Running Header: DISTANCE PERCEPTION AND OBESITY

Perceived Distance and Obesity: It's What You Weigh, Not What You Think

Mila Sugovic¹, Philip Turk², Jessica K. Witt³

¹Department of Psychological Sciences, Purdue University, West Lafayette IN

² Department of Statistics, Colorado State University, Fort Collins CO

³ Department of Psychology, Colorado State University, Fort Collins CO

Abstract

Action abilities are constrained by physical body size and characteristics, which, according to the action-specific account of perception, should influence perceived space. We examined whether physical body size or beliefs about body size affect distance perception by taking advantage of naturally-occurring dissociations typical in people who are obese but believe themselves to weigh less. Normal weight, overweight, and obese individuals made verbal distance estimates. We also collected measures of beliefs about body size and measures of physical body size. Individuals who weighed more than others estimated distances to be farther. Furthermore, physical body weight influenced perceived distance but beliefs about body size did not. The results illustrate that whereas perception is influenced by physical characteristics, it is not influenced by beliefs. The results also have implications for perception as a contributing factor for lifestyle choices: people who weigh more than others may choose to perform less physically demanding actions not as a result of how they perceive their bodies, but as a result of how they perceive the environment.

Keywords: Action-specific perception; Obesity; Distance perception; Effort; Body size

Perceived Distance and Obesity: It's What You Weigh, Not What You Think

According to the action-specific account of perception, a person's ability to perform an action influences spatial perception (Witt, 2011a). For example, softball players who are hitting better than others see the ball as bigger (Gray, 2013; Witt & Proffitt, 2005), archers shooting better than others see the target as bigger (Lee, Lee, Carello, & Turvey, 2012), and tennis players who are playing better than others perceive the ball to be moving slower (Witt & Sugovic, 2010). There are many factors that influence a person's ability to perform an action, and previous research has documented that many of these factors also influence perception. These factors include body size (e.g. Linkenauger, Witt, & Proffitt, 2011; Van der Hoort & Ehrsson, 2014; van der Hoort, Guterstam, & Ehrsson, 2011), task difficulty (e.g. Kirsch, Herbort, Butz, & Kunde, 2012; Kirsch & Kunde, 2013a, 2013b; Witt & Sugovic, 2010; Witt & Sugovic, 2012), and the energetic costs associated with performing the action (e.g. Bhalla & Proffitt, 1999; Eves, Thorpe, Lewis, & Taylor-Covill, 2014; Taylor-Covill & Eves, 2013, 2014). However, despite the growing literature demonstrating these action-specific effects, little research has examined the role of beliefs about action. In the current study, we examined whether beliefs about abilities influence perception, and if so, if this effect of beliefs is in addition to or is responsible for previously reported effects of physical abilities on perception.

Resolving which factors contribute to spatial perception will have implications for theories of vision. On one hand, it is irrelevant whether action-specific effects are driven by physical characteristics versus beliefs because both would show non-optical, and therefore top-down, influences on vision. Bottom-up influences refer to information detected by the eye itself, namely optical information, and all other non-optical sources are considered to be top-down influences. Regardless of whether physical characteristics or beliefs about the body are the relevant factor, either would demonstrate a top-down influence on perception. On the other hand, the determination between physical characteristics and

beliefs is critical because it would resolve the nature of these top-down, non-visual influences. Beliefs about the body are of a similar category to classic conceptions of top-down influences such as knowledge and expectations. A finding that beliefs influence spatial vision would challenge models of vision that considered spatial vision to be immune to top-down influences (see Cavanagh, 1999; Firestone & Scholl, 2014, in press). In contrast, an effect based on physical characteristics rather than beliefs might reveal a different kind of top-down influence for spatial vision. For example, an effect based on unconscious physical abilities rather than on conscious beliefs would preserve the idea that spatial vision is cognitively impenetrable because what is known (or thought or believed) would not exert an influence on vision (Fodor, 1983; Pylyshyn, 1999, 2003). In addition, the source of the information that feeds back to visual areas would differ depending on if the influential factor were beliefs or physical factors. Thus, in order to determine what kind of top-down effect is supported by action-specific effects, we set out to determine the unique contributions of beliefs versus physical characteristics.

Prior research on action-specific effects is consistent with both interpretations. Beliefs could play a role in spatial perception because even though physical abilities are typically manipulated, people's beliefs about their abilities often highly coincide with their physical abilities (e.g. Mark, 1987; Warren, 1984). Consequently, previous effects of a person's ability to act on perception could in fact be the result of effects based on beliefs about action. In some experiments, researchers measured beliefs as a way to assess ability. For example, in a study on the relationship between Parkour and perceived wall height, the participants rated the ease with which they could climb each wall, and no physical measurements were taken (Taylor, Witt, & Sugovic, 2011). The goal was to assess physical abilities, not specifically beliefs about abilities, with the notion that people tend to be accurate so their judgments could be used as a proxy for their abilities.

In an experiment on golfers, the researchers measured both physical performance and subjective measures of performance (Witt, Linkenauger, Bakdash, & Proffitt, 2008). Physical performance was assessed as course score after playing a round of golf. Participants were asked to rate their performance by indicating, on a scale of 1 to 7, their putting abilities in comparison to similarly-skilled players, their putting abilities on that day relative to their own typical abilities, and their overall play on that day relative to their own typical play. None of these measures (nor the composite score) related to perceived golf hole size, whereas course score (i.e. physical performance) was significantly correlated with perceived hole size. In this case, participants' assessments or beliefs about their own abilities were only moderately correlated with physical performance ($r = .14$, $r = .15$, $r = .48$; respectively). This discrepancy between physical and believed performance allowed for the assessment of the independent contributions for each, and the evidence favored the significant role of physical abilities, but not believed abilities.

Another area in which beliefs do not always align with physical characteristics is with respect to body size. Many people who are obese believe that their body is physically smaller than its actual size (Kuchler & Variyam, 2003; Truesdale & Stevens, 2008). This dissociation between physical body size and believed body size allowed us to determine the independent contributions of beliefs and physical characteristics on the perception of distance.

A person's ability to perform an action is naturally influenced by his or her physical body size. An organism's morphology, or somewhat permanent body structure, places a constraint on what the organism is capable of doing (see Proffitt & Linkenauger, 2013). For example, a person's arm length determines the range of objects that can be reached. A person's leg length determines the maximum step height they can take, and a person's body height determines what barriers they can walk under without bending. Different body sizes naturally permit some actions and hinder other actions. As a result, body size determines which actions are possible.

