The Size-Weight Illusion in Team Lifting

Yoko K. Naylor and Eric L. Amazeen, Arizona State University, Tempe, Arizona

The purpose of these studies was to examine whether or not there is a size-weight illusion when participants lift containers as a team. In Experiment 1, teams of participants lifted a set of 16 containers that varied in mass and size and reported their perceptions of heaviness and volume. In Experiment 2, participants lifted the same containers individually. A size-weight illusion was demonstrated in each experiment: Reports of perceived heaviness decreased substantially as the volumes of the containers increased for both styles of lifting. However, both the magnitude of the illusion and mean perceived heaviness were greater in the team lift. Actual or potential applications of this research include the development of safe lifting guidelines for team lifting.

INTRODUCTION

Lifters perceive larger objects to be lighter than smaller objects of the same mass. This phenomenon is commonly known as the *size-weight illusion* and has been studied extensively since the work of Charpentier (1891). Although most investigations of the size-weight illusion are psychophysical studies limited to the effect of volume on verbal reports of heaviness (see review in Jones, 1986), researchers have also investigated its role in manual lifting (e.g., Ciriello & Snook, 1983). These latter findings are important because any decrease in perceived heaviness accompanying larger boxes could lead the lifter to exceed the limits of safety (particularly in an industrial lifting situation). The size-weight illusion has not, however, been documented when containers are lifted using a common strategy with heavy containers, the team lift. The present studies explore the psychophysics of this illusion by comparing the effects of volume on perceived heaviness when participants lift containers as a team with those same effects when participants lift containers individually.

Perceived Heaviness and the Size-Weight Illusion

Any time that an object or container is lifted, the lifter has an impression of its heaviness. This perception is the basis for verbal reports of heaviness in a psychophysical experiment and the basis for decisions about whether and how to lift the object in the real world (see Karwowski et al., 1999). Numerous psychophysical experiments have shown that the perception of heaviness is a function of mass and size – that is, the perception is subject to the size-weight illusion (Jones, 1986). The magnitude of this effect can be substantial. An increase in volume alone can produce up to a 50% decrease in perceived heaviness (Stevens & Rubin, 1970), despite the fact that larger objects are generally heavier and more unwieldy. Furthermore, neither training nor cognitive effort is sufficient to eliminate the illusion (Flournoy, 1894).

Research has shown that the size-weight illusion exists in almost all individuals who are capable of lifting. Most experimental demonstrations have involved healthy adult participants. However, a size-weight illusion has also been shown in children between the ages of 2 and 16 years (Kloos & Amazeen, 2002; Pick & Pick, 1967; Robinson, 1964). These children, particularly the very young children, have substantially less experience with the influence of volume on manipulability than do adults, yet the illusion is still present. On the other end of the spectrum, this illusion has also been demonstrated with male and female industrial workers, who should have substantially greater experience with the

Address correspondence to Eric L. Amazeen, Department of Psychology, Box 871104, Arizona State University, Tempe, AZ 85287; eric.amazeen@asu.edu. HUMAN FACTORS, Vol. 46, No. 2, Summer 2004, pp. 349–356.

effects of mass and volume on perceived heaviness (Ciriello & Snook, 1983).

The present studies investigate the psychophysics of the size-weight illusion in a novel style of lifting: team lifting. This illusion has already been documented in many types of lifting conditions. In most demonstrations of the size-weight illusion, participants are able to grasp and view the object as it is being lifted. Under these circumstances, the participant has both visual and tactual information about the object's volume. However, the illusion has also been demonstrated when participants grasp the stimulus without vision (e.g., Amazeen & Jarrett, 2003; Ellis & Lederman, 1993). Similarly, the illusion has been demonstrated when participants are allowed to view the volume of the stimulus but not to grasp it. This is accomplished by having participants lift the stimulus using a handle (Amazeen, 1997, 1999) or a string (with pulleys, Masin & Crestoni, 1988; without pulleys, Ellis & Lederman, 1993). All that is necessary to generate an effect of volume on perceived heaviness is to present information (visual or tactual) about volume concurrent with the lift. In fact, the illusion has been demonstrated when the actual volume of the stimulus did not change but visual or tactual information suggested that it did (Amazeen & Turvey, 1996; Dresslar, 1894; Koseleff, 1957).

