Perspectives on Psychological Science
2015, Vol. 10(6) 865–872

DOI: 10.1177/1745691615598525
pps.sagepub.com

Awareness Is Not a Necessary Characteristic of a Perceptual Effect: Commentary on Firestone (2013)

Jessica K. Witt
Department of Psychology, Colorado State University

Abstract

Golf holes look larger to golfers who are playing better than others, and hills look steeper to people who are fatigued from a long run—or so claims the action-specific account of perception. According to this account, spatial perception of slant, distance, and size is influenced by the perceiver's ability to perform actions such as walking, throwing, or grasping. This claim is based on empirical findings that observers report hills as steeper, distances as farther, and objects as smaller when they are less capable of acting on the objects. Recently, Firestone (2013) challenged the claim that these reports reflect genuine differences in perception. One argument he levied against a perceptual interpretation is that people are not aware of these perceptual differences related to action, and they should be. Here, I argue that awareness is not a necessary condition for an effect to be perceptual, as evidenced by a lack of awareness in the case of a classic visual illusion. However, to make a strong claim for genuine effects in perception, the action-specific account must specify a perceptual mechanism, and it has yet to do so.

Keywords
action, performance, perception

When judging spatial properties of an object such as its distance, size, or speed, people show biases based on their ability to perform the intended action. For example, softball players who are hitting better than others judge the ball to be bigger (Gray, 2013; Witt & Proffitt, 2005). As another example, hills are judged as steeper to individuals who are wearing a heavy backpack, out of shape, or fatigued from a long run (Bhalla & Proffitt, 1999). According to the action-specific account of perception (Proffitt, 2006; Witt, 2011a), people judge a ball as bigger or a hill as steeper because they literally see the ball as bigger or the hill as steeper. These effects would then show that spatial perception is influenced by an intended or a recently performed action, and that the same object, which gives rise to the same optical information, would look different as a function of the perceiver's ability to perform an action. Alternatively, these effects could reflect changes in the responses themselves due to factors such as task demands or experimenter effects (Durgin et al., 2009; Durgin, Klein, Spiegel, Strawser, & Williams, 2012; Woods, Philbeck, & Danoff, 2009). In this case, action would not be part of the informational basis for spatial perception, and theories of vision would not have to accommodate these action-based effects.

In a recent article, Firestone (2013) presented several arguments for why action-specific effects are not and could not be perceptual. One argument related to phenomenal awareness. Firestone argued that purported differences in the perception of the environment due to, for example, wearing a backpack are not subjectively noticed and that they should be. According to Firestone, this lack of phenomenological effect suggests that action-specific effects are not perceptual. Here, I take issue with this claim.

The argument that if action-specific effects were truly perceptual, then they should follow a certain pattern is prevalent in the literature. For example, Loomis and Philbeck (2008) argued that if action-specific effects were perceptual, then their influences should be apparent in action-based measures such as blindwalking (see Fig. 1a). Their assertion is validated by several examples of published research in which action-based measures were closely aligned with verbal reports (e.g., Philbeck &

Corresponding Author:
Jessica K. Witt, 241 Behavioral Sciences Building, Department of Psychology, Colorado State University, Fort Collins, CO 80523-1876
E-mail: jessica.witt@colostate.edu