Consequently, according to recent research, body size also influences perception of the environment. For example, shoulder width affects perception of aperture widths (Stefanucci & Guess, 2009). Participants with broader shoulders who would have more difficulty passing through constricted doorway widths perceived the doorway widths to be narrower than did those with narrow shoulders. Modifications to the body also result in changes in perception. In a series of experiments, participants were asked to judge the distance to a target placed just beyond arm's reach. Arm length was functionally extended via use of a reach-extending tool. When using a tool, the objects appeared closer than when the tool was not used or when a short tool was used (Bloesch, Davoli, Roth, Brockmole, & Abrams, 2012; Osiurak, Morgado, & Palluel-Germain, 2012; Witt, 2011b; Witt & Proffitt, 2008; Witt, Proffitt, & Epstein, 2005).

Another technique to manipulate body size has been to render the body as being different sizes in a virtual environment. In one series of studies, the entire body was rendered as twice or half its size (Van der Hoort & Ehrsson, 2014; van der Hoort et al., 2011). In another series of experiments, the hand was rendered as larger or smaller (Linkenauger, Leyrer, Buelthoff, & Mohler, 2013) or the arm was rendered as longer or shorter (Linkenauger, Bulthoff, & Mohler, 2015). These studies found significant effects of rendered body size on perceived distance to and size of external objects. Objects looked smaller or closer when the body or hand was rendered bigger and the arm was rendered smaller.

Virtual reality allows for a dual-reality: participants can know that their bodies appear bigger even if their bodies are not actually bigger. Thus, it is unclear how results using virtual reality fit into the discussion about beliefs versus physical attributes. Certainly physical body size was not manipulated, but beliefs about one's own (physical, not virtual) body are also unlikely to be influenced. After experiencing a virtual body that is bigger, participants do not believe their own bodies to be any different in size than after experiencing a virtual body that is smaller (Piryankova et al., 2014). While

virtual reality is a wonderful tool for some research questions, the results with studies using virtual reality do not directly address the current question of interest.

In addition to structural constraints, the size of the body also places energetic constraints on action. Those who weigh more than others must carry a heavier load, so walking incurs a higher energetic cost. Energetic costs influence spatial perception. Hills appear steeper and distances appear farther to people who carry a heavy backpack (Bhalla & Proffitt, 1999; Proffitt, Stefanucci, Banton, & Epstein, 2003). Staircases appear steeper to perceivers who weigh more than others (Eves et al., 2014) or who are fatigued (Taylor-Covill & Eves, 2013). Distance across a gap appears farther to observers wearing ankle weights compared with observers who do not carry the extra weight (Lessard, Linkenauger, & Proffitt, 2009). Objects on a ground appear farther to observers who intend to throw a heavy ball compared with observers who throw a light ball (Witt, Proffitt, & Epstein, 2004). Walking specified distances presented up a hill requires more energy, and also appears farther, compared to distances presented on flat ground (Stefanucci, Proffitt, Banton, & Epstein, 2005; White, Shockley, & Riley, 2013). These studies show that the energetic costs associated with traversing a space influences perception of that space.

In order to test the separate effect of beliefs and physical abilities on perceived distance, we took advantage of a naturally occurring dissociation often found in people who are obese. Based on the previous research on energetic costs and distance perception, we expect that people with body sizes bigger than others will see distances as farther. To the extent that physical body size and beliefs about body size differ, we can determine the unique contribution of each factor.

Method

Participants

Seventy-six people participated in the experiment. Participants were community members who were recruited outside of a local superstore. Two participants had a problem understanding the task and two were excluded due to experimenter data logging errors. One participant was deemed a statistical outlier because his mean distance judgment was more than three standard deviations from the group mean, and another was excluded because one estimate was so much farther than her other estimates, even though it was not for the farthest target, and excluding her was necessary to fit statistical models. Four participants were also excluded because they classified morbidly obese. People who are morbid obesity also tend to have cognitive impairments (Smith, Hay, Campbell, & Trollor, 2011).

The final sample included sixty-six people (30 female, 36 male) between the age of 18-50 ($M = 24.4$ years old, $SD = 6.53$). According to the standard Body Mass Index (BMI) classification system, 23 were at a normal weight ($18.5 \leq BMI < 25$; 8 female, 15 male), 21 were overweight ($25 \leq BMI < 30$; 11 female, 10 male), and 22 subjects were obese ($BMI \geq 30$; 11 female, 11 male). Participants were naïve to the purpose of the experiment and received a bag of chips for participation.

Stimuli and Apparatus

Participants stood behind a piece of duct tape placed on a sidewalk and verbally estimated in feet and inches the distance to an orange sports cone presented on the sidewalk (see Figure 1). The distances were marked using chalk and were not visible to the participants. To obtain the participant's height we used a tape measure that was affixed to a nearby bus stop, and we used a bathroom scale to measure participant's weight. The measuring equipment was hidden from the participant's view prior to the end of the experiment when these measurements were taken.

Figure 1. Photograph of the test site. In this example the cone (circled in red) was placed 25m from where the participant stood (marked with duct tape at the bottom of picture).

Procedure

Each participant stood at a pre-marked location and was told that cones would be placed at a number of different distances down the path. The participant was asked to “estimate as accurately as possible in feet and inches, how far away the cone is from where you are standing.” Participants made a verbal estimate to each of 4 target distances (10, 15, 20, 25m) in 1 of 4 possible randomized orders. Prior to each trial, participants were asked to turn around and face the opposite direction while the experimenter placed the cone at the target distance.

After making all four distance estimates, the participant completed a survey. Along with demographic questions, the survey asked them to indicate their height, weight, and an evaluative measure of body size (too low, a bit low, good, a bit high, or too high). For the measure of beliefs about body size, participants selected a body image, from a scale of figures (see Figure 2), that most closely

matched their own body. The scale used here (Thompson & Gray, 1995) was modified to include larger, more overweight and obese body types. At the end, we obtained the participant's actual height and weight, which were used to calculate their Body Mass Index (BMI) and determine their BMI classification category (normal weight, overweight, or obese). The experiment took approximately 10 minutes to complete.