The Size-Weight Illusion in Industrial Lifting Tasks

The fact that the size-weight illusion is present in so many circumstances suggests that it may play a role when individuals lift heavy containers in an industrial lifting situation. In fact, research has shown that the size-weight illusion exists across the entire range of manageable containers. It has been demonstrated for stimuli that are as light and small as 20.0 g and 37.0 cc (Oberle & Amazeen, 2003) and as heavy and large as 24 kg and 40 000 cc (Luczak & Ge, 1989). On the basis of their results, Luczak and Ge concluded that volume is an important component in industrial lifting tasks. Luczak and Ge had participants report their perceptions of heaviness using a magnitude estimation procedure with a known standard (the same method used in the present studies). Nevertheless, their conclusion is consistent with previous studies (Ayoub, Mital, Bakken, Asfour, & Bathea, 1980; Ciriello & Snook, 1983; Garg & Badger, 1986; Garg & Saxena, 1980; Mital & Fard, 1986; Snook, 1978) and subsequent (Ciriello & Snook, 1999; Ciriello, Snook, & Hughes, 1993; Snook & Ciriello, 1991; Wu, 1997; Wu & Chen, 2001) investigating the role of container size on the maximum acceptable weight of lift. In all of these studies, changes in the volume or shape of the container produced changes in the maximum acceptable weight of lift, although the direction of the effect was not the same across studies (see Amazeen, 1997, and Luczak & Ge for discussions).

Lifters experiencing a size-weight illusion could be subject to increased risk for injury. This is because any illusory decrease in perceived heaviness may cause the lifter to believe erroneously that greater masses are manageable. This effect becomes more significant when one takes into consideration the lifter's biomechanical disadvantage when lifting large containers. As a result, both the National Institute for Occupational Safety and Health and the Liberty Mutual standards for safe lifting include the size of the container (see Potvin & Bent, 1997). In each case, the maximum acceptable weight for lift is revised downward for containers of increased size. These guidelines, though, are designed specifically for individual lifters. Precise safety guidelines do not exist for team lifting, despite the fact that it is a common strategy for lifting large or heavy loads (see Dennis & Barrett, 2002). Furthermore, the research that has been done on team lifting has not yet addressed the influence of container volume on either the perception of heaviness or the maximum acceptable weight for lifting.

Overview

The present studies address the question of whether or not there is a size-weight illusion in team lifting. If the size-weight illusion exists, then it will suggest that volume should play a role in determining load acceptability for this type of lift, as it does in individual lifting. In Experiment 1, teams of participants lifted a set of containers that varied in both mass and volume and reported their perceptions of heaviness and volume. These results will be compared with those of Experiment 2, in which participants individually lifted the same stimuli and reported their perceptions using the same method.

EXPERIMENT 1

In Experiment 1, we tested the hypothesis that the size-weight illusion exists in a team lift. Two participants at a time lifted a series of boxes and reported their perceptions of heaviness and volume using a magnitude estimation paradigm. If the size-weight illusion exists in this type of lift, then the larger boxes should be perceived as lighter than smaller boxes with the same mass.

Method

Participants. Sixteen pairs of students (15 men, 17 women) at Arizona State University participated in this study as a means of fulfilling a research requirement in an Introduction to Psychology course. All participants reported that they had no physical conditions or problems with their muscles, joints, or any other parts of the body that might affect their ability to lift the boxes safely or to report their perceptions of heaviness and volume.

Apparatus. The stimuli were 16 square cardboard boxes that would commonly be used for postage or storage. All of the boxes were white and had no identifying marks on them. Within the 16 stimuli, there were four levels of volume (10^3, 14^3, 18^3, and 22^3 cubic inches; or 16 387.06, 44 966.10, 95 569.36, and 174 489.46 cc) and four levels of mass (3, 8, 18, and 30 pounds; or 1.36, 3.63, 8.16, and 13.60 kg). The manipulations of mass were achieved by filling each box with bags of sand layered between sheets of Styrofoam. Care was taken to ensure that the mass was distributed evenly throughout the volume of each box. An additional box of identical appearance (mass = 14 pounds, or 6.35 kg; volume = 16^3 cubic inches, or 67 121.41 cc) was used as the standard against which the perceived heaviness and volume of the 16 stimuli would be compared.

