

A Role for Control in an Action-Specific Effect on Perception

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According to the action-specific account of perception, people perceive the spatial layout of the environment in relation to their ability to act. Pioneering research by Bhalla and Proffitt (1999) demonstrated that hills were judged as steeper to perceivers with less physiological potential. Since this seminal work, much research has shown these action-specific effects generalize beyond hill slant perception and beyond physiological potential, but the underlying mechanisms are underspecified. The present experiments explore the potential mechanism that information about action is integrated with visual information about the target. According to an integration account, information from various sources are weighted, and the strength of these weights dictates the strength of that source of information on the resulting percept. One prediction is that it should be possible to vary the strength of the weights and thereby vary the size of a particular effect. To reduce the effect of action on perception, control over the action was taken away from participants. As predicted, losing control reduced the impact of action on spatial perception. This is the first reported instance of a partial action-specific effect, and is consistent with an integration-based mechanism.

Public Significance Statement

The research demonstrates that people see the spatial properties of the environment in relation to their ability to act. For example, when a ball is easier to catch, it appears slower than when it is more difficult to catch. Thus, spatial perception is not objective but rather is of the relationship between the environment and the person. The extent to which action affects perception depends on the extent to which a person can control the action. This implies that perception, and its susceptibility to influences by action, is likely to vary under a variety of situations such as when being a passenger in a car being driven by a teenager or in a self-driven car.

Keywords: action-specific perception, speed perception, perception-action relationships, embodied cognition

Nearly 2 decades ago, Mukul Bhalla and Denny Proffitt (1999) published some of the first research to suggest that spatial perception was influenced by a perceiver's ability to perform an action. Specifically, they showed that estimates of hill slant were influenced by physiological potential such that hills were estimated to be steeper when energetic costs increased (such as when fatigued, wearing a heavy backpack, being less physically fit or being older and of declining health). Since this seminal work, other research has extended the effects of physiological potential to others aspects of spatial perception including distance and size perception. Moreover, research has shown that these effects extend beyond physiological potential to include affordance- and performance-based effects on spatial perception as well. Grouped together, these effects of a person's ability to act on spatial perception have been

termed *action-specific effects* (Proffitt, 2006, 2008; Witt, 2011a, in press).

In addition to research on extensions of the variety of action-specific effects, much research has also questioned whether spatial perception is truly influenced. Alternative accounts include the idea that responses, but not perception, are impacted. These alternative accounts have gained traction as a result of research showing that cover stories designed to eliminate demand characteristics related to wearing a backpack also eliminate the effect of the backpack on estimated slant (see below; see also Philbeck & Witt, 2015).

With much research effort dedicated to exploring the scope of these action-specific effects and determining the nature of these effects as being perceptual or not, much less work has been dedicated to understanding the underlying mechanism driving action-specific effects. This is sensible given that it might seem premature to explore a perceptual mechanism if nonperceptual explanations have not been sufficiently discredited. While many action-specific effects have not been adequately vetted to allow for strong conclusions about whether or not they are genuinely perceptual, the paddle effect (described subsequently) can be considered perceptual and thus the underlying perceptual mechanisms can be explored. The main goal of the current experiments is to further advance the influential work of Bhalla and Proffitt (1999)

The author thanks Mike Tymoski for his help on a draft of the manuscript. This work was supported by Grants BCS-1314162, BCS-1348916, and BCS-1632222 from the National Science Foundation.

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by exploring potential underlying mechanisms driving action-specific effects.

Overview of Action-Specific Effects

Since the pioneering work of [Bhalla and Proffitt \(1999\)](#), much research has expanded on the idea that a person's ability to act can impact spatial perception. Some of this research has shown other kinds of manipulations related to physiological potential affect estimated slant, such as obesity, glucose consumption, and glucose depletion ([Schnall, Zadra, & Proffitt, 2010](#); [Taylor-Covill & Eves, 2013, 2014, 2016](#)). Other research has shown ways that the energetic costs of performing an action influence other aspects of spatial perception such as perceived distance ([Lessard, Linkenauger, & Proffitt, 2009](#); [Proffitt, Stefanucci, Banton, & Epstein, 2003](#); [Stefanucci, Proffitt, Banton, & Epstein, 2005](#); [Sugovic, Turk, & Witt, 2016](#); [Witt, Proffitt, & Epstein, 2004, 2010](#); [Witt, Schuck, & Taylor, 2011](#); but see [Woods, Philbeck, & Danoff, 2009](#)).

In addition to physiological potential, research has shown that other aspects of action also influence estimates of spatial perception. One category has been performance-based effects. For example, softball players who are hitting better than others judge the ball as bigger ([Gray, 2013](#); [Witt & Proffitt, 2005](#)). Similarly, archers shooting better than others judge the target as bigger ([Lee, Lee, Carello, & Turvey, 2012](#)). Parkour athletes judge walls as shorter compared with nonparkour athletes ([Taylor, Witt, & Sugovic, 2011](#)), and tennis players returning the ball better than others judge the net as shorter ([Witt & Sugovic, 2010](#)). Similar findings have also been documented in golfers, swimmers, and athletes kicking field goals ([Witt & Dorsch, 2009](#); [Witt, Linkenauger, Bakdash, & Proffitt, 2008](#); [Witt et al., 2011](#)).