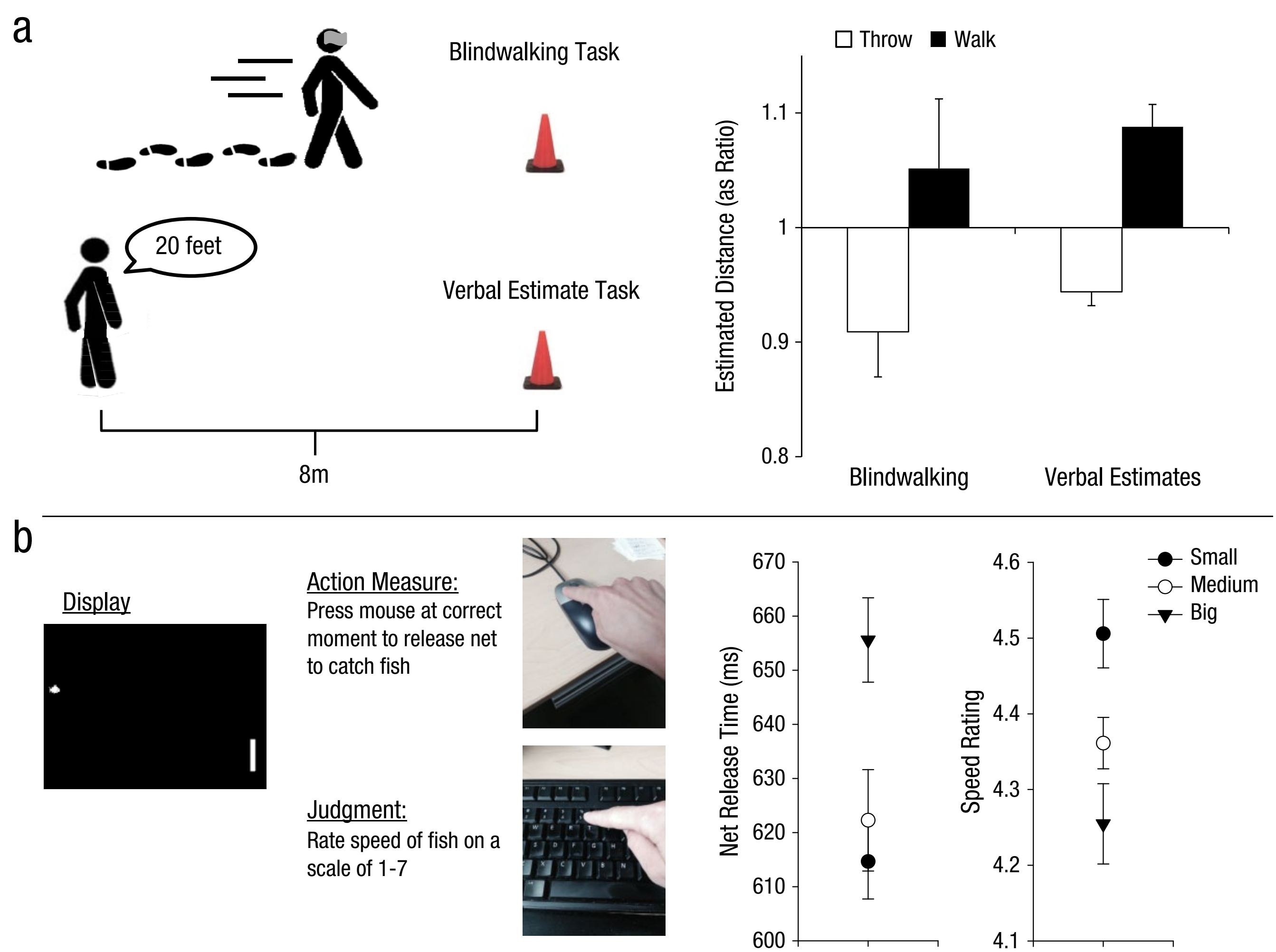

Fig. 1. Paradigms and results from two examples of action-specific studies. In the studies depicted in panel (a), participants walked on a treadmill and then viewed a target presented 8 m away with the intention to either walk to it or throw to it (Witt, Proffitt, & Epstein, 2004, 2010). The point of having participants walk on the treadmill was that it increases anticipated effort for walking: People learn that it takes a lot of effort to go nowhere and anticipate having to exert even more effort to walk a prescribed distance (Proffitt, Stefanucci, Banton, & Epstein, 2003). The point of varying the intended action was that walking on the treadmill should have increased anticipated effort only for people who intended to walk, not for people who intended to throw. Perceived distance to the target was assessed using a blindwalking task, in which participants donned a blindfold and walked to the target's location (Witt, Proffitt, & Epstein, 2010), and a verbal report, in which participants estimated the distance to the target (in feet; Witt, Proffitt, & Epstein, 2004). Both types of perceptual measures revealed the same pattern: The target appeared to be farther away to observers who intended to walk compared with observers who intended to throw. The similar pattern suggests a common underlying process as opposed to response-specific processes. Panel (b) illustrates the use of verbal judgments and an action-based measure to assess perceived speed in a computer-based fishing task. A fish moved across the screen at various speeds, and participants released a big, medium, or small net in an attempt to catch the fish. To catch the fish, participants had to select the right moment to release the net. Unknown to the participants, net release time was used as a measure of the fish's perceived speed. Participants waited longer to release the big net compared to the small net, indicating that the fish appeared to move more slowly when the net was bigger and more effective for catching the fish. Participants also rated the speed of the fish on a scale of 1 to 7 by pressing the corresponding number on a keyboard. Participants rated the fish as moving faster when they played with the small net compared with the big net. Both the action-based measure of net release time and the magnitude judgment of speed ratings showed the same effects of net size on apparent fish speed. Again, converging evidence across multiple types of measures indicated a common underlying process, which is presumed to be perceptual, as opposed to response-specific processes.

