hand opens and encompasses the object. Napier (1956) further categorized the manipulation phase into a power grip and a precision grip. The power grip uses all fingers, and there is more contact of the proximal portions of the fingers and hand with the object, sacrificing precision for force. The precision grip is intended for delicate grasp and manipulation with the pads of the fingers. A whole hand precision grip denotes all the fingers opposing the thumb, with or without force (Bennett & Castiello, 1995). Arbib et al. (1985) described the three components of grip as upward force (support), downward force, and stabilization. Our study looked only at the manipulation component of static prehension and classified grip on the basis of Arbib et al.’s theory.

**Effect of Goal on Prehension**

The reason a person reaches to an object affects the patterns of prehension. Van Vliet, Kerwin, Sheridan, and Fentem (1995) found that subjects who have had a stroke demonstrated a higher average velocity (although not significant) and a shorter movement time when asked to reach to a cup of water to drink rather than to reach to pick up the cup of water and place it in front of a line. This variation in the transport phase of prehension demonstrates the effect of alteration in the task goal. Speitel and Jacobson-Sollerman (1977) observed 30 subjects with healthy hands while serving, eating, and drinking. They found that the subjects’ grip of an object was affected by the goal. Therefore, in our study, the goal was held constant.

**Effect of Organism on Object Size**

Hand size is a biomechanical component of the human organism that may affect grasp preference when manipulating an object. Newell, Scully, Tenenbaum, et al. (1989) have identified an object-size-to-hand-size ratio, suggesting that the size of the person’s hand affects the type of grasp used on a specific object size, regardless of developmental age. The authors studied 26 preschoolers and 22 adults to determine their natural grasp patterns when reaching to objects of various sizes. The researchers also measured hand size to determine whether there was a correlation with object size and whether this correlation affected the type of grasp used. Ten cardboard cubes (ranging in size from 0.8 cm to 24.2 cm) with one open side were randomly presented to the subjects who were asked to place the cubes into slightly larger cubes. The experiment was videotaped with two cameras placed perpendicular to each other and scored by two judges blind to the experiment; interrater reliability was at least 98% on all items. The grasps were scored according to the number of hands used, the number of fingers touching the object, the amount of contact with the fingers and hand (i.e., tip, proximal finger, palm), and the orientation of the hand on the object. The results indicated that hand size correlated with object size, independent of age. In the present study, this variable was controlled by using subjects with homogeneous hand size.

**Effect of Environment on Prehension**

The environment also affects the motor planning required to achieve a movement. Hirschel, Pehoski, and Corvall (1990) observed infants (aged 7 to 14 months) eating O-shaped cereal from styrene surfaces that offered varying degrees of support for the infants’ hands. They reported that the infants used a less refined grip pattern, such as a raking grasp instead of a precision grip, when...
reaching for a piece of cereal on a less stable surface. Their study suggests that environmental demands affect the type of grasp used; thus, environmental demands were held constant in the present study.

**Effect of Task Demands on Prehension**

Task demands influence the components of prehension. Past studies have determined developmental grasp patterns by observing children manipulating a single object. By watching infants at various stages of development pick up a wooden block, Halverson (1931) determined that forceful grasps developed before precision grasps. Newell, Scally, McDonald, and Baillargeon (1989) believed that Halverson chosen an object other than a wooden block to categorize grasps, a different order of grips would have been identified. To test this hypothesis, they presented 107 infants (aged 4–8 months) with a 2.54-cm wooden cube and three lightweight toy cups of varying diameters (i.e., 1.25 cm, 2.50 cm, 8.50 cm) positioned alternately with the open side up and open side down. The infants chose to grip the open cup with the thumb and index finger, indicating that grasp patterns are based on task demands rather than developmental stages. The present study examined the effects of three task demands (object characteristics)—object size, handle size, and object weight—on prehension.

