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Perceived Heaviness Is Influenced by the Style of Lifting

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This experiment examined the influence of action on weight perception and the size-weight illusion. Participants rated the perceived heaviness of objects that varied in mass, length, and width. Half of the participants lifted each object and placed it down on the table and half placed the object on a pedestal before reporting their perception of heaviness. These tasks were performed either with or without vision. In all cases, increases in size produced decreases in perceived heaviness. For increases in both length and width, the use of vision produced a greater decrease in perceived heaviness. For increases in width alone, the task in which participants placed the object on a pedestal (a task for which the width of the object was a relevant variable) was associated with a greater decrease in perceived heaviness. Salience of information was discussed as a means by which task and modality might influence perception.

You must perceive the weight of an object in order to lift, hold, or use it. Any time that you pick up a tool, an eating utensil, or a box off a shelf, you must perceive its weight; every component of the movement, from the grip and load forces to the torques used for control and manipulation, requires this information. Action does not just follow perception, though; you must first grip and lift an object to generate the necessary stimulation (Weber, 1834/1978). In a circular fashion, actions make information available to generate the perception that will control those actions—as Gibson (1979/1986) put it, "We must perceive

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in order to move, but we must also move in order to perceive" (p. 223). This idea is explored in the present experiment wherein the movements performed by the participants are manipulated in order to investigate how the action performed with an object influences the perception of that object's weight.

INTENDED ACTIONS INFLUENCE PERCEPTION

In a variety of domains, research has supported the conclusion that our perceptions are influenced by the actions that we perform (Bhalla & Proffitt, 1999; Proffitt, Bhalla, Gossweiler, & Midgett, 1995; Proffitt, Stefanucci, Banton, & Epstein, 2003; Witt, Proffitt, & Epstein, 2004, 2005) or are capable of performing (Mark, 1987; Wagman & Taylor, 2005; Warren, 1984; Warren & Whang, 1987). For example, individuals who are either fatigued from running or carrying a heavy load perceive the slope of a hill to be steeper than they do while rested or without a load (Bhalla & Proffitt, 1999; Proffitt et al., 1995). Similarly, distances appear farther while carrying a heavy load (Proffitt et al., 2003) or after throwing a heavy ball (Witt et al., 2004). Conversely, distances appear shorter while holding a tool to extend reaching distance (Witt et al., 2005). These findings suggest that action plays a significant role in how we perceive our environment.

Such findings can be related to Gibson's (1979/1986) suggestion that we perceive objects and environments in terms of affordances—that is, we perceive what we can perform either with an object or in an environment. For example, participants are able to perceive visually both whether a flight of stairs is climbable and how much energy would be expended climbing them (Warren, 1984). Similarly, participants can perceive visually whether a surface would be an effective chair (Mark, 1987) and whether an aperture is passable (Wagman & Taylor, 2005; Warren & Whang, 1987). Perception is a function of one's physical capabilities because these capabilities influence the visual and tactual information available to the perceiver—in these cases, the optical angles specifying eyeheight (Mark, 1987; Warren & Whang, 1987) and the rotational inertia specifying the sizes and orientations of parts of the body or attachments to the body (e.g., a wheelchair; Wagman & Taylor, 2005).

Although this study focuses on the role of action in perceptual processes at the ecological level, such as those described earlier, it is useful to note that action also affects perception at the neural level. Participants who experience a right-hemisphere stroke often experience left spatial neglect. The degree of neglect in near space (within arm's reach) can be greater than (Berti & Frassinetti, 2000; Halligan & Marshall, 1991) or less than (Cowey, Small, & Ellis, 1994; Vuilleumier, Valenza, Mayer, Reverdin, & Landis, 1998) the neglect in far space (beyond arm's reach). What constitutes near and far space, though, is dynamic and influenced by tool use (Berti & Frassinetti, 2000). Iriki, Tanaka, and Iwamura

(1996) showed that when monkeys used a tool, the receptive fields for visual and haptic bimodal neurons became enlarged to include the handheld tool. Berti and Frassinetti presented a similar finding with a human stroke patient: the neglect that was originally limited to near space extended to far space while using a tool to extend reach. Action and affordances influence perception at both the ecological and neural levels.