Loomis, 1997). Following their assertion, my colleagues and I have tested action-specific effects using these very measures and have found that action-based measures reveal the same pattern as verbal judgments. For example, increased effort associated with walking influenced perceived distance to targets as assessed using both verbal estimates and blindwalking (Witt, Proffitt, & Epstein, 2004, 2010; see Fig. 1a). As another example, virtual fish moving across a computer display were perceived as moving more slowly when the net used to catch the fish was bigger rather than smaller. This pattern was found when the perceived speed of the fish was assessed using magnitude judgments and when examining the way the net was used: Observers waited longer to release the big net than the small net, which indicated that they perceived the fish as moving more slowly (Witt & Sugovic, 2013a; see Fig. 1b).

In contrast, the argument concerning the necessity of subjective awareness is not supported by any literature. Instead, the claim seems rooted in a subjective belief that surely one should notice a change in one's perception. Firestone is not alone in his belief. The belief that people will notice changes in the visual scene is what makes examples of change blindness so compelling (e.g., Simons & Chabris, 1999). Change blindness occurs when an object changes (e.g., its color or its presence) but perceivers do not detect the change. People believe that if the visual scene were to change in front of their eyes, they would be aware of it, so when something as salient as a gorilla passes in front of them, people are surprised to learn that they did not notice it.

With respect to action-specific effects, this belief seems even more applicable given that perception itself is theorized to have changed. In the gorilla study, people did not notice the gorilla because they did not see it. In the case of the backpack study, the hill was judged to be steeper by participants who wore the backpack compared to participants who did not wear the backpack (Bhalla & Proffitt, 1999). How could the hill look steeper without observers being aware of the difference in steepness? According to Firestone, this lack of awareness is evidence that action-specific effects are not perceptual.

The Necessity of Awareness

Must this prevalent belief that changes should be noticed truly be a precondition for declaring an effect perceptual or not? Firestone concedes that noticing perceptual effects is not necessary in and of itself but argues that action-specific effects should be noticeable if they are indeed perceptual, given that the effects are large and involve features toward which attention is directed (e.g., hill slant). However, a large, attended effect can still be perceptual without observers' having subjective awareness of the corresponding change in perception, as shown below.

One way to approach an argument about the necessary conditions for considering action-specific effects perceptual is to apply that same logic to well-known visual effects. My preference, in these cases, is to examine what happens with visual illusions. Visual illusions can be used to set up expectations for the kinds of effects that should and should not be found for a perceptual phenomenon. In the past, my colleagues and I used visual illusions to elucidate how signal-detection-theory measures of d' and c should change when observers experience a perceptual effect that is due to a perceptual bias rather than a change in sensitivity (Witt, Taylor, Sugovic, & Wixted, 2015). A naive view of signal detection theory (and one that is sometimes encouraged in tutorials) is that a true perceptual effect should be revealed by a change in d' and a change in c reflects only decision-based processes. By showing that visual illusions influence c and not d', this assumption about signal detection measures was both tested and proved to be wrong. Here, I applied that same logic to Firestone's assumption that large, attended perceptual effects should produce changes that are noticeable.

To evaluate whether awareness should be considered a necessary condition for an effect to be considered perceptual, I examined awareness in the case of the Ebbinghaus illusion, a classic visual illusion (see Fig. 2). In this illusion, a center circle appears smaller when surrounded by large circles than when surrounded by small circles. If switching from one illusion condition (e.g., small inducer circles) to another illusion condition (e.g., large inducer circles) does not produce a corresponding awareness of a perceptual change of circle size, awareness should not be considered necessary for the effect to be perceptual (or the Ebbinghaus illusion should not be considered perceptual, a position I doubt anyone would be likely to take).

I presented a center circle surrounded by one set of inducers, then switched the display to show the circle surrounded by the other set of inducers and asked 15 participants if they noticed any change to the perceived size of the center circle. Across 20 trials, participants reported seeing a change in the size of the center circle only 11.67% of the time when the surrounding circles changed size (see the Supplemental Material for details). Readers are invited to observe the stimuli for themselves (http://amplab.colostate.edu/EbbinghausDemo.html). Even though the center circle appears smaller when surrounded by large inducers than when surrounded by small inducers, switching between the two conditions did not lead to awareness of a change in perceived size. Therefore, we should not expect that donning a backpack should necessarily lead to awareness of a perceptual shift in hill slant, as claimed by Firestone.

Firestone argued that action-specific effects should be noticeable if they are indeed perceptual because they are large effects and that people attend to the features that are affected, such as hill slant. The Ebbinghaus illusion is also a large effect and people also attend to the very features that are affected. Following Firestone, are we to conclude that the Ebbinghaus is not, and cannot, be a perceptual effect? Instead, perhaps awareness should not be considered a necessary condition for an effect to be considered perceptual.

