Action-Specific Effects in Perception and their Potential Applications

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Abstract

Spatial perception is biased by action. Hills appear steeper and distances appear farther to individuals who would have to exert more effort to transverse the space. Objects appear closer, smaller, and faster when they are easier to obtain. Athletes who are playing better than others see their targets as bigger. These phenomena are collectively known as action-specific effects on perception. In this target article, we review evidence for action-specific effects, including evidence that they reflect genuine changes in perception, and speculate on possible applications of action's influence on vision.

Keywords: Action-Perception Relationships; Spatial Perception; Sports Perception

According to an action-specific account of perception, perceivers see the spatial layout of the environment in terms of their ability to act. For example, softball players hitting better than others judge the ball as bigger (Gray, 2013; Witt & Proffitt, 2005), and hills are reported as steeper to observers who are fatigued or burdened by a heavy load (Bhalla & Proffitt, 1999). In many of these studies, the optical information specifying the spatial dimension is exactly the same, but perceptual judgments of the target object vary as a function of action-related ability. The two examples listed above highlight two different types of action-specific effect: one involving action-related performance and one involving the action-related effort required to traverse an extent. There is also new evidence to suggest a third form of action-specific effects for which the potential consequence of an action such as benefits from successful performance or penalties associated with failure also influence perceptual judgments (Witt & Sugovic, 2013c). We start by reviewing evidence for an action-specific account of perception, and then highlight possible applications of these findings in the areas of safety, rehabilitation, diagnostic tests, and communication.

Overview of Action-Specific Effects in Perception

The initial studies demonstrating that a person's ability to act influences perception were discovered by accident. Dennis Proffitt and his lab were studying perceived slant of hills and found that most people grossly overestimated slant (Proffitt, Bhalla, Gossweiler, & Midgett, 1995). One day, however, the participants did not overestimate nearly as much. It was later discovered that many of the participants that day were on the University's women's soccer team. This anomaly bore the idea that perception of hill slant was not based solely on optical information but also a person's physical fitness. Later studies tested the idea directly and found evidence consistent with this claim. Currently, there is a plethora of research demonstrating effects of various aspects of action on perception of a range of spatial properties including slant, distance, size, height, weight, speed, and shape (for review, see Proffitt, 2006; Proffitt & Linkenauger, 2013; Witt, 2011a; Witt & Riley, 2014). While the action-specific account claims that most of these effects reveal genuine differences in perception itself, alternative accounts have been proposed that the responses, rather than perception, are affected. After reviewing evidence for action-specific effects, we will return to the issue of alternative explanations.

Behavior-based Action-Specific Effects

One aspect of action that is relevant for spatial vision is a person's ability to perform a given task. Performance can be assessed in terms of whether or not an action is possible. For example, in one set of studies, targets were presented beyond arm's reach. Participants estimated the distance to the targets with the anticipation of reaching to the targets with and without a tool. When they anticipated using the reach-extending tool, they judged the targets as closer than when they intended to reach without the tool and the targets were out of reach (Costello et al., in press; Witt & Proffitt, 2008; Witt, Proffitt, & Epstein, 2005). Importantly, the targets were only judged as closer when perceivers intended to use a long tool and not a tool that was too short to reach the targets (Osiurak, Morgado, & Palluel-Germain, 2012). Other studies have found that rather than using a tool to extend a person's ability to reach, the participants' arms can be visually extended or contracted using virtual reality. In this case, the target was judged as closer when the arm was rendered as longer than when it was rendered as shorter (Linkenauger, Bulthoff, & Mohler, in press).

The effect of a reach-extending tool on apparent distance depends on the intention to use the tool rather than on mere possession of the tool. In one study, participants estimated the distance to targets presented beyond arm's reach while holding or not holding the tool. Critically, they never reached to the targets, so the tool did not alter their ability to act in this case. Consequently, there were no differences in estimated distance to the target (Witt et al., 2005). In other words, it is not possession of the tool that is critical but whether or not the perceiver intends to use the tool to reach to the targets. In line with this claim, targets appeared closer for participants who did not hold the tool but intended to pick it up and use it to reach following each distance estimate (Witt & Proffitt, 2008). However, intending to use a tool that is too short to reach to the targets does not make them appear closer (Davoli, Brockmole, & Witt, 2012; Osiurak et al., 2012). Again, these results highlight the importance of intentions and intended abilities, rather than current states.