Procedure. A curtain was hung from the ceiling to the floor in the middle of the room. All of the experimental stimuli were kept behind the curtain and hidden from the participants' view for the entire session. The standard was kept on the participants' side of the curtain. The participants were instructed to estimate both the heaviness and volume of a set of boxes by lifting each box in tandem with their partner. Instead of reporting heaviness and volume on an extrinsic scale, such as grams or cubic centimeters, the participants rated their perceptions of each box relative to a standard box, which was given an arbitrary mass and volume of 100 (no units). At the start of each trial, the participants lifted the standard box to familiarize (or refamiliarize) themselves with its heaviness and volume. Following that, the participants lifted the stimulus box, which was slid under the curtain by the experimenter. The participants were instructed to rate the heaviness and volume of each stimulus box relative to the standard. For instance, if the stimulus felt heavier or larger than the standard, then they would assign it a number proportionately greater than 100. Similarly, if the stimulus felt lighter or smaller than the standard, then they would assign it a number proportionately smaller than 100.

This method of magnitude estimation with a standard is a common psychophysical technique (Coren, Ward, & Enns, 2004) that has been used successfully in the study of weight perception and the size-weight illusion (e.g., Amazeen, 1999; Ellis & Lederman, 1993). (See Karwowski et al., 1999, for additional methods to assess the perceived limits of safety in similar lifting tasks.) To avoid any bias attributable to social pressure, the participants were prohibited from communicating with each other regarding their perceptions. Participants reported their perceptions by writing them on a piece of paper that was given to the experimenter. Each of the 16 stimuli was presented to the participants twice in random order, for a total of 32 trials. There were no time limits. Reports of perceived heaviness and volume were averaged across the two trials per condition.

Results

The mean heaviness data for all of the stimuli as a function of mass and volume are shown in Figure 1. These data were analyzed using a within-groups analysis of variance (ANOVA). There were significant main effects of both mass and volume. As the mass of the stimuli increased from 3 to 30 pounds (1.36–13.60 kg), the reports of perceived heaviness, relative to the standard, increased from 23.2 to 210.46,

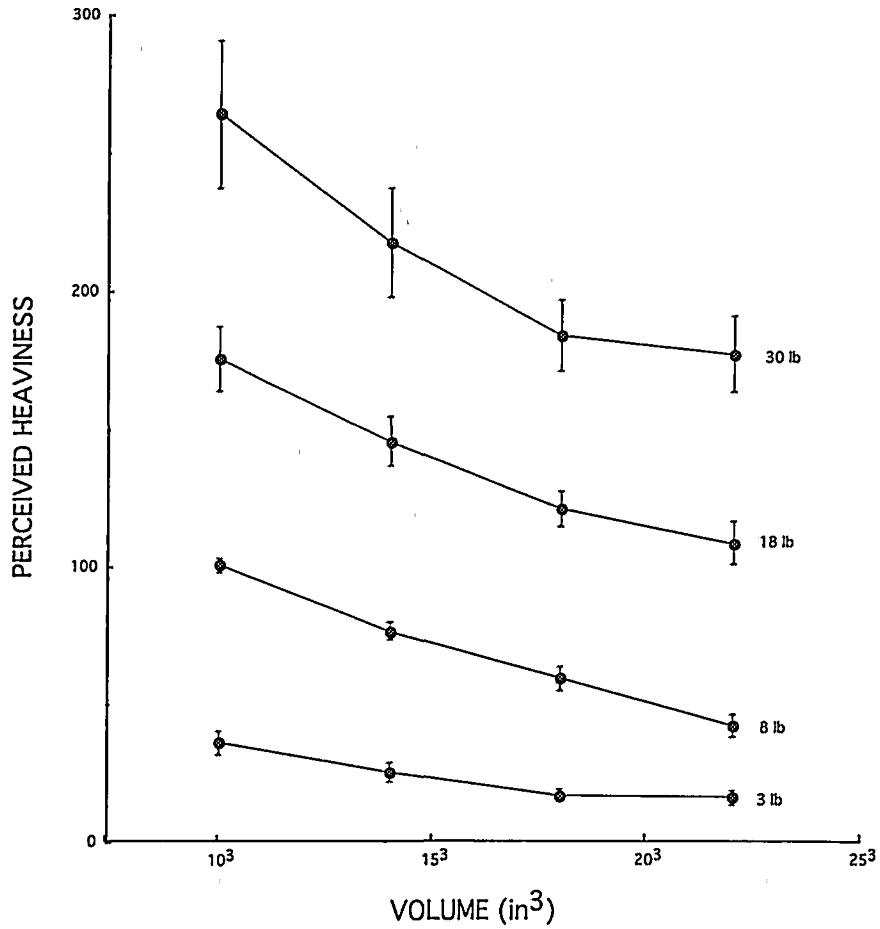

Figure 1. Perceived heaviness as a function of mass and volume during a team lift. (Metric equivalents for the mass and volume of the stimuli are identified in the text.)