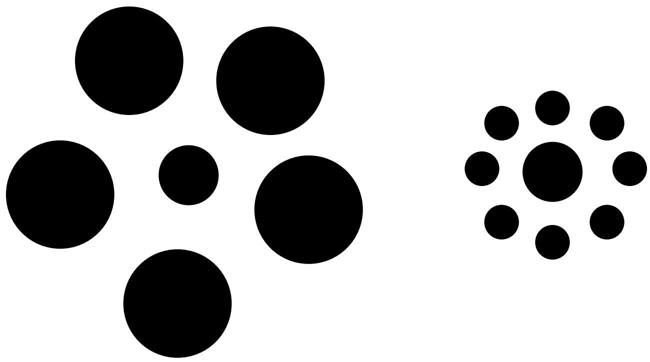

Fig. 2. The Ebbinghaus illusion. The two center circles are the same size, but the one on the left appears bigger. A demonstration of the stimuli used to assess awareness of a change in center-circle size when the surrounding inducer circles changed size is available at http://amplab.colostate.edu/EbbinghausDemo.html. A demonstration of the Dynamic Ebbinghaus illusion is available at http://illusionoftheyear.com/2014/the-dynamic-ebbinghaus/.

Being Noticeable Requires a Violation of Stability, a Signal of Change, or Knowledge of the Underlying Processes

Despite the rejection of noticeability as a necessary condition for a perceptual effect, it is still interesting to consider why putatively large perceptual shifts go unnoticed. If perception of circle size or hill slant is indeed different between conditions, as is widely agreed to be the case in the Ebbinghaus illusion and as argued to be the case in the backpack hill studies, why are these differences not noticed? If a hill slant appears 10° at one time and then 15° at another time, why does this change escape our awareness?

The winner of 2014 Illusion of the Year contest, the Dynamic Ebbinghaus illusion, speaks to this very issue (Blair, Caplovitz, & Mruczek, 2014). The creators of this illusion found that when the inducer circles in the Ebbinghaus illusion grew larger and then smaller repeatedly, the illusion itself was much reduced. However, when the same display—growing and shrinking inducer circles surrounding a static center circle—was also moved across the screen, the illusion increased in magnitude, and observers were aware of changes in center circle size. The visual system prioritizes stability and is more likely to detect changes when there is uncertainty in a display, as was the case when the entire image moved, than when there is less uncertainty, as was the case when the center circle remained in the same location (see also Glennerster, Tcheang, Gilson, Fitzgibbon, & Parker, 2006; Mruczek, Blair, & Caplovitz, 2014). In the case of the backpack example, given that the hill does not change, putting on a backpack is not likely to induce awareness of a change because there is visual information to suggest stability. Furthermore, Blair and colleagues' results suggest that putting on a backpack while looking at the hill may even reduce the purported effect of wearing a backpack on perceived hill slant because the visual system prioritizes seeing a stable, unchanging environment more than integrating relational cues such as seeing objects in relation to each other or, perhaps, in relation to one's ability to act. In other words, donning a backpack might not produce an awareness of a change in perceived hill slant because the visual system might resist such a change in order to maintain a stable image of the environment. However, as long as the observer looks away from the hill prior to making a judgment about hill slant, this should eliminate any effects based on stability and produce the theorized perceptual effects.

Other insights about why perceptual changes in hill slant due to wearing a backpack might not be noticed come from lessons on change blindness (e.g., Simons & Ambinder, 2005). To detect a change, at least one of two events must occur. Observers would need to compare their current perceptions to their previous perceptions, or there must be a signal that a change has occurred. With respect to comparing current to previous perceptions, a change in one's perception could go unnoticed if this comparison is not conducted. If observers did conduct such a comparison and their current perception did not match their previous perception, they would notice this discrepancy and would be aware that a change had occurred.

If an effect's being noticeable requires an observer's awareness that the way something looks at Time 2 is different from how it looked at Time 1, action-specific effects may very well be noticeable. In informal settings, I have frequently asked rooms full of Colorado State University students whether they have ever experienced a hill as appearing steeper when wearing a backpack. Most raise their hands. This experience is presumably based on their comparison of the hill as they see it at any given moment with previous experiences of seeing the hill. More formally, I surveyed 34 Division I college track athletes and asked if they ever noticed that the track appeared longer or shorter under various conditions. Many reported differences in perception as a result of their ability to perform at their sport (see Fig. 3). These data suggest that changes in perception due to one's ability to act can be noticeable if tested in this way.