Figure 2. Female sample images used in the picture selection task (PST). Participants were asked “which of the following drawings most accurately depicts your current body size?” A similar sample of male figures was also used.

Data Analysis

We fit a random coefficients linear mixed model (random slope and random intercept for each subject's estimates as a linear function of distance) considering a candidate set of predictors variables including Weight (W), BMI, Beliefs about Body Size as assessed by the picture selection task (PST), Distance (D), and interactions $W \times D$, $BMI \times D$, $PST \times D$. Because W and BMI were so highly correlated ($r = .84$), they were not allowed to appear in the model together. Factors such as sex and height, which have an effect on perception of hill slant (e.g. Bhalla & Proffitt, 1999; Proffitt, Bhalla, Gossweiler, & Midgett, 1995; Taylor-Covill & Eves, 2013), have been found to not have an effect on perceived distance (e.g. Proffitt et al., 2003; Stefanucci et al., 2005; Witt et al., 2004) and thus were not included in order to maintain a reasonable number of models. Altogether, we fit 16 different models chosen a priori as displayed in Table 1.

For ease of interpretation, 10 meters was subtracted from each of the Distance values to give us a set of new values (0, 5, 10, 15). Each model was fit using maximum likelihood estimation. We used Kenward-Roger degrees of freedom (Kenward & Roger, 1997) and a variance components covariance structure for the random effects. The error covariance structure was set to the error variance times the identity matrix. Estimates of the variance components for the intercept, slope, and error terms along with estimated variances of the variance component estimates were obtained from each model, as well as estimates of the fixed effects along with estimated variances of the fixed effects estimates. For each model, we obtained Akaike's Information Criterion adjusted for small sample size (AICC) (Burnham & Anderson, 2002). Two other closely related statistics were computed to assess model efficacy and uncertainty. Delta-AICC is the difference between the “best” model (smallest AICC) and another proposed model AICC. Generally speaking, models in the candidate set having delta-AICC values less than or equal to 2 have substantial empirical support. Akaike weights, or weights, are computed using delta-AICC (Burnham & Anderson, 2002), and are interpreted as the weight of evidence in favor of a model being “best” in the candidate set.

Model averaging is a statistical method by which parameter estimates from models in a candidate set are conjoined to give an overall estimate and which addresses model selection uncertainty. Of the two general expressions for model-averaged parameter estimators given in Burnham and Anderson (2002), we use the so-called “natural” estimator, which uses a parameter estimate only if the corresponding independent variable is included in the model. However, we refine and extend this approach here to only consider models where the parameter retains a common interpretation. The reason is because the interpretation of a main effect is not the same as the interpretation of a main effect when it is also involved in an interaction term in the same model. Therefore, to model average across two models with and without an interaction to estimate a main effect could potentially be misleading.

Burnham and Anderson (2002) also describe an approach for computing a model averaged standard error for parameter estimates. Using ± 2 standard errors gives us an approximate 95% confidence interval (CI) for the parameters. Thus, we obtained model averaged estimates of the variance components along with 95% CIs and obtained model averaged estimates of the fixed effects along with 95% CIs.

Table 1: Models tested.

Model	W	BMI	PST	D	W*D	BMI*D	PST*D
1							
2				X			
3	X			X			
4		X		X			
5			X	X			
6	X		X	X			
7		X	X	X			
8	X			X	X		
9	X		X	X	X		
10		X		X		X	
11		X	X	X		X	
12			X	X			X
13	X		X	X			X
14		X	X	X			X
15	X		X	X	X		X
16		X	X	X		X	X

Notes. W stands for body weight. PST stands for picture selection task. D stands for Distance.

The data analysis for this paper was generated using SAS/STAT software, Version 9.3 of the SAS System for Windows. Residual diagnostics were done for one of the saturated models to check the assumptions of the linear mixed model. As indicated previously, a subject was removed from the analysis based upon examination of the residuals.

Results

First, we examined the independent contributions of each measure to perceived distance. Then we conducted analysis (as described above) to determine the relative contribution of each factor. We had two measures of physical body size (body weight and BMI) and one measure of beliefs about body size (selected image in the picture selection task, or PST). The correlation between BMI and body weight was quite high, $r = .84, p < .001$. People who weighed more than others also had a higher BMI. The correlations between PST and body weight and between PST and BMI were both significant, $r = .65, p < .001$; $r = .74, p < .001$; respectively. As shown in Figure 3, people who were bigger believed themselves to be bigger. However, this correlation was not absolute, indicating some discrepancies between PST and physical body size.

Figure 3. Relationships between each of the three body-based predictors. Bubble size indicates the number of participants per bubble with the smallest bubble signifying 1 participant and the largest bubble signifying 5 participants.

When analyzed independently (i.e. with only distance and 1 predictor included), those who weighed more than others estimated distances as farther, $t(63.4) = 2.65$, $p = .01$, $\beta = .024$, $\beta SE = .009$ (Model 3). Those with a higher BMI than others tended to estimate distances as farther, $t(63.2) = 1.79$, $p = .08$, $\beta = .134$, $\beta SE = .076$ (Model 4). However, PST did not influence estimated distance, $t(63.1) = 0.45$, $p = .66$, $\beta = .126$, $\beta SE = .282$ (Model 5). This suggests that physical body size, but not beliefs, influences perceived distance.

There are two, more refined ways to analyze these data. We could do model fitting and select the best overall model. As shown in Table 2, the best model is Model 9, which includes body weight, PST, distance, and the interaction between body weight and distance. The finding that Model 9 has a better fit (lower AICC and greater weight) than Model 8, which includes all the same factors except PST, is one piece of evidence suggesting that both physical body size and beliefs about body size are important for perceived distance. However, when we look at the outcomes of Model 9, the coefficient for PST was only marginally significant, $t(62.8) = -1.71$, $p = .09$, $\beta = -.603$, $\beta \text{ SE} = .351$. Furthermore, the coefficient was negative: those who believed their bodies to be smaller tended to estimate distances to be farther, not closer, as would be expected if beliefs about body size were the critical driving factor of these action-specific effects. Including PST improved the fit of the model even though PST did not have a highly statistically significant effect. Body weight significantly influenced estimated distance, $t(64.7) = 2.75$, $p = .008$, $\beta = .033$, $\beta \text{ SE} = .012$. Participants who weighed more than others estimated distances as farther. This was increasingly true as distance increased, as indicated by a significant interaction between body weight and distance, $t(66) = 2.78$, $p = .008$, $\beta = .003$, $\beta \text{ SE} = .001$. As shown in Figure 4, body weight had a larger effect on perceived distance at the farther distances. This is evidence that physical characteristics of the body can be influential for distance perception.