$F(3, 93) = 89.3$, $p < .001$. As the volume of the stimuli increased from 10^3 to 22^3 cubic inches (16 387.06–174 489.46 cc), the reports of perceived heaviness decreased from 143.94 to 85.66, $F(3, 93) = 51.72$, $p < .001$. This 40% drop in perceived heaviness accompanying an increase in volume is consistent with previous demonstrations of the size-weight illusion (e.g., Stevens & Rubin, 1970). Participants lifting boxes in tandem experience a size-weight illusion. In addition to the two main effects, there was an interaction of mass and volume, indicating that the effects of volume on perceived heaviness were greater for the heavier stimuli, $F(9, 279) = 4.76$, $p < .001$. This, however, reflects only the fact that the mean drop in perceived heaviness was larger for heavier containers. When the drop in perceived heaviness was calculated as a percentage decrease, it went from a 57% drop in perceived heaviness for the 3-pound (1.36-kg) containers to a 33% drop for the 30-pound (13.60-kg) containers.

The mean perceived volume data for all of the stimuli as a function of mass and volume were analyzed using a within-groups ANOVA. The only significant effect was the main effect of volume. As the volume of the stimuli increased from 10^3 to 22^3 cubic inches (16 387.06–174 489.46 cc), the reports of perceived volume increased from 34.12 to 184.67, $F(3, 93) = 188.86$, $p < .001$. Neither the main effect of mass nor the interaction of mass and volume were significant, both $ps > .05$. Participants clearly recognized the variations in the sizes of the stimuli and based their reports solely on the geometric dimensions of the stimuli.

Discussion

In Experiment 1, teams of participants (two at a time) lifted a set of 16 stimuli that varied in both mass and volume and reported their perceptions of heaviness and volume. As the volume of the containers increased, the perceptions of heaviness decreased. The size-weight illusion exists in a team lift. This occurs despite the following facts: each participant was handling only a portion of the container, each participant was responsible for lifting only a portion of the total load, there was an additional horizontal force component caused by to the pull from the other team member (Dennis & Barrett, 2002), and there were significant changes in the kinematics of lifting when lifting as a team (Marras, Davis, Kirking, & Granata, 1999). The size-weight illusion, then, is clearly not a function of any biomechanical or psychological process specific to an individual lift. Rather, it appears that the size-weight illusion was present because the lifters had information indicating that the volumes of the containers varied.

Consistent with the results of previous psychophysical studies, the magnitude of the illusion in the present experiment was substantial. Across all levels of mass, the increase in volume resulted in a 40% decrease in perceived heaviness. Considering the masses associated with different perceived categories of safety reported by Genaidy et al. (1998, Table 6), a 40% decrease in perceived weight would generally represent a shift across a category boundary to a category of greater perceived safety. A pair of individuals lifting a very heavy container, then, could seriously underestimate the weight of that container and make potentially dangerous decisions about whether and how they should proceed. Given the wide use of team lifting for heavy or large containers by military, health care, manufacturing, and construction workers (reviewed in Dennis & Barrett, 2002), such misjudgments could be common. For individual lifting, a great deal of effort has been devoted to developing safety guidelines that include a consideration of container size in determining load acceptability (Potvin & Bent, 1997). However, such scientific efforts have not been made for team lifting (Dennis & Barett). The presence and magnitude of the illusion in the present experiment suggest a need for such efforts.

EXPERIMENT 2

In Experiment 2, individual participants lifted the same set of stimuli used in Experiment 1 and reported their perceptions of heaviness and volume. The size-weight illusion has been reported previously for stimuli of similar dimensions lifted in the same manner (Luczak & Ge, 1989). The purpose of this experiment is to establish the effects of mass and volume on perceptions of heaviness and volume during an individual lift for the same stimuli as in Experiment 1 in order to compare the effects across lifting styles.