Similar to how reaching influences perceived distance to targets, grasping influences the perceived size of objects. For example, if one's hand appears larger, objects appear smaller. This effect has been found by (1) magnifying the hand using special lenses, (2) taking advantage of pre-existing differences between perceived size of the right and left hands, (3) investigating individual differences in hand size, and (4) manipulating the hand size of individuals' self-animated virtual body in virtual environments (Linkenauger, Leyrer, Buelthoff, & Mohler, 2013; Linkenauger, Ramenzoni, & Proffitt, 2010; Linkenauger, Witt, & Proffitt, 2011). The effect of hand size on apparent object size is also evident when using indirect measures of perceived size, specifically perceived anisotropy and the size weight illusion (Linkenauger et al., 2013; Linkenauger, Mohler, & Proffitt, 2011). These effects of graspability on perceived size only occur for objects that are graspable; the perception of the size of objects that are too large to be grasped are not influenced by hand size (Linkenauger, Witt, et al., 2011).

Just as the ease with which a target can be reached or grasped can influence perceived distance and size (see also Kirsch, Herbort, Butz, & Kunde, 2012; Kirsch & Kunde, 2013a, 2013b; Morgado, Gentaz, Guinet, Osiurak, & Palluel-Germain, 2013), the ease with which a moving ball can be caught influences perceived speed of the ball. Participants completed a computer-based task modeled after the classic game Pong. A ball bounced across the screen and participants had to block it. Ease to block the ball was varied by changing the height of the paddle. After each blocking attempt, participants estimated the speed of the ball. The results showed that the ball was judged to be moving slower when the paddle was big, and more effective at blocking the ball, than when the paddle was small (Witt & Sugovic, 2010).

A final set of examples demonstrating behavior-based effects on visual perception involve the influence of sports performance on perception of the sport-relevant target. Athletes who are playing better than others judge the target as bigger. These action-specific effects have been found in athletes across numerous sports. For example, softball players who are hitting better than others judge the ball as bigger (Gray, 2013; Witt & Proffitt, 2005), and golfers playing better than others judge the hole as bigger (Witt, Linkenauger, Bakdash, & Proffitt, 2008). In these studies, the athletes were presented with a poster board with different sized circles and asked to select the circle that was the same size as the ball or the hole. We found a positive correlation between performance and selected circle size. With correlational data, the causal nature is unknown. Perhaps softball players who saw the ball as bigger were more successful at hitting the ball. To test the causal direction of the effect, we assessed perceived size of an American football field goal before and after participants attempted 10 kicks. In this experiment, the participants were athletes but did not have prior experience kicking field goals. There was no relationship between judged goal size prior to kicking and subsequent kicking performance, but there was a strong correlation between kicking performance and judged goal size after kicking (Witt & Dorsch, 2009). This result suggests that performance can influence perception.

Other examples of athletic performance on perception include swimmers, parkour experts, archers, pilots, and tennis players. Swimmers who are more skilled than others judge underwater targets as closer (Witt, Schuck, & Taylor, 2011). People trained in parkour and capable of performing a wall jump judge walls as shorter than did people not trained in parkour (Taylor, Witt, & Sugovic, 2011). Pilots who perform landings better than others judge runways as wider (Gray, Navia, & Allsop, 2014). Archers shooting better than others judge the target as bigger (Lee, Lee, Carello, & Turvey, 2012). And tennis players who return the ball better than others judge the net as lower (Witt & Sugovic, 2010). In summary, behavior-based action-specific effects are found in a wide range of scenarios.

