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BRIEF REPORT

My shadow, myself: Cast-body shadows are embodied

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Abstract Objects that serve as extensions of the body can produce a sensation of embodiment, feeling as if they are a part of us. We investigated the characteristics that drive an object's embodiment, examining whether cast-body shadows, a purely visual stimulus, are embodied. Tools are represented as an extension of the body when they enable observers to interact with distant targets, perceptually distorting space. We examined whether perceptual distortion would also result from exposure to cast-body shadows in two separate distance estimation perceptual matching tasks. If observers represent cast-body shadows as extensions of their bodies, then when these shadows extend toward a target, it should appear closer than when no shadow is present (Experiment 1). This effect should not occur when a non-cast-body shadow is cast toward a target (Experiment 2). We found perceptual distortions in both cast-body shadow and tool-use conditions, but not in our non-cast-body shadow condition. These results suggest that, although cast-body shadows do not enable interaction with objects or provide direct tactile feedback, observers nonetheless represent their shadows as if they were a part of them.

Keywords Cast-body shadows · Embodiment · Perceptual distortion

> I don't need a friend who changes when I change and who nods when I nod; my shadow does that much better. —Plutarch, c. 100 AD

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Plutarch, whether he was aware of it or not, may have been the first person to realize that the cast-body shadow is unique from other objects in the environment. As long as there is light, our shadows are always with us, extending from and moving with the bodies they resemble. Shadows are linked to the body, but unlike all other parts of the body, they are purely visual, changing with sources of illumination and lacking tactile or proprioceptive sensors. Although cast-body shadows bear a clear relationship to the physical body, it is unclear whether observers represent their shadows as a part of their own bodies. If body shadows are embodied—that is, if observers process properties of their shadows in the same way as properties of their own bodies under similar spatial, motor, and affective circumstances (de Vignemont, 2011)—then a shadow cast beyond the boundaries of the physical body should bias observers to experience themselves as extending further into the environment. A number of objects that are physically distinct from the body, such as allografts (Dubernard et al., 2003; Farnè, Roy, Giraux, Dubernard, & Sirigu, 2002), prostheses (Lotze et al., 1999; Murray, 2004), rubber hands (Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005), and tools (Cardinali, Frassinetti, et al., 2009; Farnè & Làdavas, 2000; Maravita & Iriki, 2004), can become embodied in this sense, stretching the impression of occupying space beyond the physical body's boundaries via incorporation into or extension of the body schema (for differences between incorporation and extension, see Botvinick, 2004; De Preester & Tsakiris, 2009; Legrand & Ruby, 2009; Thompson & Stapleton, 2009). In these cases, embodiment typically results from objects providing both visual and tactile feedback to the observer that potentially enables action (e.g., Murray, 2004; Ramachandran & Rogers-Ramachandran, 1996; Yamamoto, Moizumi, & Kitazawa, 2005). Like tools and other objects that can be embodied, shadows visually extend beyond the body, but unlike these objects, shadows are physically tenuous.

Movement creates visual–motor synchronies between the cast-body shadow and the physical body, but shadows themselves exist only as a two-dimensional projection. While people can act with tools or prostheses, feeling when these objects come into contact with other objects, they cannot experience direct tactile feedback via cast-body shadows. Can objects that never enable action become embodied?

We leverage a well-documented consequence of the embodiment of tools (e.g., Cardinali, Frassinetti, et al., 2009a; de Vignemont; 2011)—altered spatial perception—to determine whether the cast-body shadow is also embodied. When people use tools to reach toward and interact with a distant object, the tool acts as an extension of the body, leading observers to perceive the object as significantly closer to them (Witt & Proffitt, 2008; Witt, Proffitt, & Epstein, 2005). This occurs when using a tool to interact with objects just beyond reach, presumably because tool use expands peripersonal space (Cardinali, Brozzoli, & Farnè, 2009b; Farnè & Làdavas, 2000). Neural evidence supports this notion; bimodal neurons of the macaque monkey that code for somatosensation and vision increase the size of their visual receptive fields to include the area within reach of a tool immediately following its use (Maravita & Iriki, 2004). Behavioral results also support these findings; attention normally observed for space around the hand (Kennet, Spence, & Driver, 2002) shifts to the functional end of a tool after its use (Farnè, Iriki, & Làdavas, 2005). Tools can also alter spatial perception (Davoli, Brockmole, & Witt, 2012) when they are used to interact with targets well beyond the boundaries of peripersonal space (Rizzolatti, Fadiga, Fogassi, & Gallese, 1997), suggesting that the ability to interact with an object at any distance shrinks the perceived distance between object and observer. To determine whether cast-body shadows are also embodied despite their inability to provide tactile feedback or enable action, we investigated whether cast-body shadows are perceived as an extension of the body that perceptually distorts space.