Table 2: Model statistics from best to worst.

Model	AICC	AICC	Weight	Included Factors			
9	1379.7	0	0.43	W	(P)	<i>D</i>	W*D
8	1380.5	0.8	0.29	W		<i>D</i>	W*D
15	1381.7	2.0	0.16	W	(P)	<i>D</i>	W*D (<i>P*D</i>)
6	1384.7	5.0	0.04	W	(P)	D	
13	1384.8	5.1	0.03	W	(P)	D	<i>P*D</i>
3	1385.5	5.8	0.02	W		D	
10	1387.9	8.2	0.01			<i>D</i>	<i>B</i> B*D
11	1388.3	8.6	0.01		(P)	<i>D</i>	<i>B</i> B*D
4	1389.0	9.3	0.00			D	<i>B</i>
7	1389.4	9.7	0.00		(P)	D	B
14	1389.5	9.8	0.00		(P)	D	<i>P*D</i> B
2	1390.1	10.4	0.00			D	
16	1390.4	10.7	0.00		(P)	<i>D</i>	<i>P*D</i> <i>B</i> B*D
5	1392.0	12.3	0.00		<i>P</i>	D	
12	1392.1	12.4	0.00		<i>P</i>	D	<i>P*D</i>
1	1489.9	110.2	0.00				

Notes: AICC is defined in the text and is a measure of model fit with lower values signifying better fit. Delta AICC is the difference in current model's AICC and the AICC for the best model (Model 9). Models with Delta AICC greater than 2 are considered significantly worse models and are separated by the double line. Weight is the relative weight given to the coefficients from each model for model averaging (see text for details and see Table 3 for outcomes; note that this weight should not be confused with body weight). W stands for body weight. P stands for picture selection task. B stands for BMI. D stands for Distance. Bolded factors were significant at the $p \leq .05$ level. Factors in italics were not significant ($p > .10$). Factors in parentheses had negative coefficients.

Figure 4. Verbally estimated distance as a function of body weight and target distance. Each point represents data from one or more participants, and there are 4 points for each participant (1 for each target distance). Lines represent linear regressions from Model 9 with PST set to the mean PST of 6.62. Thicker lines correspond to farther target distances. The graph shows the increased relationship between estimated distance and body weight as target distance increases.

A second way to analyze the data is to use model-averaged estimates for each parameter. To calculate these, we use the weights for each of the 16 models based on the AICC values (see Table 2). By doing this, factors included in models that had better fit will be weighted more heavily than factors included in models that had worse fit. For example, to calculate the model-averaged estimate for PST, we multiplied the estimate of the PST main effect for each model by the weight of that model. These products are then summed over the models for which the PST main effect preserves a common interpretation, in this case models 5, 6, 7, 9, and 11. Model averaging has the important advantage of minimizing the uncertainty and bias associated with attempting to select the “best” model among a set of candidates.

The outcomes of these model-averaged estimates are shown in Table 3. Significance can be determined by examining whether the 95% CI overlaps with 0. Body weight was a significant predictor with a predicted estimate of 0.034. This value indicates that for every additional 100 lbs of body weight, participants estimated targets to be 3.4 m further. PST was not significant, suggesting that ultimately, physical body size, but not beliefs about body size, is critical for distance perception. We also note that BMI was not significant.

Table 3: Model averaged estimates and 95% confidence intervals.

Model Term	Estimate	Lower Limit	Upper Limit
Fixed Effects			
W	0.034	0.010	0.059
BMI	0.202	-0.017	0.421
PST	-0.600	-1.294	0.093
D	0.754	0.660	0.848
W*D	0.008	-0.009	0.025
BMI*D	0.015	-0.003	0.033
PST*D	-0.005	-0.094	0.085
Random Effects			
Intercept	8.058	4.381	11.736
Slope	0.106	0.059	0.152
Error	3.901	3.034	4.769

A model averaged estimate for distance was 0.754 with a 95% CI of [0.660, 0.848]. That this estimate is less than 1 is consistent with many previous findings using verbal estimates showing egocentric distance compression. That is, when verbally estimating egocentric distance (the distance from the observer to an object), perceived distance tends to be foreshortened (Gilinsky, 1951).

Results for the random components support the use of the random coefficients model as both model averaged confidence intervals for the variances of the intercepts and the slopes do not contain 0.

After having obtained these results, we ran an additional analysis to examine potential effects of sex. As stated before, previous research has found sex differences in estimated hill slant but not in estimated distance. We ran a repeated-measures ANOVA with distance as a within-subjects factor, sex

as a between-subjects factor, and weight as a covariate. We included all interactions. Sex did not significantly influence distance estimates, $F(1) = 0.41$, $p > .52$, $\eta^2_p = .01$ (estimated marginal means for females = 13.05m, $SE = 0.95$; for males = 14.24m, $SE = 0.82$). Sex did not significantly interact with distance, weight, or distance x weight (all $F_s < 1$, all $p_s > .46$, all $\eta^2_p < .013$). As has already been shown, weight significantly influenced distance estimates, $F(1, 62) = 6.63$, $p = .012$, $\eta^2_p = .10$, and the interaction between weight and target distance was significant, $F(3, 186) = 4.81$, $p = .003$, $\eta^2_p = .07$. These results confirm the decision to exclude sex from the models, and corroborate the outcome that weight significantly influences estimated distance.

Discussion

In the current study, we took advantage of naturally-occurring variations in body size and beliefs about body size to examine the relative contributions of each to perceived distance. Participants across a wide range of body weight made verbal distance estimates and performed a picture selection task that assessed their beliefs about body size. We found that physical body size, specifically body weight, influenced estimated distance but beliefs about body size did not. We address each of these findings in turn.

A person's body weight influenced perceived distance: Those who weighed more than others perceived distances to be farther. This is the first demonstration that body weight influences perceived distance. The finding is consistent with the action-specific account of perception, which claims that perception expresses the relationship between the perceiver and the environment (Witt, 2011a). Body weight was a candidate factor to influence perceived distance because distance is perceived in terms of the energetic cost required to traverse a specified extent (Proffitt, 2006). Indeed, other research has shown that body weight influences perceived slant (Eves et al., 2014). Here, we found that perceived

distance is specified by the relationship between the distal extent and the energetic costs associated with transporting one's own body weight.