Effort-Based Action-Specific Effects

In addition to behavior-based effects, the energetic costs of performing an action also influence spatial perception. Hills appear steeper to observers who are of low fitness, fatigued, wearing a heavy backpack, overweight, food-deprived, or older and of declining health (Bhalla & Proffitt, 1999; Eves, Thorpe, Lewis, & Taylor-Covill, 2014; Schnall, Zadra, & Proffitt, 2010; Taylor-Covill & Eves, 2013, 2014). Perceived distance is also a function of the effort required to perform an action. Distances appear farther to perceivers who anticipate exerting more effort to walk, jump, or throw a prescribed distance (Lessard, Linkenauger, & Proffitt, 2009; Proffitt, Stefanucci, Banton, & Epstein, 2003; Stefanucci, Proffitt, Banton, & Epstein, 2005; Witt, Proffitt, & Epstein, 2004, 2010). For example, gaps appear farther to observers wearing ankle weights than to observers without the added weight. Interestingly, ankle weights only influenced reported gap size for gaps that were short enough that they could be jumped. Once the gap was too big to be crossed, wearing ankle weights no longer influenced judged distance (Lessard et al., 2009). This study shows a boundary condition for action-specific effects: the action must be possible for an effort-based manipulation to influence spatial vision.

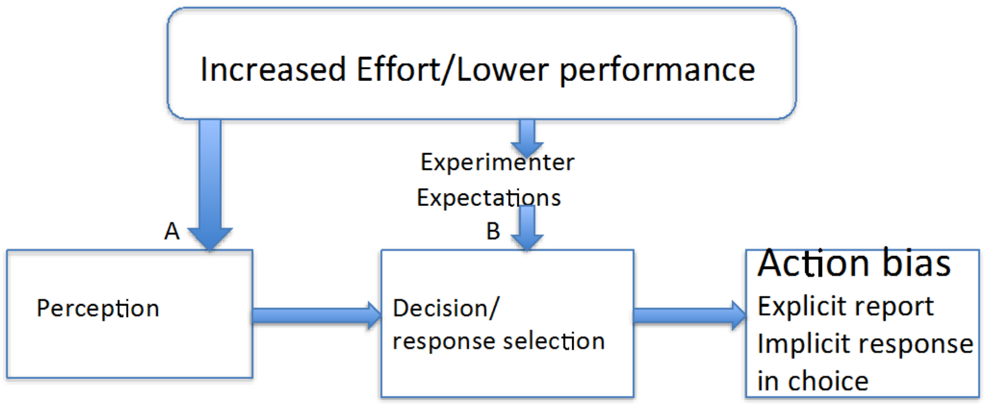
As with the tool studies, intention to act also influences effort-based effects. When a perceiver intends to throw to a target, the effort associated with throwing and not the effort associated with walking influences perceived distance to the target. This is true even if the observer just had experience with walking. Similarly, when a perceiver intends to walk to a target, the effort associated with walking and not the effort associated with throwing influences distance perception, even if the perceiver has just thrown a heavy ball to the target. These effects have been found both with verbal reports of distance and with the action-based measure of blindwalking to the target (Witt et al., 2004, 2010).

Consequence-Based Action-Specific Effects

Recently, several researchers have proposed emotion-based effects on perception. For example, vertical extents appear farther when there is increased risk of falling. The distance to the ground from a balcony appears farther than the exact same distance but viewed from the ground looking up to the balcony (Stefanucci & Proffitt, 2009). This perceptual amplification of heights is especially exaggerated for observers who are afraid of heights (Clerkin, Cody, Stefanucci, Proffitt, & Teachman, 2009; Teachman, Stefanucci, Clerkin, Cody, & Proffitt, 2008). Similarly, threatening objects such as spiders appear bigger, closer, and faster than non-threatening objects (Cole, Balcetis, & Dunning, 2013; Vasey et al., 2012; Witt & Sugovic, 2013c). These **emotion-based** effects on spatial vision could be reconceptualized as consequence-based effects. Spiders have a negative consequence if an action to avoid them fails. Heights have a life-threatening consequence if a perceiver fails to stay far enough away from the edge. Thus, perception seems to be sensitive to both the effort and likelihood of successfully performing an action as well as the consequences of the action (Witt & Sugovic, 2013c). Much more research is needed, however, to understand how the consequences of an action influence perception of the target object.