The second event that could result in a subjectively noticeable change is a signal that a change has occurred. A signal that change has occurred is more consistent with Firestone's use of the term *noticeable*, which he uses to refer to "subjectively appreciable, dynamic perceptual changes" (p. 465). According to this interpretation of being noticeable, not only would the hill be seen as steeper when wearing a backpack, but the hill would

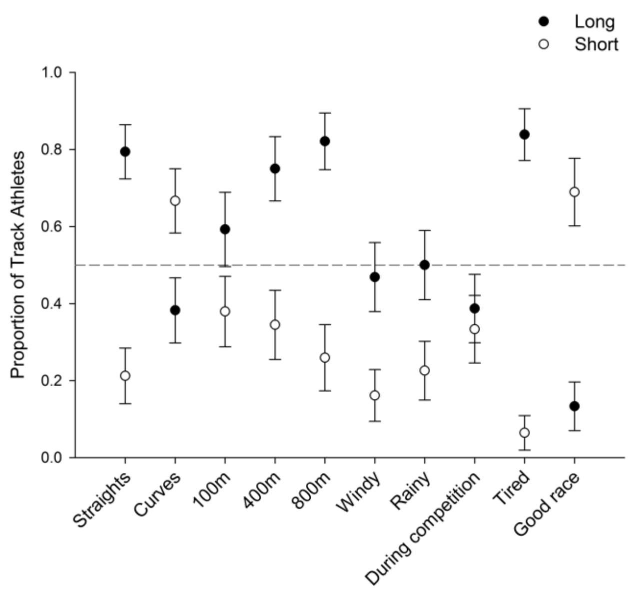

Fig. 3. Proportion of surveyed track athletes who reported that a track appeared longer or shorter as a function of the part of the track ("straights" vs. "curves"), the length of the race, and environmental or performance-related conditions. "Good race" refers to whether the athletes felt they were having a good race day. Error bars are 1 *SEM*, calculated within-subjects. The dashed line represents the point at which half of track athletes reported the experience; scores around 0 indicate that noticeable changes in track length were not experienced. A copy of the written survey is available in the Supplemental Material available online.

literally "warp before our eyes" upon our donning the backpack (Firestone, 2013, p. 464). For such warping to happen, there needs to be a signal of change. For example, a sudden movement gives rise both to a change in an object's location and a signal that a change has occurred. In the case of donning a backpack, it is possible that perception of hill slant changes but in such a way that the change is not accompanied by a signal of change. This could occur if the change in perceived hill slant were so gradual as to be below the threshold needed to signal change. Currently, there is no research on the time course of action-specific effects that would shed light on how quickly such changes occur.

Alternatively, the effect of donning a backpack on perceived hill slant might be accompanied by a signal of change, but this signal of change would likely conflict with any signals that the hill is not changing. Given the assumption of stability, which is prioritized by the visual system (Glennerster et al., 2006), any signal of change might be ignored when one is faced with information indicating a stable environment. This possibility could be tested by examining whether action-specific effects are noticeable in conditions that do not specify stability, such as was done with the Dynamic Ebbinghaus illusion (Blair et al., 2014). Virtual environments might be useful in this case, as they can be rendered with varying degrees of stability. Other scenarios could also lead to rejection of the assumption of stability. In one series of experiments, participants viewed an object under a magnifying glass, so the object appeared bigger. When participants placed their hands next to the object, the object appeared to be smaller, and many spontaneously reported that the object appeared to shrink before their eyes (Linkenauger, Ramenzoni, & Proffitt, 2010). Perhaps the reason why changes were noticed in this study was because the magnifying glass created an unusual viewing scenario in which the assumption of stability may have been rejected. More research is needed to fully understand the relationship between seeing change and the assumption of stability.

Another way by which observers could detect changes in how a hill appears would be if they were aware of the information being processed by the visual system. In this case, observers would be aware that the energetics required to ascend the hill influence perceived slant and then could be aware that the hill appears steeper upon donning a backpack. This possibility is certainly a strawman account, as it is well documented that people are not privy to the factors that contribute to vision but rather are aware of the meaningful objects in the environment. For example, in cases of color constancy, people are aware only of the color of the object (as they see it) and not the information regarding wavelength that is reflected into the eye. Even when wavelength is shown to be the same for two objects, observers still cannot help but see the object's color rather than its luminance (reflected wavelength), as evidenced by illusions such as the checkershadow illusion (Adelson, 1995).

The Underlying Mechanisms of Action-Specific Effects

Action-specific effects are claimed to be perceptual, but there are many different kinds of perceptual effects. For the idea that action-specific effects are perceptual to truly be accepted, the underlying mechanism must be specified. Some work has already begun, but much more work is needed. To help initiate additional investigations, I review some possible candidate mechanisms that should be considered.