A third category of action-specific effects concerns whether or not an action is possible. These are sometimes referred to as affordance-based action-specific effects because they focus on the affordance of the object. Affordances are the possibilities for action on or with an object ([Gibson, 1979](#)). Although perception of affordances can refer to the ease with which an action can be done, and thus the participants' willingness to perform the action ([Wagman & Malek, 2009](#)), frequently perception of affordances is measured by exploring the point at which an action is perceived as being just barely possible. For example, researchers have explored the boundary at which the width of doorways are perceived as affording passing through, or the boundary at which the height of a step is perceived as affording stepping (e.g., [Mark, 1987](#); [Warren, 1984](#); [Warren & Whang, 1987](#)). For affordance-based action-specific effects, researchers have compared spatial perception to objects within versus beyond this boundary. For example, people with broader shoulders estimated doorways to be narrower compared with people with narrower shoulders ([Stefanucci & Guess, 2009](#)). As another example, when reaching for a target presented beyond the boundary of the arm's reach, the target is estimated as closer when the participant wields a reach-extending tool that could reach the target compared with when they reach without the tool ([Davoli, Brockmole, & Witt, 2012](#); [Morgado, Gentaz, Guinet, Osiurak, & Palluel-Germain, 2013](#); [Osiurak, Morgado, & Palluel-Germain, 2012](#); [Witt, 2011b](#); [Witt & Proffitt, 2008](#); [Witt, Proffitt, & Epstein, 2005](#)). Additionally, tools presented near the boundary for reachability are estimated as being closer when their handle faces the participant than

when their handle is presented away from the participant and would require a longer, more awkward grasp ([Linkenauger, Witt, Stefanucci, Bakdash, & Proffitt, 2009](#)).

In addition to manipulating the body's capabilities via tool use, there have also been several studies conducted in virtual reality for which the perceiver's body is rendered as an avatar and the size of the avatar is manipulated. When the body is rendered as twice its normal size, nearby objects are judged as smaller, and when the body is rendered as half its normal size, nearby objects are judged as bigger relative to when the body is rendered as its actual size ([Van der Hoort & Ehrsson, 2014](#); [van der Hoort, Guterstam, & Ehrsson, 2011](#)). In virtual reality tasks involving reaching and grasping, similar effects are also observed. When the arm is rendered as longer, nearby objects are judged as closer than when the arm is rendered as shorter ([Linkenauger, Bühlhoff, & Mohler, 2015](#)). And when the hand is rendered as bigger, nearby objects are judged as smaller compared with when the hand is rendered as smaller ([Linkenauger, Leyrer, Bühlhoff, & Mohler, 2013](#)). Follow-up studies have shown that these body-based effects are not due to cues such as familiar size because similar effects are not observed when looking at a familiar object such as a pen, another person's hand, or a virtual arm that corresponds to one's own arm but that cannot be controlled ([Linkenauger et al., 2015, 2013](#); [Linkenauger, Ramenzoni, & Proffitt, 2010](#)).

It is unclear whether these body-based effects are a category of action-specific effects because many of them can be found even when no action is performed. In some cases, the action is implied (such as with reaching and grasping) but in the experiments for which the participants' bodies are rendered as lying on a table, it is unclear whether they ever anticipated interacting with the object. If these body-based effects are closely related to action, they would likely fall under the category of affordance-based action-specific effects. Otherwise, they might be their own category of effects on spatial perception.

Delineating categories of action-specific effects is important because each category of action-specific effects may involve different underlying mechanisms. In the current studies, the potential mechanisms are explored with respect to one type of action-specific effect (the paddle effect, see the following text). As evidence accumulates for a mechanism driving this effect, it will be necessary to determine if the mechanism generalizes to other categories of action-specific effects. More detailed reviews of the various kinds of action-specific effects are available elsewhere ([Gray, 2014](#); [Proffitt, 2006, 2008](#); [Proffitt & Linkenauger, 2013](#); [Witt, 2011a, in press](#); [Witt & Riley, 2014](#)).

The Paddle Effect

The action-specific effect explored in the current experiments is called the paddle effect. The paddle effect is the finding that ease to block a moving ball as a result of having a large versus small paddle influences estimated ball speed ([Witt & Sugovic, 2010](#)). The paddle effect is measured using the Pong task, which gets its name from its resemblance to the classic computer game Pong. The task takes place on a computer monitor (or a projection screen). On each trial, a virtual ball (a white circle) moves across the screen at 1 of 6 speeds, and participants attempt to block it using a paddle (a white rectangle) that they control using a joystick. On each trial, the paddle is set to a particular size, which

impacts the ease with which the ball can be caught. When the paddle is small, approximately half of the balls are successfully caught, and when the paddle is big, approximately 95% of the balls are successfully caught.

