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Tool use produces a size illusion revealing action-specific perceptual mechanisms

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ABSTRACT

In four experiments, participants estimated the sizes of target objects that were either out of reach, or that could be reached by a tool (a stylus or laser pointer). Objects reachable with the aid of a tool were perceived to be smaller than identical objects without a tool. Participants' responses to questioning rule out demand characteristics as an explanation. This new size illusion may reflect a direct impact of tool use on perceived size, or it may stem from the effects of tool use on perceived distance. Both possibilities support action specific accounts of perception.

Our perceptual systems serve the primary purpose of providing information about the environment in order to allow us to effectively navigate through it and interact with the objects that are in it. There are numerous examples that show that perception is affected by the perceiver's physical abilities to act on the environment. For example, hills look steeper when wearing a heavy backpack (Proffitt, Stefanucci, Banton, & Epstein, 2003), softball players that are hitting better perceive the ball to be bigger (Witt & Proffitt, 2005), and apertures to be walked through look smaller to people who are holding a rod that increases their overall width (Stefanucci & Geuss, 2009; for reviews see Brockmole, Davoli, Abrams, & Witt, 2013; Witt, 2011a). According to the action-specific account of perception (Proffitt, 2006; Witt, 2011a) this scaling of the environment serves the purpose of taking into account the costs (e.g., metabolic demands) or dangers (e.g., risk of injury) of a contemplated action. Indeed, participants who are glucose-depleted judge distant targets to be further away than participants who are not (Schnall, Zadra, & Proffitt, 2010; Taylor-Covill & Eves, 2016; Zadra & Proffitt, 2016; Zadra, Schnall, Weltman, & Proffitt, 2010).

One interesting finding that supports the action-specific perception account is a *tool use effect*. For example, Witt, Proffitt, and Epstein (2005) had participants estimate the distance to a target that was beyond reach. Participants either used a tool (a conductor's baton) to reach out to the target or they pointed to the target by hand. The target appeared to be closer when participants wielded the tool. A similar tool use effect has been shown when the tool used to "reach" the target is a laser pointer (and only the projected laser can reach the target; Davoli, Brockmole, & Witt, 2012), and when a person merely observes an actor use a tool but does not have a tool of their own (Bloesch, Davoli, Roth, Brockmole, & Abrams, 2012; see also Abrams & Weidler, 2015). These results show that visual processing can change when one's action capabilities are enhanced by a tool. Presumably, targets that are out of reach would appear further away to reflect the increased costs of interacting with such targets.

Nevertheless, these interpretations have not been without their critics. In particular, it has been suggested that action capabilities may sometimes influence only an individual's *responses* in an experiment, but not their perception (Durgin et al., 2009; Woods, Philbeck, & Danoff, 2009). In support of this, Durgin et al. (2009) showed that people reported an inclined ramp to be steeper when wearing a heavy backpack, but only when they believed that the backpack was a critical manipulation of the experiment. Based on this, Durgin et al. (2009) argued that demand characteristics of an experiment can bias participants' responses to mimic an effect of action capabilities on perception. Firestone (2013) has also argued that action capabilities influence response bias, but not perception per se.

In order to minimize the influence of demand characteristics on assessment of the effects of tool use, some researchers have asked participants to make judgments that are only indirectly connected to the perceptual dimensions that are thought to be affected. For example, Witt (2011b) used a shape-matching task instead of the distance estimation tasks that often had been used in earlier studies. In her study, participants viewed three circles in a triangular shape projected onto a table as shown in Fig. 1. Participants were asked to adjust reference circles presented on a separate display to reproduce the shape of the triangle on the table. When a tool was used to touch the distant circle at the top of the triangle on the table, the response triangle had a

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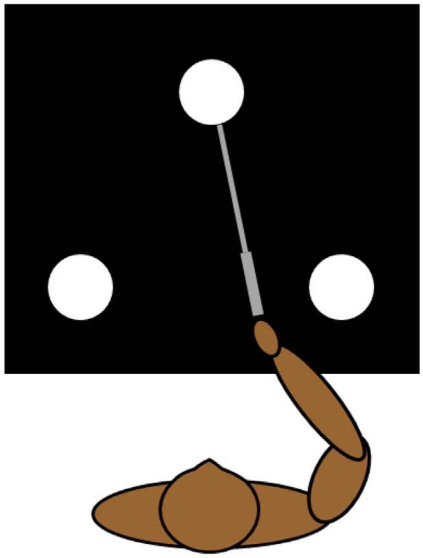

Fig. 1. Setup used by Witt (2011b) to study the tool use effect.