Given the strong correlation between body weight and BMI, it was surprising that body weight influenced estimated distance but BMI did not. Body weight corresponds to the amount of energetic work that must be done (i.e. the amount of mass that must be transported), whereas BMI corresponds to, in part, the way this weight is distributed. To the extent that BMI captures one's physiological potential to walk to targets, we would have expected BMI to have an impact on estimated distance. One issue is that BMI is limited in the extent to which it represents a person's physiological capability to perform an energy-consuming action such as walking. For example, people who are big and muscular (such as a rugby player) will have high BMI even though they also have high physiological potential to act. BMI on its own cannot dissociate between useful weight (i.e. muscle) and less useful weight (i.e. fat). Perhaps a better metric would be a combination of percent body fat and a fitness-related measure such as VO_2 Max. Previous research demonstrated that fitness (as measured by VO_2 Max) influences perceived hill slant (Bhalla & Proffitt, 1999), but no work to date has examined percent body fat.

Alternatively, mass, rather than body composition, may be the critical factor, as our data suggest. Perception might be influenced by the overall energetic work regardless of the muscle available to help achieve said goal. Such a result would be consistent with the finding that elephants, which are both big and strong, will walk long distances to avoid walking up hills (Wall, Douglas-Hamilton, & Vollrath, 2006). Moving large mass is very energetically costly, so the findings indicate that elephants will avoid actions that are particularly costly in terms of energetics. Similarly, humans may perceive distance in terms of the work needed to move one's body, regardless of muscle potential. This speculation goes well beyond our data at this point because BMI, while related to muscle potential, cannot differentiate various kinds of mass (e.g. fat versus muscle). In addition, we believe it is likely that both mass and muscle potential factor into perception, and a design that is better able to determine the

unique contribution of each factor is needed. Such research would require specifically recruiting participants with a wide range of weight and fitness capabilities such that the two factors were not highly correlated. For example, one could compare perception of distance for rugby players (fit and big) to perception of people who are big but less fit.

The goal of the current research was instead designed to differentiate between physical characteristics of the body and beliefs about the body. Whereas physical body weight influenced distance estimates, beliefs about body weight did not significantly influence distance estimates. These results suggest that distance perception is not influenced by a person's belief about his or her body size. Had beliefs about body weight influenced perceived distance, this would have been evidence against the claim that perception is cognitively impenetrable (cf. Fodor, 1983). Cognitive impenetrability is the idea that knowledge, beliefs, and expectations do not influence a particular process, in this case, perception. An example of the cognitive impenetrability of perception is apparent with visual illusions: once the perceiver knows the stimulus is an illusion, the illusion persists to the same extent as before knowledge of the illusion was acquired. Had beliefs about a person's own body weight influenced perceived distance, this would have been evidence that beliefs penetrate perceptual processes, thus indicating that distance perception is cognitively penetrable.

Furthermore, a significant effect of beliefs would have renewed the "New Look" approach to perception (Bruner, 1992). According to this approach, perceivers see objects in terms of their own needs, motivation, and values. For example, coins that were more valuable appeared bigger than coins that were worth less, and poorer children perceived coins to be bigger than rich children (Bruner & Goodman, 1947). Although the New Look approach was eventually rejected due to issues with methodology (Carter & Schooler, 1949), recent research has reinvigorated the approach by showing effects of desire and fear in perception (Balcetis & Dunning, 2010; Cole, Balcetis, & Dunning, 2013; Schnall, Harber, Stefanucci, & Proffitt, 2008; Stefanucci & Proffitt, 2009; Stefanucci, Proffitt, Clore, &

Parekh, 2008). The obtained result that beliefs do not influence perception separates current action-specific findings from previous New Look claims. The former is about physical characteristics and abilities, not beliefs.

The finding that beliefs about body size do not influence perception also has implications for the debate about whether action-specific effects reflect changes in perception or are instead due to response bias (Durgin et al., 2009; Firestone, 2013; Philbeck & Witt, in press; Proffitt, 2009; Witt, 2011a, 2011b, in press; Witt & Sugovic, 2013; Woods, Philbeck, & Danoff, 2009). According to the response-bias account, perception is similar across individuals, and apparent differences are due to adjustments that participants make to their responses in order to conform to experimenter expectations. The current results provide evidence against a response bias account because any adjustments to perceptual responses would have been driven by participants' conscious beliefs about body size. If participants had been altering their responses based on their assumptions of how they were supposed to respond, it would have been their conscious beliefs about body size that would have driven their altered responses. The current results contribute to this on-going controversy by providing evidence against the response bias account.

The finding that physical body size influences perception introduces a new non-optical factor in distance perception. This could be interpreted as a top-down effect on perception, but its origin must be processes other than those related to beliefs. Instead, we propose that information about physical body size is based on motor-related processes that contribute to perception (Kirsch et al., 2012; Kirsch & Kunde, 2013a, 2013b; Witt & Proffitt, 2008; Witt, South, & Sugovic, 2014; Witt, Sugovic, & Taylor, 2012). A growing literature supports the interconnection between motor-related processes and perceptual processes. Evidence from neurophysiology (Rizzolatti, Fadiga, Gallese, & Fogassi, 1996), neuroimaging (Buccino et al., 2001; Calvo-Merino, Glaser, Grezes, Passingham, & Haggard, 2005), and behavioral research (Blakemore, Wolpert, & Frith, 2000; Grosjean, Shiffrar, & Knoblich, 2007; Hommel, Musseler,

Aschersleben, & Prinz, 2001; Jacobs & Shiffrar, 2005; Knoblich & Flach, 2001; Musseler & Hommel, 1997a, 1997b; Shiffrar & Freyd, 1990; van der Wel, Sebanz, & Knoblich, 2013) provide support for a mutual link between perceptual and motor systems. The current experiment extends this account by demonstrating another example of how a person's action-related abilities influence perception.