Alternative Explanations

A criticism levied against the claim that action influences perception is that the effects reflect participants' perceptions of experimenter expectations, and resulting choice, rather than genuine changes in perception (Durgin et al., 2009; Firestone, 2013; Woods, Philbeck, & Danoff, 2009). A task demand, or demand characteristic (Orne, 1682), is pressure created by an experimental set-up on participants to respond in a particular way. For example, imagine an experiment for which a participant is asked to judge the slant of a hill, and then put on a backpack, and judge the hill slant again. The participant is likely to infer that the experimenter's hypothesis is that the backpack is supposed to influence her judgment of the hill, and if the participant is accommodating, she might alter her response



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in the second judgment even if the hill did not look different when viewed the second time. If she knows that backpacks certainly make hills *feel* harder to climb, she might infer that the experimenter anticipates that the hill will also *look* steeper. This kind of set-up could lead to a typical, action-specific pattern such that the hill is judged steeper by participants who wear a backpack compared to those who do not. But the difference would not be due to changes in the *responses*, not differences in *perception*.

Perception is an internal state, so researchers cannot measure perception directly. Instead, we must rely on behavioral indicators and make inferences about the underlying perception. However, these behavioral indicators are also influenced by post-perceptual processes. Therefore, it is difficult to differentiate which effects are due to genuine differences in perception as compared to changes in the response. The complexities involved in making this discrimination go beyond what can be covered in this short paper. Instead, we offer a sample of the types of issues that have been discussed, and encourage readers interested in this topic to consult the many papers dedicated to this very issue (Durgin et al., 2009; Durgin, Klein, Spiegel, Strawser, & Williams, 2012; Firestone, 2013; Firestone & Scholl, 2014; Proffitt, 2006, 2009, 2013; Proffitt & Linkenauger, 2013; Shaffer, McManama, Swank, & Durgin, 2013; Witt, 2011a, 2011b, in press; Witt & Sugovic, 2013b; Woods et al., 2009).

Determining whether a person's ability to act influences perception rather than post-perceptual processes is critical for a number of reasons. Theoretically, a comprehensive account of vision must account for all sources of information involved in visual processing, so it is relevant to know if a person's ability to act should be included as one of these sources. In addition, many vision researchers consider spatial perception to be cognitively impenetrable and modular (Fodor, 1983; Pylyshyn, 1999, 2003). This means that what is known does not influence what is seen. This cognitive impenetrability is exemplified by visual illusions such as the Shepard's tables, Muller-Lyer illusion, or Ponzo illusion specifically because knowing about the illusion does not lessen the effect of the illusion. Visual illusions persist despite knowledge about them, thereby showing the knowledge is not a source of information for spatial perception. If action-specific effects on perception are also cognitively impenetrable, the implications are that people cannot change what they see. This has potential applications when considering how these biases might affect decisions about actions (see below).

Currently, a number of strategies have been used to assess whether action's effect on perceptual judgments is due to a genuine difference in perception or to changes in the response due to task demands. One strategy is to use a cover story to prevent participants from determining the hypothesis. For example, in the original backpack study, participants were asked several questions about the weight of the backpack in order to make them think the purpose of the study "was about estimating weights, distances, and angles in general and not specifically about the relationship between the backpack and their inclination judgments" (Bhalla & Proffitt, 1999, p. 1081). Participants wearing the backpack judged the hill to be steeper compared with participants who did not wear a backpack. However, other experiments that have used an explicit cover story found that making the backpack seem incidental, rather than critical, for the experiment eliminated the effect of the backpack on reported hill slant (Durgin et al., 2009). In that experiment, participants were told that they would have their ankle muscles monitored and the equipment to do this was in the backpack. There have been extended discussions on the backpack/hill studies elsewhere (Durgin et al., 2009; Durgin et al., 2012; Firestone, 2013; Proffitt, 2009; Schnall et al., 2010; Shaffer et al., 2013; Witt, 2011a), and so they will not be repeated here. As a result, different cover stories can lead to different results in similar perceptual judgement.