Method

Participants. Sixteen students (8 men, 8 women) at Arizona State University participated in this study as a means of fulfilling a research requirement in an Introduction to Psychology course. All participants reported that they had no physical conditions or problems with their muscles, joints, or any other parts of the body that might affect their ability to lift the boxes safely or to report their perceptions of heaviness and volume.

Apparatus. The stimuli and the standard were the same square white cardboard boxes filled with sand and Styrofoam that were used in Experiment 1.

Procedure. The procedure was identical to the procedure used in Experiment 1 with the exception that participants reported their perceptions of heaviness and volume to the experimenter verbally. Each of the 16 stimuli was presented to the participants twice in random order for a total of 32 trials. Reports of perceived heaviness and volume were averaged across the two trials per condition.

Results

The mean heaviness data for all of the stimuli as a function of mass and volume are shown in Figure 2. Overall, the reports of perceived heaviness were lower for the individual lifts than they were for the team lifts in Experiment 1. The data were analyzed using a within-groups ANOVA. There were significant main effects of both mass and volume on perceived heaviness.

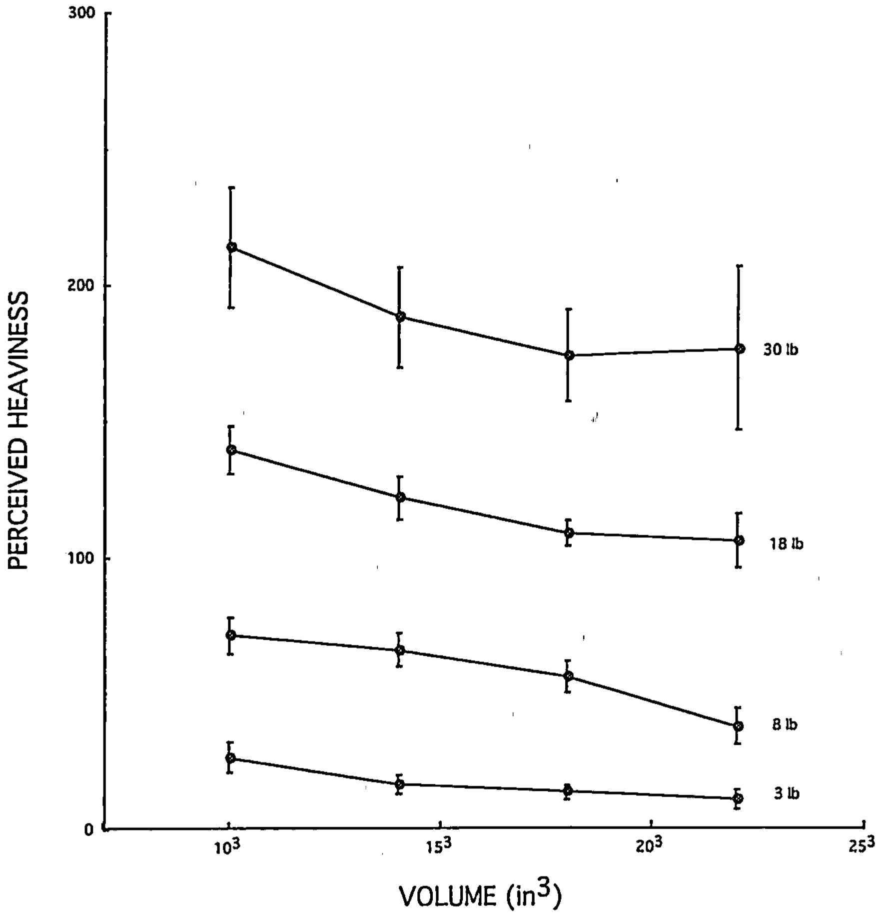

Figure 2. Perceived heaviness as a function of mass and volume during an individual lift. (Metric equivalents for the mass and volume of the stimuli are identified in the text.)