If shadows are represented as if they are a part or extension of the body, the presence of a cast-body shadow extending toward a target should reduce the perceived distance to the target. However, if objects must provide a combination of visual and tactile feedback that enables goal-directed action to become embodied, extending a tool toward a distant target should lead observers to underestimate target distance, whereas casting a body shadow toward the same target should not distort perception.

Experiment 1

To determine whether cast-body shadows are capable of becoming embodied, we implemented a design with three experimental conditions: (1) cast-body shadow present, (2) laser pointer present, and (3) baseline. Participants made distance estimations using a perceptual matching paradigm in which they indicated when an experimenter was the same distance away from them as a previously viewed stationary target.[1] We included a laser pointer condition in our design because previous work has shown that remote tool use can alter spatial perception (Davoli et al., 2012) and we wished to replicate this prior result with our matching paradigm while we examined the role of the cast-body shadow. In our baseline condition, we asked participants to make distance estimations without the presence of a cast-body shadow or laser pointer. We anticipated replicating previous findings, hypothesizing that participants would provide smaller distance estimations in the laser pointer condition than in the baseline condition. If cast-body shadows are embodied, distance estimates in this condition should also be smaller than in the baseline case. Our results indicated that, as compared with baseline, the cast-body shadow and laser pointer conditions resulted in an underestimation of distance, providing the first evidence that the cast-body shadow—a purely visual stimulus—is embodied.

Method

Twelve naïve undergraduate participants were brought into a large gym with strong natural lighting on NDSU's campus and performed our task in three experimental conditions (cast-body shadow present, laser pointer, baseline). Task order was balanced across participants.

In all three conditions, participants stood on a piece of carpet (3 ft 9 in. × 60 ft 6 in.) that extended away from them and turned away while the experimenter placed a target (an athletic cone) on the carpet at one of eight distances (20–55 ft away in 5-ft increments). The experimenter then walked back to the participants and asked them to turn toward the target, stand still, and direct their view down the length of the carpet to look at the target. After observing the target's distance, participants were instructed to turn their head 90° away from the target, observe the experimenter walk away from them without looking back at the target, and tell the experimenter to stop when they thought he was the same distance away from them as the previously viewed target. The experimenter recorded distance estimations with a rolling measuring wheel. Participants viewed the target at each of the eight distances twice for each condition.

In the baseline condition, participants performed this task under natural lighting. To determine whether cast-body shadows perceptually distort space, a 500-W floodlamp in a

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[1] We chose to use a matching paradigm to avoid the heteroscedasticity that commonly accompanies verbal estimates of distance.

20-in. reflective box was placed directly behind and above the participants, casting a body shadow that extended down the length of the carpet toward the target but did not overlap with the target. We included a third condition in which participants used a laser pointer to interact with the target to examine the sensitivity of the perceptual matching paradigm in showing tool-driven alterations in spatial perception. Our laser pointer condition was identical to the baseline condition, except that when participants faced the target, they shined a laser pointer on the target and held this pose while facing the experimenter as he walked away from them.

Afterwards, participants completed a posttest questionnaire designed to assess demand characteristics. We asked participants what they thought the experimenter was investigating, what the purpose of the study was, and what results they expected. Responses on the posttest questionnaire indicated that all participants were unaware of our hypotheses and did not anticipate experiencing changes in perception across conditions.

Results

Figure 1 displays the mean estimated distances across conditions. We analyzed these distances in a repeated measures analysis of variance (ANOVA) with condition (shadow present, laser pointer, baseline) and distance as within-subjects factors. Both condition, $F(2, 22) = 17.71$, $p < .001$, $\eta^2 = .617$, and physical distance, $F(7, 77) = 500.70$, $p < .001$, $\eta^2 = .979$, influenced reported distances, and these factors interacted with each other, $F(14, 154) = 1.87$, $p = .032$, $\eta^2 = .146$. Bonferroni post hoc comparisons revealed that participants' estimates were significantly different across shadow-present and baseline conditions ($M = -2.083$, $SE = 0.432$, CI [−3.302, −0.864], $p = .002$) and laser pointer and baseline conditions ($M = -2.438$, $SE = 0.550$, CI [−3.989, −0.886], $p = .003$), but not the shadow-present and laser pointer conditions ($M = .354$, $SE = .314$, CI [−0.531, 1.239]. These results suggest that both shining a laser pointer at a distant target and casting a body shadow toward a target alter space perception.