**Object size.** The transport phase of prehension has been found to vary with object size. Boomsma et al. (1994) found that larger object widths evoked larger peak hand apertures and shorter movement time. Von Hofsten and Ronqvist (1988) found that adults begin to close their hands earlier in the transport phase when reaching for a smaller object. These findings demonstrated that larger objects are picked up faster with less motor planning and that the hand opens less and takes longer to come to a stop for smaller objects, indicating that smaller objects require a more precise approach than larger objects.

Many experiments have ignored the natural grasp pattern when studying the effects of object size on prehension. Chieffi and Gentilucci (1993) required eight right-handed men to use a prehension grip for picking up 7-cm wooden dowels of varying diameters (1–6 cm). Castiello, Bennett, and Mucignat (1993) showed that whole hand prehension grip is the natural choice for large objects; therefore, the results from the Chieffi and Gentilucci study may reflect artificial demands rather than the natural prehensile pattern. Gentilucci et al. (1991) examined the movement patterns of eight right-handed men who were required to grasp, but not move, a large cylinder (5 cm × 6 cm) using a whole hand prehension grip and a small sphere (.5 cm) using a prehension grip. Whole hand prehension grip was defined as all fingers around an object, forming a ring, and prehension grip was defined as opposition of the index finger and thumb. Because Gentilucci et al. studied only men, and the large cylinder was only 5 cm in height, it is doubtful that all the subjects would have naturally chosen to use a whole hand prehension grip for this object.

Other studies have looked at the effects of object size on the type of grasp used, without controlling for weight. Castiello, Bennett, and Stelmach (1993) studied the natural prehension patterns of 12 right-handed students when reaching to and lifting cylinders of varying size. Their results indicated that the subjects used a prehension grip for the small (10 cm × .7 cm), lightweight (9 g) cylinder and whole hand prehension grip for the large (8 cm × 8 cm), heavy (202 g) cylinder. Because the weight was not held constant, the researchers could not conclude that the results were determined by object size alone. Castiello, Bennett, and Mucignat (1993) asked 12 subjects who were either blind, blindfolded, or had full vision to reach naturally to a small (3 cm × .7 cm) cylinder located on a 2-cm platform or to a large (5 cm × 6 cm) cylinder located 20 cm or 30 cm from the starting position. The researchers found that prehension grip was used for the small cylinder and that whole hand prehension grip was used for the large cylinder, regardless of distance from subject or visual constraint. Again, the weight was not controlled. Although these studies suggest that object size is an important environmental constraint that affects the type of grasp used, further research needs to rule out weight as a task demand.

**Handle size.** The portion of the object that is manipulated is another task constraint that may affect the grasp pattern. For instance, handle size may affect the type of grasp used when drinking from a cup. Arbib et al. (1985) discussed the effect that different-sized cup handles have on finger mapping patterns. They hypothesized that the handle size accounted for the change in grasp, and they described three functions for the five fingers of the hand: “to provide a downward force from above the handle, to provide an upward force from within the handle, and, if necessary, a third force to stabilize the handle from below” (p. 114). Arbib et al. stated that only one finger fits within a small handle, causing the work of supporting the cup to fall on the fingers outside the handle. However, a large handle allows all the fingers to fit inside, leaving no fingers to stabilize the mug. Although a robotic hand was successfully created on the basis of these principles, the research has not been applied to human subjects. In addition, cup weight and size have not been ruled out as confounding variables.

**Object weight.** No studies have researched the effect of object weight on the natural pattern of grasp, but some have found object size to influence the perception
of weight. Gordon et al. (1992) studied the effect that varying object size while maintaining a constant weight had on subjects' perceptions of object weight. Thirty children and 10 adults were asked to lift a small (8 cm³) or large (16 cm³) box 5 cm to 10 cm off the table and hold it for 2 sec to 5 sec with a prehension grip (the youngest children were allowed to use additional fingers). In all age groups, the smaller box was perceived as weighing more because it needed larger forces. If the natural grasp pattern was allowed, the results regarding the subjects' perception of weight may have differed.