In addition to using cover stories, another strategy is to use dependent measures that are more resistant to task demands. Whereas verbal reports of distance can be influenced by both perceptual changes and response-based processes (Poulton, 1979), action-based measures are thought to be less transparent, more resistant to demand characteristics and less variable (Loomis & Philbeck, 2008). Examples of action-based measures include blindfolded walking to a target and throwing a ball or a beanbag to the target. Both of these types of measures have revealed effects of action on the perceptual measure, suggesting that the effect is due to genuine differences in the underlying perception as opposed to task demands (Linkenauger et al., in press; Stefanucci & Proffitt, 2009; Witt et al., 2010; see also Witt & Sugovic, 2013a). In addition, indirect measures can also prove to be fruitful, because it is difficult or near impossible for the participant to figure out the experimental hypothesis is difficult. In one study, participants reached with or without a tool to targets presented just beyond arm's reach. Instead of estimating the distance to the target, participants made a shape judgment. The target was the far corner of a triangle comprised of the target and two other circles projected down onto the table. Participants manipulated the spacing between the two base circles in order to make the triangle equilateral. If the target circle truly appeared closer when reaching with a tool, participants should move the base circles closer together in order for the triangle to appear equilateral. This is what was found (Witt, 2011b). To the extent that using a dependent measure about size concealed the interest in distance, this measure implies a genuine difference in perception itself. It is hard to envision a subject altering the shape drawn to suite what s/he consciously believe are the experimenter's expectations in this case.

A third strategy is to use nonobvious manipulations of action so that the experimenter's hypothesis cannot be inferred. An example of a nonobvious manipulation includes the use of sugary drinks versus drinks with artificial sweetener (Schnall et al., 2010). Participants could not differentiate the drinks based on taste, but those who had the sugary, caloric drink judged hills to be less steep. While a seemingly elegant way to avoid task demands, this strategy is not without criticism. Shaffer et al. (2013) argued that those who consumed the sugary drink had more energy to resist task demands and it was this resistance that enabled these participants to provide lower slant judgments. Perhaps a better strategy was to use a quasi-experimental design as in in Eves (2014): participants assigned themselves to groups based on their food or drink selection. Participants estimated the steepness of a staircase then selected a food or drink as payment for their participation. Those who selected a high energy item (such as a banana or a sports drink) were assumed to be low-energy, and thus needed the energy provided by these items. Those who selected the high energy items judged the stairs to be steeper than did those who selected the low energy items. Given that the factor of interest – energy – was not revealed to the participants, it is unrealistic to think that these participants were influenced by task demands.

In addition to the potential role of task demands, other alternative explanations have also been offered as an explanation for action-specific effects. One is that action influences memory for the objects rather than perception (Cooper, Sterling, Bacon, & Bridgeman, 2012). While such an explanation could account for findings when the judged object is not visible, such as in the softball study (Witt & Proffitt, 2005), most studies involve perceptual judgments while the target is visible (such as in all of the distance, hill, and height studies, many of the reaching and grasping studies, some of the sport studies, and some of the speed studies). Another potential explanation is that participants report on how an object feels rather than how it looks (Woods et al., 2009). While this explanation could account for studies involving verbal judgments, it cannot explain results using action-based measures for which interpretation of the instructions is unambiguous.

In summary, many studies have examined a wide range of alternative explanations for apparent action-specific effects. Here, we have highlighted several of these studies while recognizing that an extended review paper would be necessary to capture all of the subtleties and complexities of the arguments. Although there are some discrepancies within the literature and there is no denying that expectations CAN sometimes influence responses, the evidence overwhelmingly favors the idea that a person’s ability to act can influence spatial perception

Application of Action-Specific Effects

Spatial perception of the environment such as its distances, slants, sizes, speeds, and heights are influenced by the perceiver’s ability to perform the intended action. The research thus far has focused mainly on theoretical considerations related to the visual system. Below, we speculate on several possible applications. The overarching theme of the ideas in this section is that people make decisions about what actions to perform based on what they see, and that how they see can be influenced by their expected performance.

Using visual illusions, for example, to make objects appear bigger changes how people act on the objects. In one study, an illusion was used to make a step appear taller or shorter, and this influenced maximum toe elevation as people ascended onto the step (Elliot, Vale, Whitaker, & Buckley, 2009). In another study, a visual illusion was used to make a golf hole appear smaller or bigger, and this influenced putting success (Chauvel, Wulf, & Maquestiaux, 2015; Witt, Linkenauger, & Proffitt, 2012; Wood, Vine, & Wilson, 2013). These studies show that changes in size perception can lead to better performance (see also Gray, 2014).