ACTION AND WEIGHT PERCEPTION

The suggestion that perception is influenced by action is not new for weight perception in particular or for haptic perception in general. As early as 1834, Weber (1834/1978) noted that a perceiver must lift an object in order to obtain an accurate perception of its weight—perception required action. Consequently, many subsequent models of weight perception give action a prominent role (e.g., the expectation model: Davis & Roberts, 1976; Ross & Gregory, 1970; a mental processing model: Flanagan & Beltzner, 2000; information-based models: Amazeen & Turvey, 1996; Kingma, Beek, & van Dieën, 2002; Kingma, van de Langenberg, & Beek, 2004; Kloos & Amazeen, 2002; Shockley, Carello, & Turvey, 2004; Turvey, Shockley, & Carello, 1999). Even beyond weight perception, though, the concept of a muscular sense (Bell, 1826; Sherrington, 1906; or dynamic touch: Gibson, 1966; or kinesthetic touch: Loomis & Lederman, 1986) in general highlights the importance of muscular activity to the entire sense of touch—again at both an ecological and a neural level (see Fitzpatrick, Carello, & Turvey, 1994).

Despite the general agreement that action must influence the perception of weight, there are substantial differences of opinion regarding the nature of that influence. In the expectation-class of models, it is thought that the perceiver creates a mental expectation of weight, uses that expectation to generate the necessary grip and load forces, and then finalizes the perception based on whether the initial forces under- or overestimated what was required (Davis & Roberts, 1976; Ross & Gregory, 1970); action serves to evaluate and, if necessary, correct the perception of weight. Another more cognitive model considers how the perceiver's intended response to the object (either a verbal report or a prehensile action) determines the processing that will be applied to the stimulation (Flanagan & Beltzner, 2000). In the information-based class of models, the dynamics of the grip and lifting actions create information for perception through the reactions that the object presents to such forces—that is, through its moments of inertia (Amazeen, 1997, 1999; Amazeen & Jarrett, 2003; Amazeen & Turvey, 1996; Kingma et al., 2002; Kingma et al., 2004; Kloos & Amazeen, 2002; Shockley et al., 2004; Streit, Shockley, Morris, & Riley, 2007; Streit, Shockley, & Riley, 2007; Turvey et al., 1999). Offering further support for the influence of action on perception is the research showing that the information about length that is available to dynamic touch may vary as a function of the performed activity (van de Langenberg, Kingma, & Beek, 2006).

EFFECTS OF LENGTH, WIDTH, AND VISION ON THE SIZE-WEIGHT ILLUSION

To assess the influence of activity on weight perception, this experiment investigates its influence on a particular phenomenon associated with weight perception—the *size-weight illusion*. This illusion refers to the observation that larger objects are perceived to be lighter than smaller objects. This illusion is so strong that one may experience a greater than 50% decrease in perceived weight that will not disappear even after being informed of the illusion (Flournoy, 1894). However, there is also research showing that an increase in volume may also produce an *increase* in perceived heaviness (Amazeen, 1997; Ayoub, Mital, Bakken, Asfour, & Bathea, 1980; Ciriello & Snook, 1983; Garg & Badger, 1986; Garg & Saxena, 1980; Mital & Fard, 1986). Shape seems to be a factor in determining whether and how much perceived heaviness will decrease as the objects get larger. Studies that have manipulated length separately from width have shown—consistent with an information-based reliance of weight perception on the moments of inertia—that increases in width generally produce the strongest decreases in perceived heaviness (Amazeen, 1997, 1999; Valdez & Amazeen, 2008).

Although early research demonstrated a shape-weight illusion (Dresslar, 1894), studies of the size-weight illusion have not commonly manipulated the length and width of the objects separately. Amazeen (1997) had participants hold such objects by a handle so that they would not have any haptic information about volume from enclosing the object in their hands; participants only had access to the objects through dynamic touch. Using only dynamic touch, participants would only have perceptual access to the information available in the object's inertia. As predicted by the Inertial Model proposed by Amazeen and Turvey (1996), without vision, perceived heaviness decreased with an increase in width and increased with an increase in length. With vision, the positive effect of length disappeared—increases in both length and width produced decreases in perceived heaviness. However, the decrease in perceived heaviness associated with an increase in width was greater than the increase associated with an increase in length. This suggested that visual information about volume had separate effects that superimposed on the information about weight available through dynamic touch. Specifically, all increases in visually perceived volume produced a decrease in perceived heaviness that, when superimposed on the differential effects of length and width provided by dynamic touch, produced a stronger inverse effect of length than width.

OVERVIEW

The distinct effects of width and length provide an opportunity to investigate the influence of action on perception because we can create tasks that rely differently on width and then have participants perform them with and without vision. Generally, in studies of weight perception (or touch in general), the task is to grasp and lift the object in whatever manner is most natural and then to return the object to the table or experimenter. Such tasks do not necessarily require the participant to adjust to the size or shape of the object in any particular way. Half of the participants in this study performed just such a task—they lifted a cylinder and then placed it back down on the table before reporting their perception of heaviness. A second task was used for the remaining participants—they lifted the cylinder and then placed it down on a pedestal before reporting their perception of heaviness. Because the pedestal was the same size as the cylinder, the participant needed to use the width to aim and place it properly. Based on the results of van de Langenberg et al. (2006), we expected participants to rely on different properties of the cylinders when performing different tasks. Specifically, we expected that participants performing actions that rely more on width would experience a stronger size-weight illusion associated with width. Because vision seems to be involved in these effects, half of the participants performed their lifting task with vision and half performed it without vision. We expected that the illusion would be amplified when vision was allowed.