In summary, we found that people who weighed more than others estimated distances to be farther, and perception was largely independent of the perceiver's beliefs about body size. These findings provide additional support for existing research demonstrating that a person's ability, energetic potential, or ease to walk an extent influences perceived distances (Proffitt, 2006; Witt, 2011a). Furthermore, determining that the source of information about action relates to physical characteristics rather than beliefs has implications for the underlying mechanisms. The action-related processes that feed into visual processing areas must be areas that code for physical body size and not conscious beliefs about body size. As research starts to examine the neural mechanisms underlying action-specific effects, the dissociation between physical body size and beliefs about body size could provide one tool to determine the relevant action-related processes.

There are also important health-related implications considering that obesity has been an ongoing concern in the U.S. as the prevalence rate has increased significantly over the past 30-40 years. The most common forms of treatment for obesity are diet, exercise and behavior modification, yet about one-third of U.S. adults continue to struggle with their weight. One common assumption is that people who struggle with obesity make poor behavioral and lifestyle choices. For example, obese individuals may be more likely to choose to drive than walk in conditions under which a person of a normal weight may choose to walk instead. However, if we consider that people who weigh more than others perceive the world differently, they may in fact be making reasonable behavioral decisions given the way they perceive the environment. Perceptual exaggerations of the environment have been shown to impact decisions on how to act. For example, softball players who see the ball as bigger are more

likely to swing compared with players who see the ball as smaller (Gray, 2013). More relevant to issues related to obesity, people who perceive staircases to be steeper are more likely to choose to take the escalator rather than walk up the stairs (Eves et al., 2014). Consequently, for people who weigh more than others, their perceptions may contribute to unhealthy lifestyle by guiding them towards less active alternatives (elevators instead of stairs, driving instead of walking). Understanding how people who are obese perceive the world may ultimately lead to better treatment choices that take into account perception in order to promote healthier behavioral and lifestyle choices.

Authors Note

Mila Sugovic, Department of Psychological Sciences, Purdue University. Philip Turk, Department of Statistics, Colorado State University. Jessica K. Witt, Department of Psychology, Colorado State University.

This work was supported by grants from the National Science Foundation (BCS-0957051, BCS-1314162, and BCS-1348916) to JKW.

Please address correspondence to Jessica Witt, Colorado State University, 241 Behavioral Sciences Building, Fort Collins, CO 80523 USA. Email: Jessica.Witt@ColoState.edu.

References

- Balcetis, E., & Dunning, D. (2010). Wishful seeing: more desired objects are seen as closer. *Psychol Sci*, 21(1), 147-152. doi: 10.1177/0956797609356283
- Bhalla, M., & Proffitt, D. R. (1999). Visual-motor recalibration in geographical slant perception. *Journal of Experimental Psychology: Human Perception and Performance*, 25(4), 1076-1096.
- Blakemore, S. J., Wolpert, D., & Frith, C. D. (2000). Why can't you tickle yourself? *NeuroReport*, 11(11), R11-R16.
- Bloesch, E. K., Davoli, C. C., Roth, N., Brockmole, J. R., & Abrams, R. A. (2012). Watch this! Observed tool use affects perceived distance. *Psychon Bull Rev*, 19(2), 177-183.
- Bruner, J. S. (1992). Another look at New Look 1. *American Psychologist*, 47(6), 780-783.
- Bruner, J. S., & Goodman, C. C. (1947). Value and need as organizing factors in perception. *Journal of Abnormal & Social Psychology*, 42, 33-44.
- Buccino, G., Binkofski, F., Fink, G. R., Fadiga, L., Fogassi, L., Gallese, V., . . . Freund, H. J. (2001). Action observation activates premotor and parietal areas in a somatotopic manner: an fMRI study. *European Journal of Neuroscience*, 13, 400-404.
- Burnham, K. P., & Anderson, D. R. (2002). *Model selection and multimodal inference* (Second Edition ed.). New York, NY: Springer.
- Calvo-Merino, B., Glaser, D. E., Grezes, J., Passingham, R. E., & Haggard, P. (2005). Action observation and acquired motor skills: An fMRI study with expert dancers. *Cerebral Cortex*, 15, 1243-1249.
- Carter, L. F., & Schooler, K. (1949). Value, need, and other factors in perception. *Psychol Rev*, 56(4), 200-207.
- Cavanagh, P. (1999). Top-down processes in vision. In R. A. Wilson & F. C. Keil (Eds.), *The MIT Encyclopedia of the Cognitive Sciences* (pp. 844-845). Cambridge, MA: The MIT Press.

- Cole, S., Balcetis, E., & Dunning, D. (2013). Affective signals of threat produce perceived proximity. *Psychol Sci*, 24, 34-40.
- Durgin, F. H., Baird, J. A., Greenburg, M., Russell, R., Shaughnessy, K., & Waymouth, S. (2009). Who is being deceived? The experimental demands of wearing a backpack. *Psychon Bull Rev*, 16(5), 964-969. doi: 10.3758/PBR.16.5.964
- Eves, F. F., Thorpe, S. K. S., Lewis, A., & Taylor-Covill, G. A. H. (2014). Does perceived steepness deter stair climbing when an alternative is available? *Psychon Bull Rev*, 21(3), 637-644.
- Firestone, C. (2013). How "paternalistic" is spatial perception? Why wearing a heavy backpack doesn't - and *couldn't* - make hills appear steeper. *Perspectives on Psychological Science*, 8(4), 455-473.
- Firestone, C., & Scholl, B. J. (2014). "Top-down" effects where none should be found: The El Greco fallacy in perception research. *Psychol Sci*, 25(1), 38-46.
- Firestone, C., & Scholl, B. J. (in press). Cognition does not affect perception: Evaluating the evidence for 'top-down' effects. *Behavioral and Brain Sciences*.
- Fodor, J. A. (1983). *Modularity of Mind: An Essay on Faculty Psychology*. Cambridge, MA: MIT Press.
- Gilinsky, A. S. (1951). Perceived size and distance in visual space. *Psychol Rev*, 58, 460-482.
- Gray, R. (2013). Being selective at the plate: Processing dependence between perceptual variables relates to hitting goals and performance. *Journal of Experimental Psychology: Human Perception and Performance*, 39(4), 1124-1142.
- Grosjean, M., Shiffrar, M., & Knoblich, G. (2007). Fitts's law holds for action perception. *Psychol Sci*, 18(2), 95-99. doi: 10.1111/j.1467-9280.2007.01854.x
- Hommel, B., Musseler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences*, 24, 849-937.