More critical to the current discussion is evidence that what a person sees can influence *behavioral decisions*. For example, if an object looks too big to grasp, people are not likely to attempt to grasp it, and if an object looks too far away, people are not likely to attempt to reach for it. To our knowledge, only two studies have examined the impact of action-specific perception on behavior decisions. In one study, observers estimated the steepness of a staircase, and it was found that those who estimated the stairs as steeper were more likely to take the escalator instead of walking up the stairs (Eves et al., 2014). One example application of this finding is that people who are obese and are more likely to perceive distances as farther and hills as steeper (Eves et al., 2014; Sugovic & Witt, 2011) will be less likely to choose energetically demanding options (e.g. stairs instead of an escalator) even though the exercise of climbing up the stairs would likely be beneficial. This interaction between perception and one's potential for action could lead to a cycle towards unhealthy lifestyles.

In the second study, action-specific effects were simulated by manipulating the actual size of a baseball (Gray, 2013). The subsequent effect on swing initiations showed that batters were more likely to swing when the ball appeared bigger. This is consistent with the idea that action-specific effects on perception can help people, in this case, athletes, make decisions about which actions to perform (Gray, 2014). Gray (2014) speculated that simulating action-specific effects could help train athletes on how to achieve optimal performance. Consistent with this prediction, training under conditions for which the target appears bigger or small can have effects on subsequent performance (Chauvel et al., 2015). Golfers practiced putts to a hole that looked bigger or smaller due to a surrounding visual illusion. The next day, they putted to a hole with no illusion, and those who had practiced with the perceptually bigger hole were more successful than those who had practiced with the perceptually smaller hole. The studies just discussed reveal potential applications for promoting active lifestyles and improving sports performance. Two other potential applications for the relationship between perception and subsequent behavioral decisions include safety and rehabilitation.

Safety in Vehicle Control

In safety research, one of the most critical roles of perception is how visual biases therein influence the choice of action based on that perception (Wickens, 2014). Naturally, the biggest concern occurs when that bias suggests that the environment (and human capabilities within) supports a choice that is less safe than it really is; for example, a bias to underestimate the steepness of a ski slope viewed from above looking downward could lead to an unwise decision to launch forth. In aviation, numerous illusions bias the slant (visual angle) perception of the runway on approach to landing, in such a way that bias the decision to continue (or initiate) an approach is unwise: the runway is perceived to be higher, or lower, than it really is (depending on the conditions); or the approach speed too fast or too slow (Previc & Ercoline, 2004; Wickens & Hollands, 2000).

Action-specific effects could be described as visual biases for which the perception of the environment is skewed, and one might wonder if these shifts away from geometrically-veridical perception could lead to errors in action. However, not all visual biases produce safety compromising actions. For example, some driving visual environments have been intentionally designed to create perceptual biases that will induce choices to behave more safely. One instance is the use of progressively decreasing the distances between lines across the highway approaching a traffic circle. This pattern induces the perception of acceleration, thereby encouraging a decision to decelerate (Denton, 1980).

Action-specific biases in perception could also promote safer behavioral choices. For example, seeing heights as taller (cf. Stefanucci & Proffitt, 2009) may help keep people a safe distance back from the edge of a balcony. Seeing a hill as extra steep when looking down on a skateboard (cf. Stefanucci, Proffitt, Clore, & Parekh, 2008) may help the novice choose to not descend the hill. Seeing a hill as steeper when energy-depleted or fatigued health (cf. Bhalla & Proffitt, 1999; Eves et al., 2014; Schnall et al., 2010; Taylor-Covill & Eves, 2013, 2014), could lead to decisions to avoid the hill altogether (Eves et al., 2014) or to select a slower walking pace, thereby better regulating energy expenditure and avoiding exhaustion (Proffitt, 2006; Witt, 2011a). We may say that such biases are biologically adaptive.