After each attempt to catch the ball, participants estimate the speed of the ball. The most common estimation is to categorize the ball as moving more like the slow anchor speed or more like the fast anchor speed. Participants are trained on the anchor speeds at the beginning of the experiment, and this type of estimate is called the speed bisection task because it is modeled after typical time bisection tasks. Other estimation methods include magnitude estimation for which participants rate the speed of the ball on a scale of 1 to 7 and a visual comparison task for which participants indicate whether the ball moved faster or slower than a moving comparison circle. All three of these explicit measures of perceived ball speed revealed the same pattern: the ball was estimated as faster when the paddle was smaller than when the paddle was bigger (Witt & Sugovic, 2012). The results are consistent with the claim that ease to block the ball influences perceived ball speed.

A major concern with the claims of the action-specific approach is whether a person's ability to act genuinely influences perception, rather than the responses themselves. For example, the original backpack study by Bhalla and Proffitt (1999) were later challenged as to whether they were due to response bias instead (Durgin et al., 2009). Differentiating between perceptual and post-perceptual effects is challenging because perception is an internal state that cannot be measured directly. Instead, researchers must make inferences based on observable behaviors. Most action-specific effects have not yet been vetted to determine whether or not they are perceptual. Some, like the backpack effect, have quite a bit of research dedicated to the issue but have not yet been resolved (Firestone & Scholl, 2016; Philbeck & Witt, 2015; Witt, 2017). However, there are several action-specific effects that have been sufficiently vetted for alternative explanations, and the evidence favors a perceptual explanation (Witt, 2016). One of these is the paddle effect.

Many studies have explored alternative, nonperceptual explanations for the paddle effect. Briefly, the studies have ruled out low-level visual differences, task demands and response bias, judgment-based effects, memory-based effects, and attention-based effects (King, Tenhundfeld, & Witt, 2017; Witt & Sugovic, 2010, 2012, 2013a, 2013b; Witt, Sugovic, & Dodd, 2016; Witt, Tenhundfeld, & Bielak, 2017). Given that these studies have been summarized elsewhere (Witt, 2016; Witt, Sugovic, Tenhundfeld, & King, 2016), a detailed overview will not be repeated here. Instead, this paper takes as its starting point the assertion that the paddle effect is a genuinely perceptual action-specific effect.

Potential Mechanism

Given that ease to block the ball (manipulated via paddle size) exerts an influence on perceived ball speed, the next step is to determine the underlying perceptual mechanism. To date, four mechanisms have been proposed. One is that these effects are due to attention. According to this mechanism, perceivers attend to the target differently depending on their abilities to act, and these differences in attention account for the subsequent differences in perception. For example, attending to the ball would make it appear slower than fixating a nearby stationary location, a phe-

nomenon known as the Aubert-Fleischl illusion (Aubert, 1886; Fleischl, 1882). If perceivers attended to the ball more when the paddle is big than when the paddle is small, attention could explain why the ball looks slower when the paddle is big.

Attention as a mechanism for action-specific effects has received mixed support. Attention was not supported as a mechanism for the effect of rendered body size in a virtual environment on perceived object size. When attention was forced onto a fixed location, perceivers still estimated a nearby object as bigger when the body was rendered as smaller than when the body was rendered as bigger (Van der Hoort & Ehrsson, 2014). In the case of aviation and performance landing a plane, the evidence suggested a role for attention. Pilots in a flight simulator who fixated the runway for longer time performed better landings and also perceived the runway as bigger (Gray, Navia, & Allsop, 2014). However, performance on landings still influenced perceived size even after fixation time was taken into account (R. Gray, personal communication, June, 10, 2015). Thus, although attention may play some role in the link between landing performance and perceived runway size, attention did not account for the entire effect.

Regardless of whether attention can explain other types of action-specific effects, attention is not the mechanism driving the paddle effect. In a series of experiments, attention was fixed regardless of paddle size (Witt et al., 2016). In one study, attention was forced to the ball via a secondary task, and in another study, attention was forced to the center of the display. Forcing attention to one particular object disrupts potential differences in attention when playing with the big paddle versus the small paddle. Consequently, if those attentional differences (such as looking more at the ball when the paddle is big than when the paddle is small) were responsible, the difference in perceived speed across paddle size should disappear. Instead, we found that the paddle effect persisted even when attention was focused on the ball or on the center of the display. These findings rule out differences in looking behavior as being the driving factor of the paddle effect.

A second potential mechanism relates to affordances. Affordance perception is perception of opportunities for action within the environment. For example, a Frisbee affords throwing and also affords holding water for a dog (or gin and tonic for Ultimate Frisbee players). It can act as a seat to help protect one's bottom from the wet grass, or hold various parts and pieces when working on one's bicycle. According to a strong version of the theory of affordances, affordances are the primary objects of perception and perception of spatial layout is functionally the perception of affordances within space. As stated by one proponent of this account, "from an ecological perspective, spatial properties take a back seat to affordances. In fact, affordances may be so fundamental to our perceptual experience that their perception may influence judgments of conventional spatial properties" (Fajen & Phillips, 2012, p. 72). In other words, according to this account, when people report their perception of spatial properties such as size and speed, they are actually reporting on their perception of a given affordance such as whether the object can be grasped or blocked. As a result, a spatial judgment on the size or speed of a target is actually "an implicit report on [an affordance such as] habitableness" (Lee et al., 2012, p. 1130). This mechanism reduces spatial perception to perception of affordances.