Attention-based perceptual effects

Some effects on perception are due to differences in attention. For example, looking directly at an object makes the object appear bigger than looking off to the side (Newsome, 1972). Similarly, tracking a moving object with one's eyes, known as *smooth pursuit*, makes the object appear slower than does fixating on a static location (Aubert, 1886; Fleischl, 1882). Some evidence suggests that certain action-specific effects may depend on attention (Canal-Bruland, Zhu, Van der Kamp, & Masters, 2011; Gray, Navia, & Allsop, 2014), but other studies have found action-specific effects even when looking behavior is equated across conditions (Van der Hoort & Ehrsson, 2014). Given the wide variety of action-specific effects, it is entirely possible that multiple mechanisms are involved and that some might rely on attention whereas others do not.

Top-down conceptual effects

Some perceptual effects are due to top-down influences based on conceptual processing. For example, color perception is influenced by knowledge of object color (Land, 1977), object category (Goldstone, 1995; Levin & Banaji, 2006), and memory of the object's color (Hansen, Olkkonen, Walter, & Gegenfurtner, 2006). Action-related influences could be likened to these conceptual influences. For example, poor performance could activate the concept of a smaller target, which could then influence perceived target size.

The mechanism for such top-down effects could be akin to Bayesian integration. Action-related information could form a prior that is integrated with visual information. Like other priors (e.g., Adams, Graf, & Ernst, 2004), the prior related to action could be based on statistical patterns of experience. For example, wearing a backpack or being fatigued could be associated with steeper hills, and this could create a prior for seeing the hill as steeper. Similarly, poor athletic performance could be associated with smaller targets, and this could create a prior for seeing targets as smaller. Alternatively, the mechanism for top-down effects could be one of grounded cognition (Barsalou, 1999). Being fatigued or wearing a backpack could generate a perceptual simulation of steep hills, which could be combined with perceptual stimulation from an actual hill to produce a perception of the hill as steeper.

Higher-order invariants or cue integration

Another possible mechanism could stem from similarity between action-specific effects and multimodal effects. Information is detected from multiple sensory systems and combined to produce effects in vision based on audition or effects in touch based on vision (e.g., Ernst & Banks, 2002; Shams, Kamitani, & Shimojo, 2000). Information could be detected from the action system through proprioceptive and intereoceptive receptors (see Witt & Riley, 2014, for extended discussion) or through motor simulations (Witt & Proffitt, 2008). Given that information about one's ability to act can be detected, there are two possible ways that this information could be combined with visual information to produce action-specific effects. Information from vision and action could give rise to high-order invariants that could be detected from the global array (cf. Stoffregen & Bardy, 2001). These invariants would specify the spatial layout of the environment as it relates to the observer's ability to act (Witt & Riley, 2014). Alternatively, information from multiple systems could be integrated, just as various depth cues are integrated with each other. The integration could be similar to the kinds of Bayesian integration found with multimodal effects (Ernst & Banks, 2002).

Perceptual scaling

Another candidate mechanism is the perceptual "ruler" provided by the body that can be used to scale optical information from visual angles into distances and sizes (Proffitt & Linkenauger, 2013). The initial unit for all optical information is in visual angle, but observers perceive objects in terms of their size and depth, not in terms of their visual angles. Somehow the visual angles must be transformed into the units that are perceived. Proffitt and Linkenauger (2013) argued that the body provides the ruler used to make this transformation. For example, the visual angle of a graspable object such as a strawberry could be scaled into size by using the hand as the ruler. Proffitt and Linkenauger likened this approach to that of eye-height scaling of distance to and height of objects (Sedgwick, 1986).

A major advantage of their theory is that it explains a problem that has not yet satisfactorily been addressed, which is how visual angles are transformed into the units that are perceived (Proffitt, 2013). However, the visual angle produced by an object such as a strawberry does not always relate to the size of the hand in a lawful, one-to-one manner (Firestone, 2013). If the strawberry is next to or on the hand, the relationship is lawful, and the perceived size of the strawberry would be specified by the relationship between projected strawberry size, projected hand size, and physical hand size. However, if the strawberry is not near the hand or the hand is not visible, then this relationship is not lawful. For instance, if one viewed a strawberry on the table and then moved one's head closer to the strawberry, this would necessarily change the visual angle projected by the strawberry, but one's hand size would not change. So, it is unclear how a changing visual angle could be transformed by an unchanging hand size to produce a consistent perception of strawberry size. However, given that this problem is not unique to the perceptual-ruler account put forth by Proffitt and Linkenauger (2013) and is a problem that must be resolved for all accounts of spatial perception, I would not yet view it as a fatal flaw of the action-specific account (as was done by Firestone, 2013) and instead would argue that more theoretical work needs to be done to resolve the issue for both an action-specific account and a non-action-specific account. As pointed out by Proffitt (2013), Firestone criticized the account without putting forth an alternative explanation that could resolve the issue of transforming visual angles into the units that are perceived.