METHOD

Participants

One hundred (49 male, 51 female) undergraduate students at Arizona State University participated in this experiment in exchange for course credit. Ninety-two participants reported being right-handed and 8 reported being left-handed.

Design

Participants lifted each of 64 cylinders (composed of four levels each of Mass, Length, and Width) and reported their perceptions of heaviness. In addition to the three object-based repeated-measures factors, there were two lift-based between-participants factors, creating four groups of 25 participants. The first between-participants factor was Lifting Task; half of the participants simply lifted each object and placed it back down on the table next to a cylinder held in the opposite hand whereas the other half had to stack the object on top of the cylinder (the pedestal) in the opposite hand. The second factor was Vision; half of the participants could see their hands and the objects in their hands as they performed the task whereas the other half extended their arms through a curtain to occlude their view of their hands and the objects in their hands.

Apparatus

The cylinders that the participants rated were 64 plastic cylinders created with a factorial combination of four levels each of mass (340 g, 470 g, 600 g, and 730 g), length (7.75 cm, 10.25 cm, 15.25 cm, and 20.25 cm), and width (4.75 cm, 6 cm, 9 cm, and 11.75 cm). An additional cylinder (length = 15.25 cm, width = 9 cm, mass = 500 g) was created to serve as a standard. As a proportion of the dimensions of the standard, the cylinders ranged from 0.68 to 1.46 mass, 0.51 to 1.33 length, and 0.53 to 1.31 width. All objects were made of black ABS (Acrylonitrile-Butadiene-Styrene) pipe cut to length and sealed with plastic caps. Mass was manipulated by evenly distributing lead shot and rocks in caulking and expanding foam throughout each cylinder. There was no auditory information about the contents. Four additional empty cylinders (length = 15.5 cm; widths = 4.75 cm, 6 cm, 9 cm, and 11.75 cm) without any manipulation of mass were created to serve as the pedestals for the stacking task.

Procedure

Each participant was assigned to one of the four groups based on the between-participants factors of Lifting Task and Vision (lift-vision, lift-no vision, stack-vision, and stack-no vision.) Upon entering the room, the participant was seated across the table from the experimenter with ample room on the table for the lifting task. On each trial, the participant was first given the standard to lift with their preferred hand. The standard was given a heaviness of 100 (arbitrary units) and the participant was instructed to report his or her perception of the weight of the experimental cylinders relative to this standard; cylinders that felt heavier than the standard would be given a rating proportionately greater than 100 whereas those that felt lighter than the standard would be given a rating proportionately less than 100. Once the participant felt comfortable with the weight of the standard, he or she was given an experimental cylinder in the preferred hand and the pedestal of the same width in the nonpreferred hand. Participants in the Lifting conditions were instructed to lift the cylinder and place it next to the pedestal in the other hand before reporting their perception.

(The pedestal was never lifted or moved and was only given to make the tactual information about size equivalent across Lifting Task conditions.) Participants in the Stacking conditions were instructed to lift the cylinder and stack it on top of the pedestal in the other hand before reporting their perception. Participants in the No Vision conditions performed all tasks with their arms extended through a curtain that was hung from the ceiling. Participants in the Vision conditions were allowed to see their hands and the cylinders in their hands. However, all of the other cylinders and pedestals were hidden from view and none of the participants was ever allowed to see the entire set of cylinders. The entire experimental session took less than 1 hr and consisted of 128 trials, 2 trials for each of the 64 cylinders. Participants could choose to pause briefly between trials to avoid fatigue.

Analysis

Data were analyzed using both multiple regression (to generate power functions) and analysis of variance (ANOVA). Power functions were generated by regressing perceived heaviness against the relevant independent variables in log-log coordinates; the resulting regression slope for each independent variable was the exponent on that variable in the power function. In the ANOVA, because there were a number of between-participants comparisons, it was necessary to account for the different ranges employed by each participant. Therefore, the data were normalized by calculating a z score for each data point relative to the mean and standard deviation of the 128 trials for each participant. These perceived heaviness$_{norm}$ data were analyzed with a 2 (Lifting Task) $\times$ 2 (Vision) $\times$ 4 (Mass) $\times$ 4 (Length) $\times$ 4 (Width) mixed ANOVA. Post hoc tests were conducted using linear trend analyses. An alpha level of .05 was used for all statistical tests.