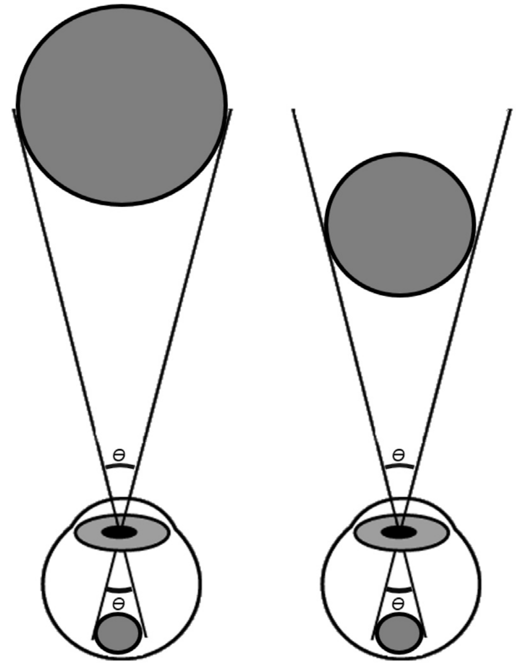

Fig. 2. Effect of perceived distance on perceived size, based on size-distance invariance. The proximal size of the target (θ) is identical in both cases, so the closer object must also be smaller.

compressed shape compared to when the tool was not used, suggesting that the top of the triangle appeared closer with the tool. Witt argued that this finding is unlikely to reflect demand characteristics because participants would be unlikely to predict that tool use should change the perceived shape of the triangle. Instead, the findings are consistent with a truly perceptual effect of tool use.

Nevertheless, it is not inconceivable that a participant might infer the hypothesized change in shape. For example, if one thought that a tool would cause a touched object to appear closer, then it is not too difficult to create a shape that fulfills that expectation in much the same way that some have argued that distance judgments fulfill participant expectations (e.g., Durgin et al., 2009). Thus, in the present study, to learn more about the perceptual consequences of tool use we employed a judgment that not only is an indirect consequence of a distance change as are the shape judgments used by Witt (2011b), but which also typically leads to an inverted effect when people reason about it. In particular, we asked people to make judgments about the *sizes* of objects that were either reached or not reached by a tool. Perceived size depends upon perceived distance due to size-distance invariance (Epstein, 1963). As illustrated in Fig. 2, given two objects with equal retinal sizes, the one that is closer must also be smaller. So if use of a tool to reach an object that is beyond one's unaided reach causes the object to appear closer, the object should also appear smaller.

Size-distance invariance provides a partial explanation for many common size illusions, such as the moon illusion or the Ponzo (railroad tracks) illusion. In these illusions, one of two equal-sized objects is perceived to be larger than the other due to the (incorrect) perception that the object is further from the viewer. Importantly, when asked to reason about the size-distance relationship, many observers make the opposite prediction. We present support for that in Experiments 2b and 3, below. Anecdotally, many undergraduate students exhibit confusion about the reasoning underlying one explanation of the moon illusion: "The moon looks bigger when near the horizon because it appears *further* away there? Shouldn't it look smaller if it was further away?". Given this sort of reasoning, a change in perceived size in the hypothesized direction would be unlikely to stem from demand characteristics. Size judgments have been used as an indirect measure of perceived distance (specifically height) in several studies and the patterns of results correspond closely to results obtained using explicit estimates of distance (Stefanucci & Proffitt, 2009; Stefanucci & Storbeck, 2009).

In the present study participants viewed target circles of various sizes with or without a reach-extending tool (a stylus in Experiments 1, 2a and 2b, and a laser pointer in Experiment 3). The target circle was presented at a fixed location during the experiment. In a *tool* condition, participants had to briefly tap (with a stylus) or illuminate (with a laser pointer) the target circle at the beginning of each trial. In a *no tool* condition, they were asked to point toward the target circle using their hand or a non-functional laser pointer. Following the pointing, participants were asked to estimate the size of the target circle by matching the size of an adjustable reference circle.

1. Experiment 1

1.1. Method

1.1.1. Participants

Twenty-four participants (14 females) from Washington University in St. Louis participated to fulfill a partial requirement for course credit. All of them had normal or corrected-to-normal vision.

1.1.2. Apparatus

Fig. 3 shows the experimental setup. All stimuli were projected onto a screen (158 cm × 187 cm) on the floor of a dimly lit room. Stimuli were presented, and responses recorded using Psychopy software (Peirce, 2007). Participants sat on a chair positioned on one side of the short edge of the screen. A wireless keyboard was placed on a table on the side of the participant's non-dominant hand for recording responses.

1.1.3. Stimuli and procedure

Each trial began with the appearance of a yellow circle (the *target circle*) on the screen (see Fig. 3). The circle was aligned to the participant's midline, and was 99 cm away–beyond the reach of the hand. The target circle was shown in one of four sizes (31.0 mm, 38.7 mm, 46.4 mm, or 54.2 mm in diameter). In the *tool* condition, participants were asked to briefly tap the target circle with a stylus (65 cm long) held in their dominant hand. In the *no-tool* condition, they were asked to simply point at the target circle with their index finger. In both conditions, participants had to reach their arms toward the target circle, thus the only difference between two conditions was whether they