As the mass of the stimuli increased from 3 to 30 pounds (1.36–13.60 kg), the reports of perceived heaviness increased from 16.55 to 188.05, $F(3, 45) = 54.52$, $p < .001$. Although the reports of perceived heaviness in this experiment were lower, the ratio of perceived heaviness reports for the 30-pound (13.60-kg) stimuli to the 3-pound (1.36-kg) stimuli, 11.36, was greater than the ratio from Experiment 1, 9.07. Participants appear more sensitive to variations in mass when they lift the stimuli individually. As the volume of the stimuli increased from 10^3 to 22^3 cubic inches (16 387.06–174 489.46 cc), the reports of perceived heaviness decreased from 112.73 to 82.47, $F(3, 45) = 16.11$, $p < .001$. This 27% decrease in perceived heaviness is consistent with the size-weight illusion.

As expected, participants lifting these stimuli individually experienced a size-weight illusion. The strength of this illusion, though, when measured as a percentage decrease in perceived heaviness, was lower during the individual lift. The interaction of mass and volume was not significant, $F(9, 135) = 1.34$, $p > .2$. However, when the decrease in perceived heaviness was calculated as a percentage drop, it went from a 61% drop in perceived heaviness for the 3-pound (1.36-kg) containers to a 17% drop for the 30-pound (13.60-kg) containers.

The mean perceived volume data for all of the stimuli as a function of mass and volume were analyzed using a within-groups ANOVA. As in Experiment 1, the only effect that was significant was the main effect of volume. As the volume of the stimuli increased from 10^3 to 22^3 cubic inches (16 387.06–174 489.46 cc), the reports of perceived volume increased from 31.58 to 202.58, $F(3, 45) = 66.89$, $p < .001$.

Neither the main effect of mass nor the interaction of mass and volume were significant, both $ps > .3$. Participants clearly recognized the variations in the sizes of the stimuli and based their reports solely on the geometric dimensions of the stimuli.

GENERAL DISCUSSION

The main purpose of these studies was to determine whether the size-weight illusion would be present in a team lift. The results of Experiment 1 showed that there is a size-weight illusion when containers are lifted using this strategy. These results were similar to those of Experiment 2, in which the size-weight illusion was present when participants lifted the same containers individually. Whether lifted by an individual or a team, larger containers are perceived to be substantially lighter than smaller containers of the same mass. This decrease in perceived heaviness may also correspond to a substantial increase in perceived safety (e.g., Genaidy et al., 1998).

Perceived Heaviness and Team Lifting

A notable difference between the results of the two experiments is that the mean heaviness judgments were greater in the team lifting condition than they were in the individual lifting condition. This effect is counterintuitive because the participant is responsible for providing vertical support for only a portion of the total mass. If their reports of heaviness reflected only the amount of mass that they were supporting, then these reports should be substantially lower in the team lifting condition. In the team lift, though, members support more than just their portion of the vertical force. Members are also pulling the load toward themselves, resulting in an additional horizontal force that must be balanced by the other member of the team (Dennis & Barrett, 2002). Under these circumstances, a given container may feel less wieldy and would, therefore, be given a higher rating for heaviness. Stating that the container is heavier may be another way of saying that it is difficult to lift, support, and control (see Amazeen, 1997; Bingham, Schmidt, & Rosenblum, 1989; Genaidy et al., 1998; and Turvey, Shockley, & Carello, 1999, for similar conclusions). This increase in perceived heaviness may help to explain why the lifting capacity of a team is consistently less than the sum of the individuals' lifting capacities (Karwowski, 1988; Karwowski & Mital, 1986; Karwowski & Pongpatanasuegsa, 1988; Rice, Sharp, Nindle, & Bills, 1995; Sharp, Rice, Nindle, & Mello, 1995), unless the lifters are the same height (Johnson & Lewis, 1989).

A second difference across the two experiments is that the magnitude of the illusion was not the same across styles of lifting. The effect of volume on perceived heaviness was greater in the team lifting condition than in the individual lifting condition. This difference may be related to the fact that the magnitude of the illusion decreases as the mass of the containers increases. In both experiments, the percentage drop in perceived heaviness as a function of an increase in volume was smallest for the heaviest containers. Such a decrease in illusion magnitude has been identified previously and has been associated with specific changes in the slope and intercept of the psychophysical function relating perceived heaviness to volume across levels of mass (Stevens & Rubin, 1970). Stevens and Rubin suggested that this effect was related to the range of masses that one found manageable: The illusion should be strongest in the middle of this range and decrease toward the upper and lower ends. With their increased lifting capacity, the team lifters would find the heavier containers to be more toward the middle of their acceptable range than would the individual lifters. This may have caused the lifters to experience a greater magnitude of illusion.