- Jacobs, A., & Shiffrar, M. (2005). Walking perception by walking observers. *Journal of Experimental Psychology: Human Perception and Performance*, 31(1), 157-169. doi: 10.1037/0096-1523.31.1.157
- Kenward, M. G., & Roger, J. H. (1997). Small sample inference for fixed effects from restricted maximum likelihood. *Biometrics*, 53(3), 983-997.
- Kirsch, W., Herbort, O., Butz, M. V., & Kunde, W. (2012). Influence of motor planning on distance perception within peripersonal space. *PLoS ONE*, 7, e34880.
- Kirsch, W., & Kunde, W. (2013a). Moving further moves things further away in visual perception: Position-based movement planning affects distance judgments. *Experimental Brain Research*, 226, 431-440.
- Kirsch, W., & Kunde, W. (2013b). Visual near space is scaled to parameters of current action plans. *Journal of Experimental Psychology: Human Perception and Performance*, 39(5), 1313-1325.
- Knoblich, G., & Flach, R. (2001). Predicting the effects of actions: Interactions of perception and action. *Psychol Sci*, 12, 467-472.
- Kuchler, F., & Variyam, J. N. (2003). Mistakes were made: Misperception as a barrier to reducing obesity. *International Journal of Obesity*, 27, 856-851.
- Lee, Y., Lee, S., Carello, C., & Turvey, M. T. (2012). An archer's perceived form scales the "hitableness" of archery targets. *Journal of Experimental Psychology: Human Perception and Performance*, 38(5), 1125-1131.
- Lessard, D. A., Linkenauger, S. A., & Proffitt, D. R. (2009). Look before you leap: Jumping ability affects distance perception. *Perception*, 38, 1863-1866.
- Linkenauger, S. A., Bulthoff, H. H., & Mohler, B. J. (2015). Virtual arm's reach influences perceived distance but only after experience reaching. *Neuropsychologia*, 70, 393-401. doi: 10.1016/j.neuropsychologia.2014.10.034

- Linkenauger, S. A., Leyrer, M., Buelthoff, H. H., & Mohler, B. J. (2013). Welcome to wonderland: The influence of the size and shape of a virtual hand on the perceived size and shape of virtual objects. *PLoS ONE*, 8(7), e68594.
- Linkenauger, S. A., Witt, J. K., & Proffitt, D. R. (2011). Taking a hands-on approach: apparent grasping ability scales the perception of object size. *Journal of Experimental Psychology: Human Perception and Performance*, 37(5), 1432-1441. doi: 10.1037/a0024248
- Mark, L. S. (1987). Eyeheight-scaled information about affordances: A study of sitting and stair climbing. *Journal of Experimental Psychology: Human Perception and Performance*, 13(3), 361-370.
- Musseler, J., & Hommel, B. (1997a). Blindness to response-compatible stimuli. *Journal of Experimental Psychology: Human Perception and Performance*, 23(3), 861-872.
- Musseler, J., & Hommel, B. (1997b). Detecting and identifying response-compatible stimuli. *Psychon Bull Rev*, 4(1), 125-129.
- Osiurak, F., Morgado, N., & Palluel-Germain, R. (2012). Tool use and perceived distance: When unreachable becomes spontaneously reachable. *Experimental Brain Research*, 218(2), 331-339.
- Philbeck, J. W., & Witt, J. K. (in press). Action-specific influences on perception and post-perceptual processes: Present controversies and future directions. *Psychol Bull*.
- Piryankova, I., Wong, H. Y., Linkenauger, S. A., Stinson, C., Longo, M. R., Buelthoff, H. H., & Mohler, B. J. (2014). Owning an overweight or underweight body: Distinguishing the physical, experienced, and virtual body. *PLoS ONE*, 8(9), e103428.
- Proffitt, D. R. (2006). Embodied perception and the economy of action. *Perspectives on Psychological Science*, 1(2), 110-122.
- Proffitt, D. R. (2009). Affordances matter in geographical slant perception. *Psychon Bull Rev*, 16(5), 970-972. doi: Doi 10.3758/Pbr.16.5.970

- Proffitt, D. R., Bhalla, M., Gossweiler, R., & Midgett, J. (1995). Perceiving geographical slant. *Psychon Bull Rev*, 2(4), 409-428.
- Proffitt, D. R., & Linkenauger, S. A. (2013). Perception viewed as a phenotypic expression. In W. Prinz, M. Beisert & A. Herwig (Eds.), *Action Science: Foundations of an Emerging Discipline* (pp. 171-198). Cambridge, MA: MIT Press.
- Proffitt, D. R., Stefanucci, J., Banton, T., & Epstein, W. (2003). The role of effort in perceiving distance. *Psychol Sci*, 14(2), 106-112.
- Pylyshyn, Z. W. (1999). Is vision continuous with cognition? The case for cognitive impenetrability of visual perception. *Behavioral and Brain Sciences*, 22, 341-423.
- Pylyshyn, Z. W. (2003). *Seeing and Visualizing: It's not what you Think*. Cambridge, MA: MIT Press.
- Rizzolatti, G., Fadiga, L., Gallese, V., & Fogassi, L. (1996). Premotor cortex and the recognition of motor actions. *Cognitive Brain Research*, 3, 131-141.
- Schnall, S., Harber, K. D., Stefanucci, J. K., & Proffitt, D. R. (2008). Social Support and the Perception of Geographical Slant. *Journal of Experimental Social Psychology*, 44(5), 1246-1255. doi: 10.1016/j.jesp.2008.04.011
- Shiffrar, M., & Freyd, J. (1990). Apparent motion of the human body. *Psychol Sci*, 1, 257-264.
- Smith, E., Hay, P., Campbell, L., & Trollor, J. N. (2011). A review of the association between obesity and cognitive function across the lifespan: implications for novel approaches to prevention and treatment. *Obesity Reviews*, 12, 740-755.
- Stefanucci, J. K., & Guess, M. N. (2009). Big people, little world: The body influences size perception. *Perception*, 38, 1782-1795.
- Stefanucci, J. K., & Proffitt, D. R. (2009). The roles of altitude and fear in the perception of height. *Journal of Experimental Psychology: Human Perception and Performance*, 35(2), 424-438. doi: 10.1037/a0013894