RESULTS

Perceived Heaviness

Main effects. As expected, there were significant main effects of Mass ($F(3, 288) = 2989.12$, $p < .05$, $\eta^2 = .97$), Length ($F(3, 288) = 299.85$, $p < .05$, $\eta^2 = .76$), and Width ($F(3, 288) = 467.69$, $p < .05$, $\eta^2 = .83$) on perceived heaviness$_{norm}$. Linear trend analyses indicated that these effects were all in directions consistent with previous findings regarding weight perception and the size-weight illusion: as Mass increased from 340 g to 730 g, perceived heaviness$_{norm}$ increased from −0.99 to 1.00 ($F(1, 96) = 5930.46$, $p < .05$, $\eta^2 =$ .98); as Length increased from 7.75 cm to 20.25 cm, perceived heaviness$_{norm}$ decreased from 0.33 to −.26 (see Figure 1; $F(1, 96) = 449.39$, $p < .05$, $\eta^2 =$

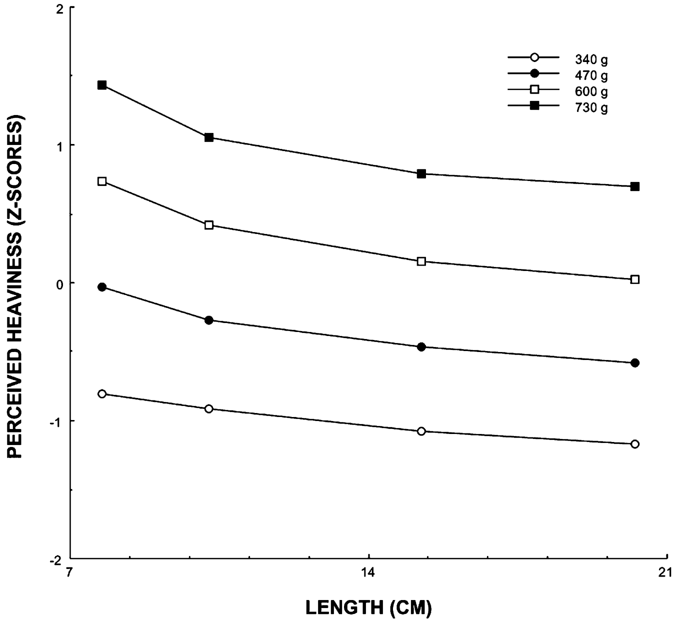

FIGURE 1 Effects of Length and Mass on perceived heaviness$_{norm}$.

.82); and as Width increased from 4.75 cm to 11.75 cm, perceived heaviness$_{norm}$ decreased from 0.51 to –0.40 (see Figure 2; $F(1, 96) = 647.48$, $p < .05$, $\eta^2 = .87$). Because the data were normalized, there were no differences in the means across either Lifting Task or Vision.

Effects of Length, Width, and Vision. Although both Length and Width had inverse effects on perceived heaviness, a comparison of both the means and η^2 values suggests that Width had a stronger effect than Length. To evaluate this further, the power function for mean perceived heaviness as a function of Mass, Length, and Width was calculated. The resulting power function (see Table 1) was perceived heaviness $= 10^{-0.55}\text{Mass}^{1.25}\text{Length}^{-0.29}\text{Width}^{-0.48}$, $R^2 = 0.99$, $F(3, 63) = 1304.80$, $p < .05$; the 95% confidence intervals on the exponents were 1.21 to 1.30 for Mass, –0.33 to –0.26 for Length, and –0.52 to –0.44 for Width. The exponents on Length and Width were each beyond the 95% confidence interval of the other, indicating a significant difference between the two exponents. The more negative exponent on Width supports the suggestion that Width had a stronger effect on perceived heaviness than Length.

The stronger effect of Width is predicted by the inertial model proposed by Amazeen and colleagues (Amazeen, 1997, 1999; Amazeen & Jarrett, 2003;

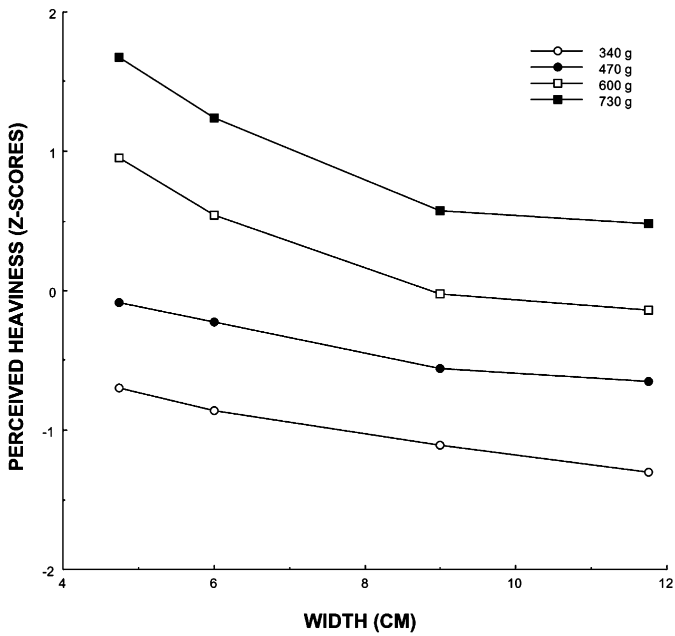

FIGURE 2 Effects of Width and Mass on perceived heaviness$_{norm}$.