Conclusions

Although there were notable differences in mean perceived heaviness and the magnitude of the illusion, both team lifters and individual lifters experienced a size-weight illusion. Larger containers were perceived to be lighter than smaller containers. Not only did the team lifters experience an illusion, they experienced a stronger illusion than did the individual lifters. One could expect, then, that the lifters – in particular the team lifters – would perceive the larger containers to be safer to lift. These results highlight the need for additional scientific evidence to develop safe lifting guidelines, procedures, and educational programs for both team and individual lifters (Dennis & Barrett, 2002).

REFERENCES

Amazeen, E. L. (1997). The effects of volume on perceived heaviness by dynamic touch: With and without vision. *Ecological Psychology, 9,* 245–263.

Amazeen, E. L. (1999). Perceptual independence of size and weight by dynamic touch. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 102–119.

Amazeen, E. L., & Jarrett, W. D. (2003). The role of rotational inertia in the haptic and haptic + visual size-weight illusions. *Ecological Psychology, 15,* 317–333.

Amazeen, E. L., & Turvey, M. T. (1996). Weight perception and the haptic size-weight illusion are functions of the inertia tensor. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 213–232.

Ayoub, M. M., Mital, A., Bakken, G. M., Asfour, S. S., & Bathea, N. J. (1980). Development of strength and capacities norms for manual materials handling activities: The state of the art. *Human Factors, 22,* 271–283.

Bingham, G. P., Schmidt, R. C., & Rosenblum, L. D. (1989). Hefting for a maximum distance throw: A smart perceptual mechanism. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 507–528.

Charpentier, A. (1891). Analyse experimentale de quelques elements de la sensation de poids [Experimental study of some aspects of weight perception]. *Archives de Physiologie Normales et Pathologiques, 3,* 122–135.

Ciriello, V. M., & Snook, S. H. (1983). A study of size, distance, height, and frequency effects on manual handling tasks. *Human Factors, 25,* 473–483.

Ciriello, V. M., & Snook, S. H. (1999). Survey of manual handling tasks. *International Journal of Industrial Ergonomics, 23,* 149–156.

Ciriello, V. M., Snook, S. H., & Hughes, G. J. (1993). Further studies of psychophysically determined maximum weights and forces. *Human Factors, 35,* 175–186.

Coren, S., Ward, L. M., & Enns, J. T. (2004). *Sensation and perception.* Hoboken, NJ: Wiley.

Dennis, G. J., & Barrett, R. S. (2002). Spinal loads during individual and team lifting. *Ergonomics, 45,* 671–681.

Dresslar, F. B. (1894). Studies in the psychology of touch. *American Journal of Psychology, 6,* 313–368.

Ellis, R. R., & Lederman, S. J. (1993). The role of haptic vs. visual volume cues in the size-weight illusion. *Perception and Psychophysics, 53,* 315–324.

Flournoy, T. (1894). De l'influence de la perception visuelle des corps sur leur poids apparent [The influence of visual perception on the apparent weight of objects]. *L'Annee Psychologique, 1,* 198–208.

Garg, A., & Badger, D. (1986). Maximum acceptable weight and maximum voluntary isometric strength for asymmetric lifting. *Ergonomics, 29,* 879–892.

Garg, A., & Saxena, U. (1980). Container characteristics and maximum acceptable weight of lift. *Human Factors, 22,* 487–495.

Genaidy, A. M., Karwowski, W., Christensen, D. M., Vogiatzis, C., Deraiseh, N., & Prins, A. (1998). What is "heavy"? *Ergonomics, 41,* 420–432

Johnson, S., & Lewis, D. (1989). A psychophysical study of two-person manual materials handling tasks. In *Proceedings of the Human Factors Society 33rd Annual Meeting* (pp. 651–653). Santa Monica, CA: Human Factors and Ergonomics Society.

Jones, L. A. (1986). Perception of force and weight: Theory and research. *Psychological Bulletin, 100,* 29–42.

Karwowski, W. (1988). Maximum load lifting capacity of males and females in teamwork. In *Proceedings of the Human Factors Society 32nd Annual Meeting* (pp. 680–682). Santa Monica, CA: Human Factors and Ergonomics Society.