A third mechanism is called the perceptual ruler. This account emphasizes that all incoming optical and oculomotor

information takes the form of visual angles. Given that perceptual experience is not of visual angles but of external space, optical information must be transformed or scaled from visual angles to the metrics that are perceived. Proffitt and Linkenauger (2013) argued that the ruler used to perform this scaling is and must be grounded in the body. This account builds on a well-accepted example of body-based scaling. Eye height can be used to perceive object distance. The angle of declination to look at the object relative to the horizon can be used in relation to eye height to specify object distance (Sedgwick, 1986). The combination of eye height and angle of gaze can also be used to specify object height (Wraga, 1999). These are examples of body-based scaling by which some aspect of the body (eye height) can be combined with a visual angle (the angle(s) between the horizon and the object) to specify a spatial property (object distance or object height).

According to the perceptual ruler account, this type of body-based scaling extends to all types of spatial perception. For example, the perceived size of a graspable object is scaled to the size of the hand. When the hand is rendered as bigger (either via a magnifying lens or in a virtual environment), nearby objects appear smaller (Linkenauger et al., 2010, 2013; Linkenauger, Mohler, & Proffitt, 2011). Importantly, this hand-based scaling is not due to familiar size effects because the effects are not present when a familiar object is rendered as bigger or smaller. The effects of hand size on perceived object size are also not apparent when the hand is not the perceiver's own hand, suggesting own-body-based scaling rather than effects due to familiar size. It is clear how this kind of hand-based scaling could work when the hand is present near the object because the visual angles of the hand and the object are comparable (Witt, 2015). This account has not yet explained how such scaling could occur when the hand and object are not located near each other (Firestone, 2013). Despite some limitations that the account has not yet addressed, the idea that the body provides the perceptual ruler for scaling visual angles is compelling. Furthermore, critics of this account (e.g., Firestone, 2013) have not provided an alternative option other than the body that can be used to scale visual angles (Proffitt, 2013).

The perceptual ruler account can also be extended to other kinds of action-specific effects such as those of performance on perception. Good performance corresponds with consistent performance, whereas poor performance corresponds with more variable performance. The standard deviation of the performance could provide the ruler with which to scale perceived target size. When performance is more variable, the ruler is bigger, so the target is scaled as smaller. When performance is better and thus less variable, the ruler is smaller, so the target is scaled as bigger. The perceptual ruler account is currently underspecified as to which rulers are selected and used at any given time. For example, it is unclear whether (or when) perceived size of a golf hole is scaled to putting performance or to hand size. Future research could resolve these empirical questions.

A fourth potential mechanism is that action-specific effects are similar to multimodal effects in that information from various sources are integrated together. In the case of multimodal effects, information from one sensory system (such as audition) is weighted and integrated with information from another sensory system (such as vision). Analogously, for action-specific effects, information about action could be weighted and integrated with

visual information. According to this mechanism, action-specific effects could be considered another type of multimodal effect with the added stipulation that one of the incoming sources of information relates to the body and its potential for action.

The integration account raises the question: what is the source of information about action? Given that body size influences spatial perception (Stefanucci & Guess, 2009; Sugovic et al., 2016; van der Hoort et al., 2011), one source of information must relate to the size of the body. Body size can be directly perceived via haptics, vision, and/or proprioception. One need not depend upon stored representations of body size but rather can actively detect the size of the body at any given time, meaning that body size can be detected online. Another source of information relates to action-boundaries. For example, objects within reach are perceived as closer compared with objects beyond reach (e.g., Witt et al., 2005). Action-boundaries can be visually specified based on prior experience (Fajen, 2005). In addition, action-boundaries can be anticipated based on forward models (Witt & Proffitt, 2008). A forward model predicts the outcome of an action, both in terms of the external effects on the environment and the internal effects on the body. Therefore, a forward model is an apt source of information related to action—as it influences spatial perception. One type of action-specific effects relates to the outcome of the action on the external environment (such as whether an object can be reached or the likelihood of successfully hitting the softball). Another type of action-specific effects relates to the outcome of the action on the internal environment (i.e., the body, such as the energetic costs associated with performing the action). Given that both aspects of action influence spatial perception, the source(s) of this information must include both aspects. A forward model captures both aspects of action and therefore could be one of the sources of information about action that drives action-specific effects. Forward models can also capture performance variability, which is another aspect of action that influences spatial perception. For example, in the Pong task, perceivers are more likely to have success blocking the ball when playing with the big paddle than with the small paddle. There must be a process that can anticipate increased success with the big paddle relative to the small paddle that provides this information to perceptual processes.