Amazeen & Turvey, 1996; Kloos & Amazeen, 2002). Strictly speaking, this model predicts a positive effect of Length and an inverse effect of Width for perceivers using rotational inertia alone; however, that only holds when participants have no information about volume beyond that available through dynamic touch. Research has shown that when participants can view volume, there is an inverse effect of visually perceived volume superimposed on the effects rotational inertia, resulting in a relatively stronger inverse effect of width (Amazeen, 1997). In this experiment, all participants grasped the cylinders using haptic touch and, therefore, would have additional tactual information about volume beyond that provided by dynamic touch. The effects of haptic touch could superimpose on the effects of rotational inertia, producing the same stronger effect of width observed by Amazeen (1997).

If the influence of dynamic touch superimposed with the effects of volume perceived by haptic touch alone or in combination with vision, then we should expect both the stronger effect of Width demonstrated earlier and a further strengthening of the effects of Length and Width when participants were allowed to view the cylinders. There were, in fact, interactions of Length and Vision ($F(3, 288) = 18.12$, $p < .05$, $\eta^2 = .16$) and Width and Vision ($F(3, 288) =$

TABLE 1
Power Functions Relating Perceived Heaviness to the Mass, Length, and Width of the Cylinders

Group	*Power Function*
Overall	Perceived heaviness $= 10^{-0.55}$Mass$^{1.25}$Length$^{-0.29}$Width$^{-0.48}$
Lift-Vision	Perceived heaviness $= 10^{-0.34}$Mass$^{1.25}$Length$^{-0.40}$Width$^{-0.57}$
Lift-No Vision	Perceived heaviness $= 10^{-0.54}$Mass$^{1.17}$Length$^{-0.21}$Width$^{-0.33}$
Stack-Vision	Perceived heaviness $= 10^{-0.60}$Mass$^{1.31}$Length$^{-0.36}$Width$^{-0.56}$
Stack-No Vision	Perceived heaviness $= 10^{-0.73}$Mass$^{1.28}$Length$^{-0.21}$Width$^{-0.47}$
Lift	Perceived heaviness $= 10^{-0.44}$Mass$^{1.21}$Length$^{-0.30}$Width$^{-0.45}$
Stack	Perceived heaviness $= 10^{-0.67}$Mass$^{1.30}$Length$^{-0.28}$Width$^{-0.51}$

Note. Power functions are reported for all participants together, for participants in each of the four groups, and for participants in either the lifting or stacking conditions. Confidence intervals associated with each exponent are reported in the text.

11.72, $p < .05$, $\eta^2 = .11$). As can be seen in Figures 3 and 4, in each case there was a stronger inverse effect of size when vision was allowed: increasing Length from 7.75 cm to 20.25 cm produced a decrease in perceived heaviness$_{norm}$ from 0.27 to –0.18 when vision was occluded and a decrease from 0.39 to –0.34 when vision was allowed; increasing Width from 4.75 cm to 11.75 cm produced a decrease in perceived heaviness$_{norm}$ from 0.42 to –0.34 when vision was occluded and a decrease from 0.59 to –0.46 when vision was allowed. There was no significant interaction of Vision, Length, and Width, $F(9, 864) = 1.67$, *ns*.

These findings were further supported by the separate power functions for the four groups (see Table 1). The power function for the participants in the lift-vision group was perceived heaviness $= 10^{-0.34}$Mass$^{1.25}$Length$^{-0.40}$Width$^{-0.57}$, $R^2 = 0.97$, $F(3, 63) = 573.99$, $p < .05$; the 95% confidence intervals on the exponents were 1.17 to 1.32 for Mass, –0.45 to –0.34 for Length, and –0.63 to –0.51 for Width. The power function for the participants in the lift-no vision group was perceived heaviness $= 10^{-0.54}$Mass$^{1.17}$Length$^{-0.21}$Width$^{-0.33}$, $R^2 = 0.98$, $F(3, 63) = 1228.73$, $p < .05$; the 95% confidence intervals on the exponents were 1.12 to 1.21 for Mass, –0.24 to –0.17 for Length, and –0.36 to –0.29 for Width. The power function for the participants in the stack-vision group was perceived heaviness $= 10^{-0.60}$Mass$^{1.31}$Length$^{-0.36}$Width$^{-0.56}$, $R^2 = 0.97$, $F(3, 63) = 581.98$, $p < .05$; the 95% confidence intervals on the exponents were 1.24 to 1.39 for Mass, –0.42 to –0.30 for Length, and –0.62 to –0.50 for Width. Finally, the power function for the participants in the stack-no vision group was perceived heaviness $= 10^{-0.73}$Mass$^{1.28}$Length$^{-0.21}$Width$^{-0.47}$, $R^2 = 0.98$, $F(3, 63) = 1054.79$, $p < .05$; the 95% confidence intervals on the exponents were 1.23 to 1.33 for Mass, –0.25 to –0.17 for Length, and –0.51 to –0.43 for Width. In all four groups, the exponents on Length and Width were