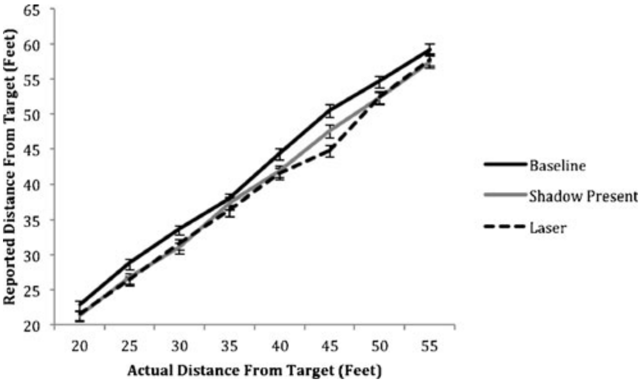

Fig. 1 Mean estimated distance from target for the baseline, shadow-present, and laser pointer conditions. Error bars represent one standard error of the mean

Discussion

The results of Experiment 1 suggest that both the cast-body shadow and laser pointer act as extensions of the physical body that affect space perception. The perceptual distortion we found in the laser pointer condition aligns with previous findings of distortion in verbal estimate experiments (Davoli et al., 2012), validating the perceptual matching paradigm used here. Our results further demonstrate that a visual object that affords no interaction—the body shadow—can perceptually distort space. However, we cannot conclude that the cast-body shadow is unique in its influence on space perception on the basis of the results of Experiment 1. We posit that participants perceived the target as closer to them in the shadow condition because they represented their shadows as a part of themselves that extended toward the target, but this leaves open the possibility that any visual stimulus extending from an observer to a target may likewise influence perception. In Experiment 2, we therefore continued by examining the influence of nonbody shadows on distance perception.

Experiment 2

To investigate how the presence of a visual signal extending toward a target influences distance perception, we implemented a second experiment with three conditions: (1) cast-body shadow present, (2) non-cast-body shadow present, and (3) baseline. Participants performed the same task as in Experiment 1, but instead of using a laser pointer, they made distance estimates in a condition where a large file cabinet was placed directly behind them that cast a blocky shadow down the length of the carpet. If the effect we observed in Experiment 1 was solely due to low-level stimulus differences induced by any shadow, participants should estimate shorter distances in both the cast-body and non-cast-body shadow conditions than in the baseline condition. However, if the cast-body shadow altered perception in Experiment 1 specifically because it was embodied, we would expect distance estimates in the cast-body shadow condition to be shorter than in either the non-cast-body shadow or baseline condition. Our results supported this prediction, providing additional evidence that the cast-body shadow—and only the cast-body shadow—is embodied.

Method

Fourteen naïve undergraduate participants were brought into a hallway of the psychology department at NDSU and performed our task in three experimental conditions: (cast-body shadow, non-cast-body shadow, baseline). The design was identical to that in Experiment 1, with the exception that a smaller space led us to test distances in 4-ft increments (16–44 ft).

In the non-cast-body shadow condition, participants performed the distance estimation task in the presence of a shadow that was not their own. A file cabinet behind participants cast a shadow down the length of the carpet that obscured the participants' body shadow. By comparing performance in this condition against that in the cast-body shadow condition, we are able to determine whether any condition that creates a visual signal extending toward a target alters perception. Afterward, participants completed the posttest questionnaire described previously. These responses suggested that participants were unaware of our hypotheses.

Results

Figure 2 displays the mean estimated distances across conditions. We analyzed these distances in a repeated measures ANOVA with condition (cast-body shadow present, non-cast-body shadow present, baseline) and distance as within-subjects factors. Both condition, $F(2, 26) = 4.191$, $p < .05$, $\eta^2 = .244$, and physical distance, $F(7, 91) = 306.314$, $p < .001$, $\eta^2 = .959$, influenced reported distances, but these factors did not interact with each other. Bonferroni post hoc comparisons revealed that participants estimated significantly shorter distances in the cast-body shadow condition than in either the non-cast-body shadow condition ($M = -1.763$, $SE = 0.523$, CI[−3.199, −.327], $p = .015$) or the baseline condition ($M = -1.790$, $SE = 0.574$, CI[−3.367, −.213], $p = .024$) but did not differ in their estimates for the latter conditions ($M = -0.027$, $SE = 0.951$, CI[−2.637, 2.583]). These results show that the cast-body shadow perceptually distorts space but a similar shadow not originating from the body does not.