Instead of a forward model being the source of action information, another option is the learned associations between paddle size and likelihood of blocking success. Participants could learn that they have less success with the small paddle than with the big paddle, and this learned association could provide the information that relates paddle size to ball blocking success. A third option is that the source of information about action is similar to those proposed by the other mechanisms. For example, the source could be visual experience of the variability of one's performance. According to the perceptual ruler account, poor golfing performance tends to be the result of more variable performance, and the increased variability of the position of the ball relative to the cup could provide an extended ruler with which to scale visual angles related to hole size (Proffitt & Linkenauger, 2013). Despite using a similar source of information, in the integration account, this information would be weighted and integrated whereas for the perceptual ruler account, this information serves as a scale with which

to transform visual angles into perceived spatial dimensions and for the affordances account, this information scales visual angles into perceived affordances that are implicitly reported.

From a theoretical perspective, distinguishing between these potential mechanisms can be straightforward. For example, a theoretical approach that is committed to the notion that only optical information can influence perception automatically excludes sources of information such as that from a forward model, and is more consistent with the notion of an affordance-based mechanism or the perceptual ruler account rather than the integration account. In contrast, a theoretical approach that considers top-down influences as essential for the functioning of perception (e.g., Rock, 1983) would be more consistent with an integration approach. However, distinguishing between the potential mechanisms from an empirical standpoint is less obvious, especially given that the current data is consistent with all of the mechanisms (except an attention-based mechanism, at least for the paddle effect).

The strategy of the current experiments, as an initial attempt to empirically differentiate the potential mechanisms, was to look for partial effects. A partial effect means that action still influences spatial perception, but the size of this influence would be reduced. In the case of the paddle effect, perceived ball speed would still be influenced by paddle size but to a lesser degree. A partial effect can help distinguish between mechanisms because it is specifically predicted by an integration account and inconsistent with the affordance and perceptual ruler accounts. According to an integration account, each source of incoming information is weighted, and these weights are dynamic, meaning that they can change. If information about action is weighted, it should be possible to reduce the weights and thereby reduce the size of the action-specific effect.

Currently, there are no known partial effects within the action-specific literature. There are factors that can eliminate an action-specific effect. For example, the paddle effect is eliminated when differences in ball blocking performance across the paddles are removed (Witt & Sugovic, 2012). For other types of action-specific effects, there are similar factors that eliminate the effect. Perceived distance to objects is influenced by the rendered size of the perceiver's arm in virtual reality, but only when the perceiver can control the arm and not when the arm is inert or is the arm of someone else (Linkenauger et al., 2015). However, there are no reports of partial action-specific effects in the literature. It is currently unknown if the lack of partial action-specific effects is because it is not possible for action to have a partial effect on perception or because the factors that dictate the weight on information about action have not yet been explored.

As an initial attempt to determine whether partial action-specific effects are possible, the current experiments explored the perceiver's ability to control the paddle as a potential moderating factor. *Action* can be defined as volitional control over one's movements to have a desired impact on the environment or the body. When the link between the perceiver's movements (i.e., wrist and hand movements to move the joystick) and the corresponding action (i.e., intentionally moving the paddle) is severed, the perceiver has a reduced ability to act. As a result, the visual system may reduce the weight on the information related to action, which would reduce the action-specific effect of paddle size on perceived ball speed. Put another way, action might have a larger influence (or be weighted more heavily) on subsequent perception when the action can be controlled, whereas action might have less influence (or be

weighted less heavily) on perception when control over the action is lost. For instance, a skilled hockey player having a good night might see the opponent's goal as bigger. But if he loses his balance, falls, and starts sliding down the ice, his skill would be less relevant given that he has reduced control over the execution of a shot. Given that skill would be less relevant for performance, skill might also be less relevant for perception when control is lost. More generally, when aspects of an action are less relevant for the outcomes of the action, they may have less of an effect on perception. This pattern would suggest that degree of control of action has a moderating influence on action's effect on perception.

Participants completed a modified version of the Pong task. At the start of each trial, the participant was cued as to the likelihood that they would have control over the paddle throughout the entire trial. One cue indicated that control was likely to be maintained whereas the other cue indicated that control was likely to be lost. If information about action is weighted and integrated, the anticipated loss of control could lead to reduced weights on information about likelihood of successfully blocking the ball. This would lead to a reduced paddle effect. In this case, control would be a modulating factor of the relationship between action and perception.

Another possible outcome is that control could exert an influence on perception of ball speed itself, rather than on the weighting of the information about action. Loss of control should lead to decreased performance, and decreased performance should lead to the perception that the ball appears to be moving faster. In this case, control would have a main effect rather than an interaction with paddle size. To summarize the predictions, if the results reveal an interaction between control and paddle size, this suggests that information about action is weighted before exerting an influence on perception and that control is a factor that can influence the weights. If there is no interaction, this suggests that control can affect perceived speed (presumably by influencing performance) but does not influence the weight of information related to action. This evidence would be consistent with an underlying mechanism for which information about action is not weighted or integrated with other sources of visual information (such as the affordance-based and perceptual ruler mechanisms).