Harshfield and DeHardt (1970) asked subjects to rate five 1.5-in. cubes from lightest to heaviest. Each cube was equal in size and weight but made of various materials, including balsa wood, mahogany, aluminum, brass, and steel. The cubes were ranked in the opposite order listed, suggesting that the cubes that were perceived to be heavy felt light compared with the subject's preconceived idea of the object's weight. Both studies suggest that an object's characteristics provide the central nervous system with a preconceived perception of weight. However, no studies compared the effect of object weight on patterns of grasp.

Summary

The task demands, goal, human organism, and environment all influence the components of prehension. By holding the latter three variables constant, task demands may be researched effectively. Three task demands appear critical to the pattern of grasp for the process of drinking from a cup: cups size, handle size, and weight. In our study, each task demand was studied independently. The hypotheses for this study were:

1. The number of fingers placed through the handle will be significantly greater for a cup with a larger handle than for cups with smaller handles, with size and weight of cups held constant.
2. The number of supporting fingers will be significantly greater for a cup of a larger size than for cups of smaller sizes, with handle size and weight of cups held constant.
3. There will be a significant difference in the number of supporting fingers in similar appearing cups of varying weights when the subject lifts the cup.

Method

Subjects

Only women whose hand aperture fell within 13.9 cm to 17.3 cm were accepted for this study. These values were obtained as follows. One hundred nine college women (11 left handed, 98 right handed) self-measured their dominant hand, after a demonstration by the researcher, using the same plastic ruler. The measurements were rounded to the nearest tenth of a centimeter. Average hand aperture was found by measuring the distance on the dominant hand from the tip of the thumb to the tip of the index finger when the index finger was fully extended and the thumb radially abducted, neither flexed nor extended. The average hand aperture for these women was 15.6 cm (±1.7 cm). This measurement was used to determine the height needed for the largest handle.

Thirty-five college women volunteered to participate in the experiment, 30 of whom were selected for this study because they were within one standard deviation of the average hand width and reported no pain and no present or past orthopedic or neurological deficits affecting the dominant hand. The subjects' ages ranged from 20 to 45 years (M = 27.6 years), and they provided information regarding date of birth and dominant hand.

Instrument

To measure the number of fingers (type of grasp used), a Panasonic AG-195 video camera was placed across from the subject in a horizontal plane. The lens was focused on the cup. To determine reliability of measurement, the videotapes were scored by two judges: the researcher and a person who was blind to the experiment. The agreement was 98.8% for handle size, 97.7% for cup size, and 96.6% for cup weight. The scores from the judge who was blind to the experiment were used as the data. The scores represented the number of digits placed in the handle and the number of digits supporting the cup (i.e., fingers under the handle or fingers placed around the cup). The grasp was scored at the point when the cup was lifted from the table.

Procedure

The study consisted of three experiments. Experiment 1 involved three cups that were 12 cm in height and weighed 309.0 g. The internal spaces of the handles were 2 cm, 4 cm, and 8 cm. Experiment 2 involved three cups that had a 2-cm internal handle space and weighed 705.9 g. The cup heights were 4 cm, 8 cm, and 12 cm. Experi-
ment 3 involved two cups that had a 2-cm internal handle space and were 12 cm in height. The cups weighed 309.0 g and 705.9 g. The cups were weighed when filled with cold water. All cups were made of clay with a blue, lead-free glaze (see Figures 1–3). The thickness of the rims and handles remained constant within each group of cups.

The experiment was performed on each subject individually in a quiet room. The subject sat at a 74-cm high table. The height from the floor to the seat of the chair was 45 cm. Neither the chair nor the table were adjustable, but they were appropriate for an average adult woman.

Before reaching, the subject's hand was placed in a starting position on the table so that the elbow was in 75° of flexion (as verified by goniometer) with the forearm in a neutral position, neither pronated nor supinated. The experimenter placed the cups on the table directly in front of the subject and at a distance where the subject's arm reached 10° short of extension. The cups were consistently placed at the same location for each trial. Without using the handle, the experimenter placed the cups upright on the table with the handle oriented toward the subject's dominant hand. The 4-cm cup was placed at the edge of an 8-cm support and the 8-cm cup was placed at the edge of a 4-cm support to promote a natural angle at the wrist. Each series of cups was presented in random order.