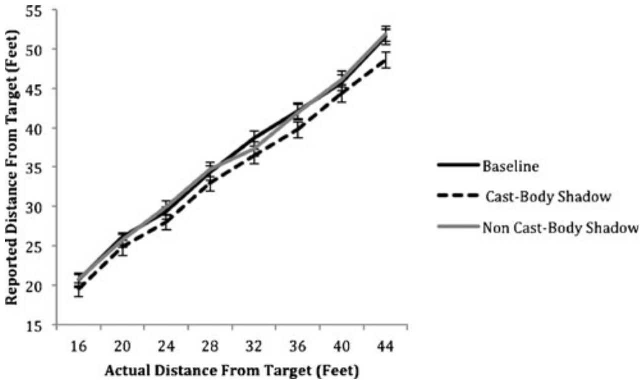

Fig. 2 Mean estimated distance from target for the baseline, cast-body shadow present, and non-cast-body shadow present conditions. Error bars represent one standard error of the mean

Discussion

The target in Experiment 2 appeared closer to participants only when their own shadows extended toward the target, suggesting that visual signals induce perceptual distortions only when there is a link between these signals and observers' bodies. The shadow of the cabinet extended from a participant's body but did not resemble the body's shape or mirror its movements. The cabinet's shadow did not alter space perception because participants presumably did not represent the cabinet's shadow as if it were a part or extension of their own body. However, as in Experiment 1, we found that when observers saw their own shadow extending to a target, targets appeared closer.

General discussion

Our results provide the first evidence that cast-body shadows are represented as an extension of the physical body that alters space perception. Although cast-body shadows share characteristics with other objects that are capable of becoming embodied—bearing anatomical resemblance to the body, like allografts, prostheses, and rubber hands—in these cases of embodiment, a combination of visual and tactile perception drives the sense of personal ownership observers feel over them (e.g., Durgin, Evans, Dunphy, Klostermann, & Simmons, 2007; Murray, 2004; Ramachandran & Rogers-Ramachandran, 1996). While tools need not resemble the body in order to feel as if they are a natural extension of it, like allografts, prostheses, and rubber hands, combined visual–tactile feedback is key to the process of their embodiment (Yamamoto et al., 2005). Imagined tool use in the absence of visual feedback can create perceptual distortion (Davoli et al., 2012; Witt & Proffitt, 2008), suggesting that motor simulations of interactions can make users feel as if the tool is an extension of their body, presumably via the same patterns of neural activations that occur during real interactions (e.g., Creem-Regehr & Lee, 2005; Higuchi, Imamizu, & Kawato, 2007). Also, visual feedback that induces illusory tactile sensations can lead observers to incorporate a rubber hand into the body schema (Durgin et al., 2007), suggesting that imagined or illusory synchronous visuo-tactile feedback is also sufficient to create a sense of embodiment. However, whether we consider real or imagined tool use, we cannot escape the fact that it is impossible to act with or receive tactile feedback from one's shadow, restricting the ability to engage in shadow motor simulations or receive visual–tactile input from the shadow itself. Yet we have shown that cast-body shadows distort perception as if they are embodied, demonstrating that observers can process an object as if it were a part of them even when that object can never provide direct tactile feedback.

Cast-body shadows are similar to tools in that they extend from our body and can modify the representation of perceived space, but unlike tools, cast-body shadows cannot enable action. Recent theories on the relationship between action and perception suggest that action capabilities and intentions have direct and immediate effects on perception (Proffitt, 2006; Witt, 2011). A variety of empirical evidence supports this perception-for-action account (e.g., Davoli et al., 2012; Linkenauger, Witt, Bakdash, Stefanucci, & Proffitt, 2009; Thomas, Davoli, & Brockmole, 2013; Witt & Proffitt, 2008; Witt et al., 2005), and in our laser pointer condition, we replicated the basic effect of an interaction-driven change in perception. We do not wish to dispute the idea of perception for action but, rather, to expand the notion of embodiment-based perceptual distortion beyond situations involving target-focused action. Researchers have recently argued that potential expansions of the embodied cognition literature should focus on the role played by the body independently of its role in goal-directed actions (Borghi & Cimatti, 2010). Our work provides a first step in this direction, showing that an extension of the physical body that inherently lacks the capability to interact with objects or complete a goal-directed action can still become embodied.

If action and tactile feedback do not play a role in the embodiment of the body shadow, what does? Subtle synchronies between the visual movement of body shadows and proprioceptive signals—or previous experience with these synchronies—could have been the driving influence behind the embodiment of cast-body shadows. Indeed, Holmes and Spence (2006) proposed that one effect of cast-body shadows may be to bind extrapersonal visual events to simultaneously occurring proprioceptive events. Shadows also may alter observers' perception of the world because of their strong anatomical resemblance to the physical body, causing observers to process the location of the cast-body shadow in the same way they would process the location of a part of their own body (de Vignemont, 2011). Pavani and Castiello (2004) have shown that visual distractors presented at the location of a cast-hand shadow produce cross-modal interference on a tactile judgment task that is similar to conditions in which the visual distractors are presented on the hands themselves, also suggesting that the brain automatically codes cast-body shadows as related to the body itself (Maravita, 2006). Regardless of the particular characteristics that drive the embodiment of cast-body shadows, our work points to the usefulness of these objects in advancing understanding of when, and how, observers come to feel as if an object is a part of them.

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