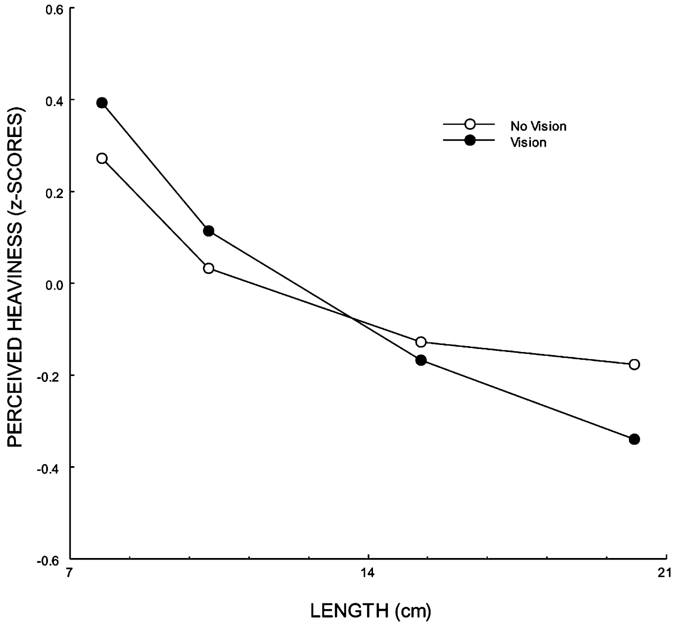

FIGURE 3 Effects of Length on perceived heaviness$_{norm}$ with and without vision.

each beyond the 95% confidence interval of the other, indicating a significant difference between the two exponents. The fact that the exponent on Width was always more negative than the exponent on Length suggests, again, that the effect of Width on perceived heaviness was stronger than the effect of Length. Finally, the exponents on both Length and Width were significantly more negative (i.e., beyond the 95% confidence intervals) when vision was allowed.

There were additional results that did not speak directly to the present questions concerning the role of lifting in weight perception yet were consistent with a dependence of weight perception on rotational inertia. These were the significant interactions of Length and Width ($F(9, 864) = 7.04$, $p < .05$, $\eta^2 = .07$), Mass and Length ($F(9, 864) = 13.24$, $p < .05$, $\eta^2 = .12$), Mass and Width ($F(9, 864) = 39.85$, $p < .05$, $\eta^2 = .29$), Mass and Length and Width ($F(27, 2592) = 2.85$, $p < .05$, $\eta^2 = .03$), and Mass and Length and Width and Vision ($F(27, 2592) = 1.57$, $p < .05$, $\eta^2 = .02$). The source of the Length × Width interaction was a decrease in the effect of each variable at higher levels of the other variable. The change in rotational inertia associated with an increase of one variable may have been masked by the relatively greater rotational inertia associated with a higher level of the other variable. The source of the interactions involving Mass was always a strengthening of the effect of size at higher levels

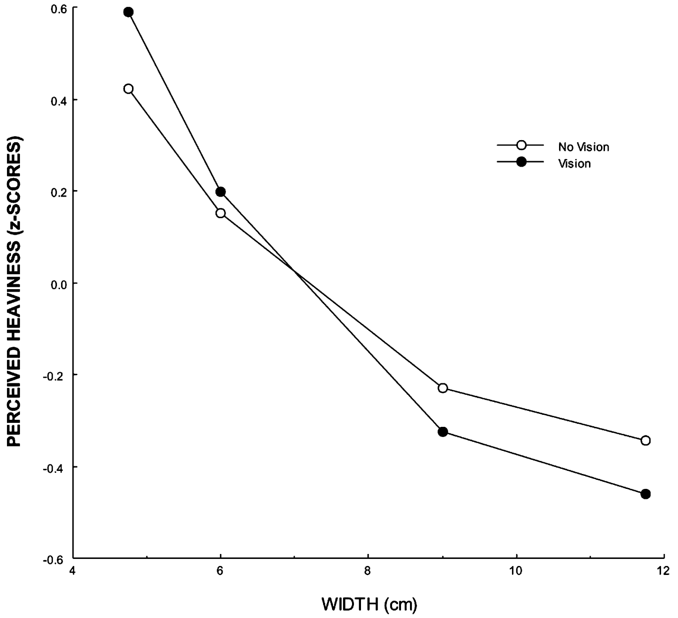

FIGURE 4 Effects of Width on perceived heaviness$_{norm}$ with and without vision.