Experiment 1: More Versus Less Control

The ease with which a ball can be blocked influences perceived speed of the ball. The purpose of this experiment was to examine whether the extent to which blocking ease influences perceived speed is modulated by control over the paddle. We manipulated control by severing the link between the movements of the joystick and their effect on the paddle.

Method

Participants. Forty-five students from an introductory psychology course volunteered in exchange for course credit. A power analysis revealed that 40 participants were needed to achieve 80% power to find an interaction such that a full-sized paddle effect was found under one condition but a half-sized paddle effect was found under the other condition. This would certainly be enough power to find a full elimination of the paddle effect in the second condition. For each experiment, I selected a date on which to end data collection that I anticipated would achieve the desired number of participants.



Figure 1. Overview of the display. In the actual experiment, the background was black, the gray area was invisible, and the paddle was either red or blue. The illustration shows the start of a trial with the big paddle. The paddle could only freeze when the ball was in the gray zone.

Stimuli and apparatus. Stimuli were presented on a 19-in. computer monitor with a black background. The stimuli consisted of a white ball (1.6 cm in diameter) that bounced across the screen at speeds ranging from 18 cm/s to 74 cm/s. A rectangle served as the paddle that was used to catch the ball. The paddle was 1 cm wide and set to one of two heights on each trial (1.97 or 9.86 cm). The paddle was also set to one of two colors (red or blue) on each trial. Color specified the likelihood that the paddle would remain under control, and the correspondence between color and likelihood of control was randomly determined for each participant. Participants controlled the vertical position of the paddle using a joystick. The ball's start location was 1.85 cm from the left side of the screen (see Figure 1). The paddle was located 2.73 cm from the right side of the screen. The distance between the centers of the ball and paddle was 32 cm.

Procedure. Participants were first trained on the slow and fast anchor speeds. Text on the screen indicated whether the speed would be fast or slow. Then the ball moved from left to right with no vertical displacement at either the slow speed (18 cm/s) or the fast speed (74 cm/s). Participants viewed three exposures of each speed, and order was randomized. Participants then viewed an additional three exposures of each speed without any prior identification and instead participants were required to identify the speed by pressing the left or right buttons on a joystick, which were labeled *slow* and *fast*, respectively. Participants received feedback on their speed judgments (*correct* or *incorrect*) at this stage only. This task is easy, and performance was at 99%. After training, participants completed the test trials.

On each test trial, the ball bounced across the screen at one of six speeds (26 cm/s to 67 cm/s). The ball traveled left to right and moved along a diagonal. The angle of this diagonal differed as a function of ball speed so that the path of the ball varied across trials and was thus harder to catch.¹ The vertical component of the ball's movement (up vs. down) was randomized to start, and reversed when the ball reached the top or bottom of the display. The vertical component also reversed at random approximately 5% of the time in order to make the blocking task more difficult.

Participants controlled the vertical position of the paddle by moving a joystick forward and backward. On each trial, the paddle

was set to one of two heights (small or big) and one of two colors (red or blue). The color of the paddle corresponded to the two control conditions. In the high-control condition, the paddle was set to freeze at random 20% of the time. In actuality, it froze 18% ($SD = 2.7\%$) of the time. In the low-control condition, the paddle was set to freeze at random 80% of the time. In actuality, it froze 78% ($SD = 3.2\%$) of the time. At the beginning of each trial, a freeze location was determined in case it was needed. The freeze location was determined randomly but was restricted to locations between 5.5 and 29.5 cm to the right of the left edge of the screen (see gray area in Figure 1). On trials for which the paddle did not freeze, this value was ignored. On trials for which the paddle froze, the freezing took place once the ball reached this point. Once the paddle was frozen, the joystick's movements no longer controlled its position.

Regardless of whether or not the participant was able to control the paddle, if the paddle was positioned to correctly catch the ball, the ball stopped on the paddle; otherwise the ball continued and disappeared at the edge of the display. After each attempt to block the ball, participants estimated the speed of the ball via a speed-bisection task for which they classified each ball as moving more like the slow anchor speed or more like the fast anchor speed by pressing the corresponding button on the joystick. Each block contained 48 trials (2 paddle sizes $\times$ 2 control conditions $\times$ 6 speeds $\times$ 2 repetitions), and order was randomized within a block. Participants completed eight blocks of trials for a total of 384 trials. The experiment took approximately 30 min.

Results and Discussion

Both manipulations of paddle size and control condition influenced the proportion of balls successfully blocked. Proportion of balls successfully blocked was entered into a 2×2 repeated-measures analysis of variance (ANOVA) with paddle size and control condition as within-subjects factors. Balls were blocked more successfully in the high-control condition than the low-control condition, $F(1, 44) = 576.21, p < .001, \eta_p^2 = .93$. Balls were blocked more successfully when the paddle was big than when it was small, $F(1, 44) = 3155.57, p < .001, \eta_p^2 = .99$. The difference in blocking success between the two paddle sizes was reduced in the low-control condition compared with the high-control condition, $F(1, 44) = 38.42, p < .001, \eta_p^2 = .47$ (see Table 1).