Karwowski, W., Lee, W., Jamaldin, B., Gaddie, P., Jang, R., & Alqesaimi, K. K. (1999). Beyond psychophysics: The need for a cognitive engineering approach to setting limits in manual lifting tasks. *Ergonomics, 42,* 40–60.

Karwowski, W., & Mital, A. (1986). Isometric and isokinetic testing of lifting strength of males in teamwork. *Ergonomics, 29,* 869–878.

Karwowski, W., & Pongpatanasuegsa, N. (1988). Testing of isometric and isokinetic lifting strengths of untrained females in teamwork. *Ergonomics, 31,* 291–301.

Kloos, H., & Amazeen, E. L. (2002). Perceiving heaviness by dynamic touch: An investigation of the size-weight illusion in preschoolers. *British Journal of Developmental Psychology, 20,* 171–183.

Koseleff, P. (1957). Studies in the perception of heaviness: I. Some relevant facts concerning the size-weight-effect (SWE). *Acta Psychologica, 13,* 242–252.

Luczak, H., & Ge, S. (1989). Fuzzy modeling of relations between physical weight and perceived heaviness: The effect of size-weight illusion in industrial lifting tasks. *Ergonomics, 32,* 823–837.

Marras, W. S., Davis, K. G., Kirking, B. C., & Granata, K. P. (1999). Spine loading and trunk kinematics during team lifting. *Ergonomics, 42,* 1258–1273.

Masin, S. C., & Crestoni, L. (1988). Experimental demonstration of the sensory basis of the size-weight illusion. *Perception and Psychophysics, 44,* 309–312.

Mital, A., & Fard, H. F. (1986). Psychophysical and physiological responses to lifting symmetrical and asymmetrical loads symmetrically and asymmetrically. *Ergonomics, 29,* 1263–1272.

Oberle, C. D., & Amazeen, E. L. (2003). Independence and separability of volume and mass in the size-weight illusion. *Perception and Psychophysics, 65,* 831–843.

Pick, H. L., & Pick, A. D. (1967). A developmental and analytic study of the size-weight illusion. *Journal of Experimental Child Psychology, 5,* 362–371.

Potvin, J. R., & Bent, L. R. (1997). NIOSH equation horizontal distances associated with the Liberty Mutual (Snook) lifting table box widths. *Ergonomics, 40,* 650–655.

Rice, V. J., Sharp, M. A., Nindle, B. C., & Bills, R. K. (1995). Prediction of two-person team lifting capacity. In *Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting* (pp. 645–649). Santa Monica, CA: Human Factors and Ergonomics Society.

Robinson, H. B. (1964). An experimental examination of the size-weight illusion in young children. *Child Development, 35,* 91–107.

Sharp, M. A., Rice, V. J., Nindle, B. C., & Mello, P. (1995). Maximum acceptable load for lifting and carrying in two-person teams. In *Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting* (pp. 640–644). Santa Monica, CA: Human Factors and Ergonomics Society.

Snook, S. H. (1978). The design of manual handling tasks. *Ergonomics, 21,* 963–985.

Snook, S. H., & Ciriello, V. M. (1991). The design of manual handling tasks: Revised tables of maximum acceptable weights and forces. *Ergonomics, 34,* 1197–1213.

Stevens, J. C., & Rubin, L. L. (1970). Psychophysical scales of apparent heaviness and the size-weight illusion. *Perception and Psychophysics, 8,* 225–230.

Turvey, M. T., Shockley, K., & Carello, C. (1999). Affordance, proper function, and the physical basis of perceived heaviness. *Cognition, 73,* B17–B26.

Wu, S. P. (1997). Maximum acceptable weight of lift by Chinese experienced male handlers. *Applied Ergonomics, 28,* 237–244.

Wu, S. P., & Chen, C. C. (2001). Psychophysical determination of load carrying capacity for a 1-h work period by Chinese males. *Ergonomics, 44,* 1008–1023.

Yoko K. Naylor is a student at Arizona State University. She received her B.A. in child education from Nakamura Gakuen University, Fukuoka, Japan, in 1995.

Eric L. Amazeen is an assistant professor of psychology at Arizona State University. He received his Ph.D. in psychology in 1996 from the University of Connecticut.

Date received: June 23, 2003
Date accepted: November 20, 2003