of Mass (see Figures 1 and 2). In this case, more mass would be moved with an increase in size, resulting in greater changes in rotational inertia and, presumably, perceived heaviness. The fact that Mass, Length, and Width also interacted with Vision suggests, again, that vision may affect the participant's attunement to rotational inertia. None of the other effects involving Vision were significant.

Effects of Lifting Task. It was predicted that performing the stacking task would strengthen the effect of width because participants would be forced to attend to and use the width of the cylinders in performing the task. We expected, therefore, a significant interaction of Width and Lifting Task. However, the only effect in which Lifting Task had a significant effect was the Mass × Width × Lifting Task interaction, $F(9, 864) = 1.99$, $p < .05$, $\eta^2 = .02$. Although the overall effect of Width did, in fact, increase from the placing to the stacking tasks (as Width increased from 4.75 cm to 11.75 cm, perceived heaviness$_{norm}$ decreased from 0.49 to -0.37 in the placing task and from 0.53 to -0.43 in the stacking task), the interaction of Width and Lifting Task was not significant, $F(3, 288) = 1.47$, *ns*. This was because Lifting Task had a weaker effect at lower levels of Mass. The increased effect of Lifting Task at greater levels of

Mass was the source for the three-way interaction. None of the other effects involving Lifting Task were significant, $p > .05$.

Power functions calculated for the data from the participants performing the lifting and stacking tasks separately demonstrated more clearly a strengthening of the effect of Width when performing the stacking task (see Table 1). The power function for the participants in the lifting groups was perceived heaviness = $10^{-0.44}\text{Mass}^{1.21}\text{Length}^{-0.30}\text{Width}^{-0.45}$, $R^2 = 0.98$, $F(3, 63) = 1117.52$, $p < .05$; the 95% confidence intervals on the exponents were 1.16 to 1.25 for Mass, –0.34 to –0.26 for Length, and –0.49 to –0.41 for Width. The power function for the participants in the stacking groups was perceived heaviness = $10^{-0.67}\text{Mass}^{1.30}\text{Length}^{-0.28}\text{Width}^{-0.51}$, $R^2 = 0.98$, $F(3, 63) = 1153.80$, $p < .05$; the 95% confidence intervals on the exponents were 1.25 to 1.35 for Mass, –0.32 to –0.25 for Length, and –0.56 to –0.47 for Width.

DISCUSSION

The goal of this experiment was to examine the influence of the style of lifting on weight perception and the size-weight illusion. Participants were presented with a set of cylinders that varied in mass, length, and width. The movements performed by the participants prior to reporting perceived heaviness were manipulated. Half of the participants lifted the cylinder and placed it down on the table and half placed the cylinder on a pedestal before reporting their perception of heaviness. These tasks were performed either with or without vision. In all cases, increases in size produced decreases in perceived heaviness. However, the strength of this effect was influenced by the manipulations of vision and task. For increases in both length and width, the use of vision produced a greater decrease in perceived heaviness. For increases in width alone, the task in which participants placed the cylinder on a pedestal (a task for which the width of the object was a relevant variable) was associated with a greater decrease in perceived heaviness. These results further support roles for vision and task in weight perception and the size-weight illusion.

Effects of Task

Consistent with the research showing an effect of the task being performed on perception (Berti & Frassinetti, 2000; Bhalla & Proffitt, 1999; Iriki et al., 1996; Mark, 1987; Proffitt et al., 1995, Proffitt et al., 2003; Wagman & Taylor, 2005; Warren, 1984; Warren & Whang, 1987; Witt et al., 2004, 2005), the task performed by perceivers in this experiment influenced their perceptions of heaviness. Participants experienced a greater inverse effect of width on perceived heaviness while performing a stacking task that required accommodations for the width of the cylinders.

In this study, action did not simply follow perception. Perceivers lifted the cylinders in order to generate the information for perceived heaviness. As would be expected from Gibson (1979/1986), the perceivers in this experiment moved in order to perceive. What was more striking, though, was the observation that movement did not simply make generic information available. That is to say, the movements did more than just reveal, say, the set of resistances to rotational accelerations represented in the inertia tensor that would combine according to some psychophysical function to generate the perception of weight. For the psychophysical functions to vary across tasks, changes in the style of lifting must have led the perceiver to use different information or to use the information differently. Similarly, in a study investigating fast perceptual learning in dynamic touch, Wagman, Shockley, Riley, and Turvey, (2001) found that both exploration (i.e., the manner in which one lifts and wields the object) and the perceptual variables that one attunes to can change with brief practice.

