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. 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.
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.
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 $15^\circ$ at one time and then $10^\circ$ 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...
Awareness Not Necessary for Perceptual Effect

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. 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.

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 checkerboard 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 object.
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 interoceptive 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

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