A practice session preceded each experiment to eliminate possible preprogrammed perceptions of object size-weight proportions. Practice sessions were not videotaped. During the experiment, the subjects completed three trials for each cup. For each trial, the subjects were asked to reach in a natural way to pick up the cup and take a drink of water. The subject completed all movements in one session and had approximately a 10-sec rest between movements.

Data Analysis

Using SIGMASTAT (Jandel Scientific, 1992), the non-parametric Friedman's test was applied to the data to determine whether significantly more fingers were placed through the handle of the cup with the 8-cm handle compared with the cups with 4-cm and 2-cm handles and whether there were significantly more fingers placed around the 12-cm cup than around the 8-cm and 4-cm cups. Wilcoxon signed rank tests were used to determine whether there were significant differences in the number of supporting fingers used for the 309.0-g cup and the 705.9-g cup.

Results

For each experimental condition, the score was the average of the three trials. There were no significant differences in scores due to order or sequence.

The number of fingers placed through the handle was found to be significantly greater for the cup with the 8-cm handle than for the cups with the 4-cm and 2-cm handles (cup size and weight held constant), \( \chi^2(2) = 49.8, p < .001 \). Each condition was significantly different from each other as determined by the Newman–Keuls test. Most subjects used four fingers to grasp the 8-cm handles.

![Figure 1. Experiment 1: 2-cm, 4-cm, and 8-cm cup handles.](http://ajot.aota.org)
handle, two or three fingers to grasp the 4-cm handle, and one finger to grasp the 2-cm handle. The number of supporting fingers was not found to be significantly greater for the 12-cm cup than for the 8-cm and 4-cm cups (handle size and weight held constant), $\chi^2(2) = .20$, $p = .905$. Twenty-five subjects used three fingers to support the cup with the 2-cm handle, regardless of cup height or weight. There was no significant difference in

the number of supporting fingers used to lift the 309.0-g and 705.9-g cups. Twenty-eight subjects used the same grasp pattern for both weight conditions.

Discussion

Our results support the research of Arbib et al. (1985), who hypothesized that handle size accounted for the change in grasp pattern. They stated that the "embedded perceptual schemas for grasping will provide three visual cues: a target near the inside of the handle, the size of the handle, and the orientation of the handle" (p. 116). As the handle size increased, the number of fingers used for the second virtual finger (inside the handle) increased.

Arbib et al. (1985) stated that after a hand has made contact with an object, "tactile feedback then shapes the hand to the object" (p. 112). Because the handle is the area of tactile contact for the cup, it provides the feedback that determines grasp pattern. Although the grasp pattern did not differ for the object characteristics of height and weight, these characteristics may affect other components of the grasping phase. Further research is needed to determine whether the amount of force, or muscle action, applied to the cup and handle when lifting the cup to

Figure 2. Experiment 2: 4-cm, 8-cm, and 12-cm cup heights.

Figure 3. Experiment 3: 309.0-g and 705.9-g cup weights.
drink changes when object height is altered.

Now that data from a control group has been acquired, further research can compare the results of this study to a group of women of similar age and sized hands who experience upper-extremity weakness, joint stiffness, tremors, spasticity, or edema in order to determine how grasping patterns differ secondary to these biomechanical constraints. The Systems Model of Motor Control suggests that a motor performance, such as drinking from a cup, is the product of the physical, biomechanical demands required to lift an object. The demands of the task include the inherent qualities of the object as well as the person’s attributes and abilities, such as hand size and muscle strength (Mathiowetz & Bass-Haugen, 1995). Therefore, adaptation of object characteristics, such as handle size, for persons with limited hand use may provide an environment that evokes more optimal performance. In addition, the cup height and weight may be altered to meet the needs of a person without affecting the pattern of grasp.

Acknowledgments

We thank Jay Flint for designing the cups used in this study and Sheila Flint for volunteering her time. This article is based on a thesis completed by the first author.

References