The information-based class of models (Amazeen & Turvey, 1996; Kingma et al., 2002; Kingma et al., 2004; Kloos & Amazeen, 2002; Shockley et al., 2004; Turvey et al., 1999) assumes at some level that participants will perform equivalently across a variety of situations; generally, universal psychophysical functions connecting information to perception are sought. The effect of task, then, could be seen to undermine the basis of an informational account by suggesting that perceivers elect to use whatever information they choose whenever they like. An alternative account would probably rely on some internal cognitive state rather than relying on a property or process that only exists in the interaction between the perceiver and the perceived. We believe that this would be a mistaken interpretation (see also Wagman et al., 2001). In fact, we see the present results as supporting an information-based account when that account is considered within an ecological perspective on perception and action. In this experiment, perceptions were more influenced by width when width was more directly related to the style of lifting. The relation between object and perception, then, is not at the whim of the perceiver; it is a reflection of the relation between object and action. Perceivers use the information called for by the task that they are performing or intend to perform. A possible mechanism for this effect is discussed in the following section.

Effects of Vision

The exponents on the power functions relating length and width to perceived heaviness were significantly more negative when participants could see the cylinders in their hands, indicating that the size-weight illusion was stronger when vision was allowed. Such changes in the exponents of the power functions have been noted previously (Amazeen, 1997; Amazeen & Jarrett, 2003). In fact, despite the fact that vision is not generally necessary for the size-weight illusion (Amazeen, 1997, 1999; Amazeen & Jarrett, 2003; Amazeen & Turvey, 1996; Ellis & Lederman, 1993; Kloos & Amazeen, 2002; Oberle & Amazeen, 2003; Valdez & Amazeen, 2008), research consistently shows that it can play a significant role (Amazeen, 1997, 1999; Ellis & Lederman, 1993; Koseleff, 1957; Streit, Shockley, Morris, et al., 2007; Streit, Shockley, & Riley, 2007; Valdez & Amazeen, 2008).

Amazeen and Jarrett (2003) analyzed perceived size data to determine whether the addition of vision produced variations in perceived size that could explain the observed effects on perceived heaviness. No such effects of vision on perceived size were apparent. Instead, the increased exponents on the psychophysical functions relating rotational inertia to perceived heaviness suggested that vision improved the perceivers' sensitivity to dynamical properties of the cylinders. Vision improved the detection of information in rotational inertia. In the present experiment, vision also seemed to improve access to the task-relevant properties of the objects in the hands. As was concluded earlier, an information-based account needs to be considered in the broader ecological context of the task being performed and, in this case, the perceptual system being used.

These findings are also informed by those of Streit and colleagues (Streit, Shockley, Morris, et al. 2007; Streit, Shockley, & Riley, 2007). In these studies, virtual visual feedback about wielding was manipulated to show that vision can be used to detect dynamic properties such as rotational inertia, consistent with the aforementioned interpretation. A difference between these studies and the present experiment, though, is that Streit and colleagues manipulated the information available to vision across conditions via an optical gain—that is, there were qualitative difference in information across conditions. In the present experiment, though, the object's physical properties and resistance to wielding was the same with or without vision. Nevertheless, perceivers were more sensitive to the size of the objects with vision. Again, an information-based account should always be provided within the ecological context of the task and perceptual system.

CONCLUSIONS

After noting that different styles of wielding led perceivers to use different information in the perception of length by dynamic touch, van de Langenberg el al. (2006) concluded that this likely resulted from variations in the salience of information accompanying manipulations of wielding. It may be that the manipulations of optical gain used by Streit, Shockley, Morris, et al. (2007) and Streit, Shockley, and Riley (2007) also effectively increased the salience of the object's dynamic properties. In the present experiment and others, manipulations of modality may influence perception by influencing the salience of certain object properties. Variations in the salience of size may have been the mechanism behind the effects of both vision and task in the present experiment. Any task requires the actor to attend to the relevant information in order to perform the task successfully; in this study the tasks were designed specifically to manipulate how much the perceiver would attend to the object's width. As attention is directed more toward any given property, that property will become more salient to the observer, producing the types of effects seen by van de Langenberg et al. and here. A possible implication of the present results is that this direction of attention is not the exclusive domain of perceptual processes preceding action; the task requirements of action direct attention toward certain relevant properties with the result that these properties may be more salient to, and thereby have greater effects on, both action and perception.

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