However action-specific effects could also lead to the alternative bias: the experience of less anticipated effort (or better anticipated performance), perhaps by the more skilled, more fit individual could induce perception to support a riskier course of action. Thus the fitter individual might perceive a weight to be lifted as smaller (and therefore lighter) than it is, inducing her to undertake a dangerous lift. Or the fitter individual might perceive a hill to be less steep, inducing her to push herself too hard, leading to exhaustion and potential injury. Where action-specific effects are likely to be problematic, we suspect, is when the shifts in perception do not align with the perceiver's abilities. Although the action-specific account proposes that perception is aligned with abilities, misalignment could result from errors in the system tasked with integrating optical and action-relevant information.

To add another lament to our human factors safety analysis, in many human system environments, the performance and effort are often "machine mediated". For example we can speak of the performance capabilities of an automobile or aircraft; and we can describe the "effort" of these vehicles in terms of energy consumption and engine strain. Thus, applying the model, we can analyze the extent to which performance/effort characteristics that are fed back to the vehicle operator can influence the perception of the environment in which they operate, hence the feasibility to perform in those environments, and, ultimately, the choice to initiate unsafe or unwise performance. These perceptual aspects typically involve variables of speed, time, distance and weight (mass), because often more extreme ends of these continua can be associated with greater frequency or cost of accidents such as collisions. For example higher speeds, shorter time-to-impact (or longer time to react), closer distances to surfaces, or greater mass upon collision.

Currently, there is little research on whether large machines are embodied and produce action-specific effects in spatial vision. It would be interesting if action-specific effects occur under unmediated circumstances but not when operating heavy machinery. Given that people have learned to make behavior decisions based primarily on what they see, if perception is influenced by their abilities to act in some circumstances but not others, it would be important to explore the consequences of action on perception. For example, will an aircraft pilot flying a plane with considerably more power perceive an approach as farther from the ground, because of the greater reserve climbing capability, and therefore flow a lower (or steeper) approach than is wise? Do these aspects of large machines influence spatial perception? Such a role for action-specific perception could be critical with respect to safety.

Rehabilitation

Action capabilities change throughout the lifetime due to body morphology being in a constant state of flux as bodies develop and age. Typically, these changes occur slowly, and consequently, subsequent changes in our perceptions go unnoticed due to the torpidity of these transformations. However, the influence of the body on perception does become apparent when considering one's experiences in spatial environments as a child. Consider the example of revisiting one's childhood home as an adult. Countertops that seemed massively high now appear short and usable; the toy teapot now appears too small to contain a cup of tea much less serve a full party; the seemingly steep hill in the neighborhood does not appear so when not doggedly pedaling up it on one's first bicycle. Reflecting on these experiences makes it obvious that our spatial experiences were different when we were small; yet, we do not experience it happening, because our bodies and their action capabilities slowly change over time.

Unfortunately for some individuals, not all changes in morphology are gradual. Many individuals suffer the loss of function in their extremities due to factors including but not limited to limb loss, paresis or paralysis due to stroke or trauma, insult and injury. These changes in morphology are drastic and often immediate. According to the action-specific account of perception, these alterations in morphology should also influence certain spatial perceptions associated with the alteration. For example, in the opposite direction as in the aforementioned tool studies, loss of the use of an arm, hand or leg should lead to expansions of perceived distance and size in near space on the side of the body for which the limb was lost. Indeed, upper extremity amputees do show neglect of the space around and near their amputated limb (Makin, Wilf, Schwartz, & Zohary, 2010). In addition, the loss of use of the lower extremities should result in expansions of perceived distances in far space, especially on the injured body side. Supporting this notion, paralysis to the leg has been shown to influence perceived verticality and target position on the ground plane depending on the side of the injured leg (Blane, 1962).

Although these perceptual influences during injury may reflect the action capabilities of the patient following the injury, they also act as a hurdle in the recovery process. For many individuals recovering from stroke or injury, partial or full recovery of limb function can be accomplished, but this recovery involves a great deal of time, determination, and frustration associated with constantly retraining the injured limb. Now consider that due to changes in perceived space, objects in which these individuals should interact appear hopelessly far away. This perception is likely to discourage the consistent practice essential for rehabilitation. If an object appears impossibly far away or impossibly big, this perception will discourage reaching for or grasping the object. Without action, the system will not recalibrate to one's new abilities, creating a vicious cycle for which action never seems possible. However, this cycle would only be relevant for injuries in which practice performing an action is necessary for recovery.