Perceptual judgments of ball speed were estimated by calculating the point of subjective equality (PSE). The PSE corresponds to the point at which there are an equal number of judgments made that the ball is moving like the slow anchor speed and the fast anchor speed. In other words, the PSE is the speed of the ball that looks equally slow and fast. As shown in Figure 2, when the ball is judged as faster (small paddle conditions), this results in a lower PSE. Therefore, a lower PSE corresponds to seeing the ball as moving faster. PSEs were calculated for each paddle size and control condition combination for each participant from the slopes and intercepts from

¹ The position of the ball was updated every 4 ms, and the ball was displaced to the right by 2 to 7 pixels and vertically by 2 pixels at each update. This resulted in six test speeds: 26.1, 33.3, 41.3, 49.7, 58.4, and 67.2 cm/s.

Table 1

Mean Proportion of Balls Successfully Blocked (and Standard Deviation in Parentheses) as a Function of Experiment, Paddle Size (Small or Big), and Control Condition

Condition	Experiment 1		Experiment 2		Experiment 3	
	Small	Big	Small	Big	Small	Big
High control	.38 (.08)	.82 (.07)	.46 (.08)	.90 (.07)	.67 (.11)	.90 (.06)
Low control	.21 (.04)	.56 (.06)	.22 (.04)	.57 (.07)	.18 (.04)	.58 (.07)

Note. High control refers to the full-control condition in Experiment 2.

binary logistic regressions.² Two participants had at least two PSEs that were beyond at least 1.5 times the interquartile range. They were removed prior to analysis, although their inclusion did not alter the pattern of results.

PSEs were submitted to a repeated-measures ANOVA with control condition and paddle size as within-subjects factors. Paddle size significantly influenced the PSEs, $F(1, 42) = 130.19$, $p < .001$, $\eta_p^2 = .76$. The ball was estimated as moving faster when the paddle was smaller than when it was bigger. Control condition significantly influenced PSEs, $F(1, 42) = 4.13$, $p = .048$, $\eta_p^2 = .09$. Balls were judged as faster in the high-control condition compared with the low-control condition. Critically, there was a significant interaction between paddle size and control condition, $F(1, 42) = 4.98$, $p = .031$, $\eta_p^2 = .11$. As shown in Figure 3, paddle size had a larger effect in the high-control condition than in the low-control condition.

It may seem surprising that when playing with the small paddle, participants judged the ball as moving slower when in the low-control condition than the high-control condition given that they blocked the ball more successfully in the high-control condition. That the ball looks slower even though blocking success is worse is inconsistent with an affordance-based account for which participants are implicitly reporting blocking ease. However, the result is consistent with the claim that ease to block the ball affects perceived ball speed but that the information about blocking ease is

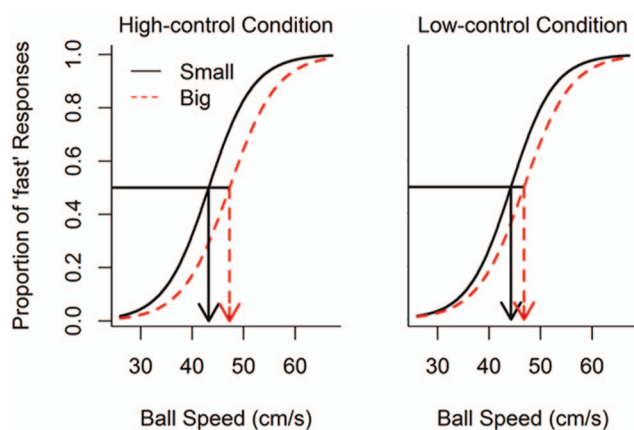


Figure 2. Proportion of “fast” responses as a function of ball speed, paddle size, and control condition for Experiment 1. Lines represent binary logistic regressions based on mean coefficients. Arrows point to the mean point of subjective equality (PSEs) for each condition. See the online article for the color version of this figure.

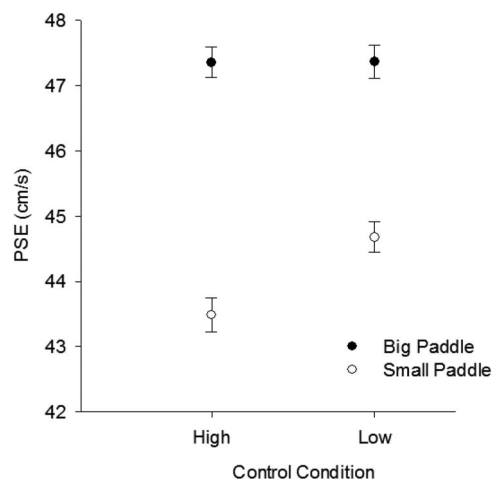


Figure 3. Points of subjective equality (PSEs) are plotted as a function of paddle size and control condition for Experiment 1. Error bars represent 1 standard error of measurement (SEM) calculated within-subjects. A lower PSE indicates the ball was judged as faster.

weighted. The point of objective equality (i.e., mean physical ball speed) is 46 cm/s, so the ball still looks faster than its actual speed when the paddle is small, but to a lesser extent, because (presumably) less weight is placed on ease to block the ball when in a low-control condition.