- Stefanucci, J. K., Proffitt, D. R., Banton, T., & Epstein, W. (2005). Distances appear different on hills. *Perception & Psychophysics*, 67(6), 1052-1060.
- Stefanucci, J. K., Proffitt, D. R., Clore, G., & Parekh, N. (2008). Skating down a steeper slope: Fear influences the perception of geographical slant. *Perception*, 37, 321-323.
- Taylor-Covill, G. A. H., & Eves, F. F. (2013). Slant perception for stairs and screens: Effects of sex and fatigue in a laboratory environment. *Perception*, 42(4), 459-469.
- Taylor-Covill, G. A. H., & Eves, F. F. (2014). When what we need influences what we see: Choice of energetic replenishment is linked with perceived steepness. *Journal of Experimental Psychology: Human Perception and Performance*, 40(3), 915-919.
- Taylor, J. E. T., Witt, J. K., & Sugovic, M. (2011). When walls are no longer barriers: Perception of wall height in parkour. *Perception*, 40(6), 757-760. doi: Doi 10.1068/P6855
- Thompson, M. A., & Gray, J. (1995). Development and validation of a new body-image assessment scale. *Journal of Personality Assessment*, 64(2), 258-269.
- Truesdale, K. P., & Stevens, J. (2008). Do the obese know they are obese? *North Carolina Medical Journal*, 69, 188-194.
- Van der Hoort, B., & Ehrsson, H. H. (2014). Body ownership affects visual perception of object size by rescaling the visual representation of external space. *Attention, Perception, & Psychophysics*, 76(5), 1414-1428.
- van der Hoort, B., Guterstam, A., & Ehrsson, H. H. (2011). Being Barbie: The size of one's own body determines the perceived size of the world. *PLoS ONE*, 6(5), e20195.
- van der Wel, R. P. R. D., Sebanz, N., & Knoblich, G. (2013). Action perception from a common coding perspective. In K. L. Johnson & M. Shiffrar (Eds.), *People Watching: Social, Perceptual, and Neurophysiological Studies of Body Perception* (pp. 101-120). New York, NY: Oxford University Press.

- Wall, J., Douglas-Hamilton, I., & Vollrath, F. (2006). Elephants avoid costly mountaineering. *Current Biology*, 16(14), R527-R529.
- Warren, W. H. (1984). Perceiving affordances: The visual guidance of stair climbing. *Journal of Experimental Psychology: Human Perception and Performance*, 10, 683-703.
- White, E. J., Shockley, K., & Riley, M. A. (2013). Multimodally specified energy expenditure and action-based distance judgments. *Psychon Bull Rev*, 20(6), 1371-1377.
- Witt, J. K. (2011a). Action's Effect on Perception. *Current Directions in Psychological Science*, 20(3), 201-206. doi: 10.1177/0963721411408770
- Witt, J. K. (2011b). Tool use influences perceived shape and perceived parallelism, which serve as indirect measures of perceived distance. *Journal of Experimental Psychology: Human Perception and Performance*, 37(4), 1148-1156. doi: 10.1037/a0021933
- Witt, J. K. (in press). Awareness is not a necessary characteristic of a perceptual effect: Commentary on Firestone (2013). *Perspectives on Psychological Science*.
- Witt, J. K., Linkenauger, S. A., Bakdash, J. Z., & Proffitt, D. R. (2008). Putting to a bigger hole: Golf performance relates to perceived size. *Psychon Bull Rev*, 15(3), 581-585. doi: Doi 10.3758/15.3.581
- Witt, J. K., & Proffitt, D. R. (2005). See the ball, hit the ball - Apparent ball size is correlated with batting average. *Psychol Sci*, 16(12), 937-938. doi: DOI 10.1111/j.1467-9280.2005.01640.x
- Witt, J. K., & Proffitt, D. R. (2008). Action-specific influences on distance perception: A role for motor simulation. *Journal of Experimental Psychology: Human Perception and Performance*, 34(6), 1479-1492. doi: 10.1037/a0010781
- Witt, J. K., Proffitt, D. R., & Epstein, W. (2004). Perceiving distance: A role of effort and intent. *Perception*, 33(5), 577-590. doi: Doi 10.1068/P5090

- Witt, J. K., Proffitt, D. R., & Epstein, W. (2005). Tool use affects perceived distance, but only when you intend to use it. *Journal of Experimental Psychology: Human Perception and Performance*, 31(5), 880-888. doi: 10.1037/0096-1523.31.5.880
- Witt, J. K., South, S. C., & Sugovic, M. (2014). A perceiver's own abilities influence perception, even when observing others. *Psychon Bull Rev*, 21(2), 384-389.
- Witt, J. K., & Sugovic, M. (2010). Performance and ease influence perceived speed. *Perception*, 39(10), 1341-1353. doi: Doi 10.1068/P6699
- Witt, J. K., & Sugovic, M. (2012). Does ease to block a ball affect perceived ball speed? Examination of alternative hypotheses. *Journal of Experimental Psychology: Human Perception and Performance*, 38(5), 1202-1214. doi: 10.1037/a0026512
- Witt, J. K., & Sugovic, M. (2013). Response bias cannot explain action-specific effects: Evidence from compliant and non-compliant participants. *Perception*, 42, 138-152.
- Witt, J. K., Sugovic, M., & Taylor, J. E. T. (2012). Action-specific effects in a social context: others' abilities influence perceived speed. *Journal of Experimental Psychology: Human Perception and Performance*, 38(3), 715-725. doi: 10.1037/a0026261
- Woods, A. J., Philbeck, J. W., & Danoff, J. V. (2009). The various perceptions of distance: an alternative view of how effort affects distance judgments. *Journal of Experimental Psychology: Human Perception and Performance*, 35(4), 1104-1117. doi: 10.1037/a0013622

Figure Captions

Figure 1. Photograph of the test site. In this example the cone (circled in red) was placed 25m from where the participant stood (marked with duct tape at the bottom of picture).

Figure 2. Female sample images used in the picture selection task (PST). Participants were asked “which of the following drawings most accurately depicts your current body size?” A similar sample of male figures was also used.

Figure 3. Relationships between each of the three body-based predictors. Bubble size indicates the number of participants per bubble with the smallest bubble signifying 1 participant and the largest bubble signifying 5 participants.

Figure 4. Estimated distance as a function of body weight and target distance. Each point represents data from one or more participants, and there are 4 points for each participant (1 for each target distance). The graph shows the increased relationship between estimated distance and body weight as target distance increases. Lines represent linear regressions from Model 9 with thicker lines corresponding to farther target distances.