The current array of candidate mechanisms for a perceptual account of action-specific effects highlights the need to resolve two issues. The first concerns determining the specific source of information related to action, and the second determining how this information interacts with optical information. That these issues are unresolved should not be considered a fatal flaw of the account, but they will need to be resolved before a claim that action-specific effects are perceptual can be fully embraced.

Summary

The issue of whether action-specific effects are perceptual or not has raised a number of insights and lively debates. Firestone (2013) claimed that action-specific effects are not subjectively noticeable and that they should be. Consequently, he concluded that action-specific effects are not, and could not, be perceptual. Here, I have used the Ebbinghaus illusion to argue that large, attended perceptual effects need not be noticeable, thereby rejecting one of his main claims.

With respect to the claim that action-specific effects are perceptual, there are currently a number of supporting results, including findings from studies using indirect and action-based measures (Linkenauger, Bulthoff, & Mohler, 2015; Stefanucci & Proffitt, 2009; Van der Hoort & Ehrsson, 2014; Witt, 2011b; Witt et al., 2010; Witt & Sugovic, 2013a) and studies that have controlled for decisional processes (Schnall, Zadra, & Proffitt, 2010; Taylor-Covill & Eves, 2014; Witt & Sugovic, 2013b). Where the action-specific account is lacking is not in evidence for a perceptual effect but in evidence for an underlying mechanism. For me, the greatest strength of Firestone's article was the realization that researchers who argue that action-specific effects are perceptual have not done enough to specify the nature of these purported perceptual effects. However, whereas Firestone views this as a fatal flaw that proves the effects are not perceptual, I take it as a push for us to devote ourselves to determining the underlying mechanism. The strongest argument for a perceptual effect cannot be made until a mechanism has been specified.

Acknowledgments

The author would like to thank Chaz Firestone, Dan Simons, Larry Barsalou, and Bobbie Spellman for their thoughtful and useful comments.

Declaration of Conflicting Interests

The author declared no conflicts of interest with respect to the authorship or the publication of this article.

Funding

This work was supported by National Science Foundation Grants BCS-1314162 and BCS-1348916.

Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

References

Adams, W. J., Graf, E. W., & Ernst, M. O. (2004). Experience can change the "light-from-above" prior. *Nature Neuroscience*, *7*, 1057–1058.

Adelson, E. H. (1995). *Checkershadow illusion*. Retrieved from http://persci.mit.edu/gallery/checkershadow

Aubert, H. (1886). Die Bewegungsempfindung [The sensation of movement]. *Pflüggers Archiv (European Journal of Physiology)*, *39*, 347–370.

Barsalou, L. W. (1999). Perceptions of perceptual symbols. *Behavioral & Brain Sciences*, *22*, 577–660.

Bhalla, M., & Proffitt, D. R. (1999). Visual-motor recalibration in geographical slant perception. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 1076–1096.

Blair, C. D., Caplovitz, G. P., & Mruczek, R. E. B. (2014). *The Dynamic Ebbinghaus illusion*. Retrieved from http://illusionoftheyear.com/2014/the-dynamic-ebbinghaus/

Canal-Bruland, R., Zhu, F. F., Van der Kamp, J., & Masters, R. S. W. (2011). Target-directed visual attention is a prerequisite for action-specific perception. *Acta Psychologica*, *136*, 285–289.

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. *Psychonomic Bulletin & Review*, *16*, 964–969. doi:10.3758/PBR.16.5.964

Durgin, F. H., Klein, B., Spiegel, A., Strawser, C. J., & Williams, M. (2012). The social psychology of perception experiments: Hills, backpacks, glucose, and the problem of generalizability. *Journal of Experimental Psychology: Human Perception and Performance*, *38*, 1582–1595.

Ernst, M. O., & Banks, M. S. (2002). Humans integrate visual and haptic information in a statistically optimal fashion. *Nature*, *415*, 429–433.

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*, 455–473.

Fleischl, E. V. (1882). Physiologisch-optische Notizen, 2 [Physiologically-optical notes, 2]. Mitteilung. *Sitzung Wiener Bereich der Akademie der Wissenschaften*, *3*, 7–25.

Glennerster, A., Tcheang, L., Gilson, S. J., Fitzgibbon, A. W., & Parker, A. J. (2006). Humans ignore motion and stereo cues in favor of a fictional stable world. *Current Biology*, *16*, 428–432. doi:10.1016/j.cub.2006.01.019

Goldstone, R. L. (1995). Effects of categorization on color perception. *Psychological Science*, *5*, 298–304.

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*, 1124–1142.

Gray, R., Navia, J. A., & Allsop, J. (2014). Action-specific effects in aviation: What determines judged runway size? *Perception*, *43*, 145–154.