One way of overcoming this obstacle has been accomplished using virtual environments which provide the patient visual-motor feedback of their virtual arm reaching farther in the virtual environment than it is actually moving in the physical environment (Adamovich, Fluet, Tunik, & Merians, 2009; Subramanian et al., 2007). This experience allows individuals to recalibrate their perceptions of reachable space and carry over this recalibration from the virtual to the real world (Jack et al., 2001; Jang et al., 2005). In other words, after experiencing that advantage in virtual environments, objects in the real world appear more act-on-able.

Diagnostic Measures

Because perceived distance acts as an index of functionality, perceived distance in near and far space can be used as an objective measure of recovery in rehabilitation therapy. As individuals recover their action capabilities, that recovery should be reflected in their perceptions of space. Consider a patient recovering from a stroke that debilitated the use of his or her arm. As the patient recovers, objects in near space should appear closer and closer as the use of the arm increases. Hence, increases in distance perception can be used as an indicator of recovery and a converging measure of the patient's perceptions of the recovery of their action capabilities. For individuals that must learn to use prosthetic limbs, perceived distance can also act as an index of the patient's perceptions of the efficacy of their prosthetic limb and predict the likelihood that they continue to use the prosthesis. As individuals begin to perceive the prosthetic limb with respect to the abilities that it affords, such as reaching and grasping, objects should appear closer and smaller. Indeed, most individuals with upper extremity limb loss fail to continue with the use of their prosthetic limb due to the failure to recognize its benefits, which has caused a large degree of concern in the medical community (McFarland, Hubbard Winkler, Heinemann, Jones, & Esquenazi, 2010). Perceived distance and size could act as an objective measure of patients' perceptions of the limb's usefulness in an effort to predict potential prosthetic limb abandonment.

Additionally, perceived distance can act as an objective diagnostic measure for disorders and injuries that are composed of cognitive and physiological variables. Chronic pain disorder is a prime example of this, as it is notoriously difficult to objectively diagnose due to the biopsychosocial variables, which characterize it. Interestingly, individuals with lower extremity chronic pain perceive distances in far space to be farther than age matched controls (Witt et al., 2009). Consequently, perceived distance has the potential to act as an objective diagnostic tool to complement the existing subjective questionnaire measures. For example, if a patient perceives objects' distances differently than age-matched peers, then along with the presence of other converging symptoms, it is likely that this individual is suffering from the associated disorder.

Communication

In various contexts, successfully communicating the location of certain objects as well as directions can be highly contingent on individuals' estimates of distance, size and geographical slant. This ability is highly valued in military scenarios when soldiers are communicating to others either their own location or that of a target of interest. This ability is also relevant in survival scenarios when communicating to others one's own location or that of another individual. However, the research investigating action specific perception has shown that perceived distance and slant vary based on the perceiver's energetic resources at the time. For example, fatigued individuals will see distances as being farther and geographical slants as being steeper than individuals that are energized. Hence a distance that may appear to be, for example, 12 meters to one individual, may appear to be 8 meters to another. If a remote operator instructs a foot soldier to turn after traversing 8 meter, the soldier will turn at a greater distance than instructed. After several errors similar to this, the soldier could end up in a completely different location than intended. In addition, if told to ascend a given geographical slant amongst others, misperceptions could result in the ascension of the wrong slant. Hence, from this work, instructions should rely more on visual landmarks and other solutions, such as GPS coordinates, rather than perceived spatial extents or inclines.

Summary

Action-specific effects in spatial perception have been documented in a wide range of tasks and scenarios. The findings demonstrate that spatial perception is influenced by the perceiver's ability to perform an action including whether or not an action can be performed successfully, with ease, and without high energetic demands. The majority of research on action-specific effects thus far has focused on documenting the breadth of these effects and on examining whether the findings reflect genuine changes in perception. Consequently, other critical issues have been neglected, such as potential applications for action-specific effects in spatial vision. Here, we outlined several possible applications that are deserving of future consideration and research. These include safety concerns, especially with respect to vehicle operation, rehabilitation, diagnostic tests, and communication between individuals.

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