Hansen, T., Olkkonen, M., Walter, S., & Gegenfurtner, K. R. (2006). Memory modulates color appearance. *Nature Neuroscience*, *9*, 1367–1368.

Land, E. H. (1977, December). The retinex theory of color vision. *Scientific American*, *237*(6), 108–128.

Levin, D. T., & Banaji, M. R. (2006). Distortions in the perceived lightness of faces: The role of race categories. *Journal of Experimental Psychology: General*, *135*, 501–512.

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.

Linkenauger, S. A., Ramenzoni, V., & Proffitt, D. R. (2010). Illusory shrinkage and growth: Body-based rescaling affects the perception of size. *Psychological Science*, *21*, 1318–1325. doi:10.1177/0956797610380700

Loomis, J. M., & Philbeck, J. W. (2008). Measuring perception with spatial updating and action. In R. L. Klatzky, M. Behrmann, & B. MacWhinney (Eds.), *Embodiment, ego-space, and action* (pp. 1–44). Mahwah, NJ: Erlbaum.

Mruczek, R. E. B., Blair, C. D., & Caplovitz, G. P. (2014). Dynamic size illusion contrast: A relative size illusion modulated by stimulus motion and eye movements. *Journal of Vision*, *14*(3), Article 2. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3941261/

Newsome, L. R. (1972). Visual angle and apparent size of objects in peripheral vision. *Perception & Psychophysics*, *12*, 300–304.

Philbeck, J. W., & Loomis, J. M. (1997). Comparison of two indicators of perceived egocentric distance under full-cue and reduced-cue conditions. *Journal of Experimental Psychology: Human Perception and Performance*, *23*, 72–85.

Proffitt, D. R. (2006). Embodied perception and the economy of action. *Perspectives on Psychological Science*, *1*(2), 110–122.

Proffitt, D. R. (2013). An embodied approach to perception: By what units are visual perceptions scaled? *Perspectives on Psychological Science*, *8*, 474–483.

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. *Psychological Science*, *14*(2), 106–112.

Schnall, S., Zadra, J. R., & Proffitt, D. R. (2010). Direct evidence for the economy of action: Glucose and the perception of geographical slant. *Perception*, *39*, 464–482.

Sedgwick, H. (1986). Space perception. In K. R. Boff, L. Kaufman, & J. P. Thomas (Eds.), *Handbook of perception and human performance* (Vol. 1, pp. 1–57). New York, NY: Wiley.

Shams, L., Kamitani, Y., & Shimojo, S. (2000). What you see is what you hear. *Nature*, *408*, 788.

Simons, D. J., & Ambinder, M. S. (2005). Change blindness: Theory and consequences. *Current Directions in Psychological Science*, *14*, 44–48.

Simons, D. J., & Chabris, C. F. (1999). Gorillas in our midst: Sustained attentional blindness for dynamic events. *Perception*, *28*, 1059–1074.

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*, 424–438. doi:10.1037/a0013894

Stoffregen, T. A., & Bardy, B. G. (2001). On specification and the senses. *Behavioral & Brain Sciences*, *24*, 195–261.

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*, 915–919.

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*, 1414–1428.

Witt, J. K. (2011a). Action's effect on perception. *Current Directions in Psychological Science*, *20*, 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*, 1148–1156. doi:10.1037/a0021933

Witt, J. K., & Proffitt, D. R. (2005). See the ball, hit the ball—Apparent ball size is correlated with batting average. *Psychological Science*, *16*, 937–938. 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*, 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*, 577–590. doi:10.1068/P5090

Witt, J. K., Proffitt, D. R., & Epstein, W. (2010). When and how are spatial perceptions scaled? *Journal of Experimental Psychology: Human Perception and Performance*, *36*, 1153–1160. doi:10.1037/A0019947

Witt, J. K., & Riley, M. A. (2014). Discovering your inner Gibson: Reconciling action-specific and ecological approaches to perception-action. *Psychonomic Bulletin & Review*, *21*, 1353–1370.

Witt, J. K., & Sugovic, M. (2013a). Catching ease influences perceived speed: Evidence for action-specific effects from action-based measures. *Psychonomic Bulletin & Review*, *20*, 1364–1370.

Witt, J. K., & Sugovic, M. (2013b). Response bias cannot explain action-specific effects: Evidence from compliant and non-compliant participants. *Perception*, *42*, 138–152.

Witt, J. K., Taylor, J. E. T., Sugovic, M., & Wixted, J. T. (2015). Signal detection measures cannot distinguish perceptual biases from response biases. *Perception*, *44*, 289–300.

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*, 1104–1117. doi:10.1037/a0013622