The pattern of results indicates that a person's ability to block the balls (due to paddle size) had a larger effect on estimated speed when they could anticipate full control over the paddle than when they anticipated losing control. Put another way, when control was reduced, ease to block the ball had less impact on perceived speed. This pattern is consistent with the idea that information about action is weighted as it exerts its influence on perceived speed and that control can influence this weight.

When analyzed separately, the paddle effect was significant for both control conditions. For the high-control condition, a paired-samples t test indicated that participants estimated the ball as moving faster when the paddle was small than when the paddle was big, $t(42) = 9.88$, $p < .001$, $d_{RM} = .80$, $M_{diff} = 3.87$ cm/s. Although reduced, a significant paddle effect also was found for the low-control condition, $t(42) = 6.91$, $p < .001$, $d_{RM} = .55$, $M_{diff} = 2.69$ cm/s. This latter result shows that even when control was lost, the paddle effect still emerged despite being diminished.

² There were not enough trials to calculate PSEs for when the paddle froze in the high-control condition, nor to calculate PSEs for when the paddle did not freeze in the low-control condition (the binary logistic regressions did not converge for most participants when these trials were analyzed separately). Removing these trials before calculating PSEs did not change the pattern of outcomes, which is not surprising given that they comprised approximately 20% of all trials. In addition, comparing data across all trials for which the paddle froze (regardless of whether it was a high-control or low-control condition) to all trials for which the paddle did not freeze produced the same outcomes as the comparison between high-control and low-control. Again, this is not surprising given that control condition and freeze occurrence were set to correspond to each other. I proceeded with analyzing based on control condition, rather than freeze occurrence, because the trials were perfectly balanced across paddle size and ball speed.

Before interpreting this result, the next step was to replicate the study.

Experiment 2: Full Control Versus Less Control

This experiment was a near-exact replication of Experiment 1. The only difference was that the high-control condition was replaced with a full-control condition.

Method

Thirty-six students participated in exchange for course credit. None had participated in Experiment 1 or any other Pong experiments. The set-up was the same as in Experiment 1 except that instead of a high-control condition, there was a full-control condition. When the paddle was red (for some participants, blue for others), the paddle remained under control for the entire duration of the trial. When the paddle was the other color, the paddle was set to freeze at random 80% of the time. As before, after each attempt to block the ball, regardless of whether the paddle froze and regardless of whether or not the ball was blocked, participants estimated the speed of the ball via the speed bisection task.

Results and Discussion

As in Experiment 1, participants blocked the ball more successfully when they had full control over the paddle than in the low-control condition, and when the paddle was big than when it was small, $F_s > 800$, $p_s < .001$, $\eta_p^2 > .92$ (see Table 1). The interaction between control condition and paddle size was also significant, $F(1, 35) = 18.82$, $p < .001$, $\eta_p^2 = .35$.

PSEs were calculated and analyzed as before. No participants were identified as outliers. Paddle size significantly influenced the PSEs, $F(1, 35) = 70.90$, $p < .001$, $\eta_p^2 = .67$. Control condition did not influence the PSEs, $F(1, 35) = 0.10$, $p = .76$, $\eta_p^2 < .01$. Critically, the interaction between paddle size and control condition was significant, $F(1, 35) = 13.09$, $p = .001$, $\eta_p^2 = .27$. Paddle size had a larger effect on PSEs in the full-control condition than in the low-control condition (see Figures 4 and 5). Paired-samples t tests were conducted to compare the effect of the paddle size for each control condition. In the full-control condition, the paddle effect was significant, $t(35) = 8.28$, $p < .001$, $d_{RM} = .75$, $M_{diff} = 3.97$ cm/s. In the low-control condition, the paddle effect was also significant, $t(35) = 5.59$, $p < .001$, $d_{RM} = .44$, $M_{diff} = 2.22$ cm/s. As in Experiment 1, there was a significant but reduced paddle effect when control was lost.

One potential mechanism that could underlie action-specific effects such as the paddle effect is that information about action is one source of information for perception and that this information is weighted. If weighted, there should be factors that could affect these weights, which would influence the magnitude of the action-specific effect. Previously, no research had reported a partial or moderated effect of action on spatial perception. Here, the hypothesis was that eliminating control would decrease the effect of the action on perceived ball speed. The data match these predictions.

However, the reduced paddle effect could be due to reduced impact of paddle size on ball blocking success, rather than on control per se. If this were the case, the outcome of each trial would be relevant for estimated speed, rather than control over the

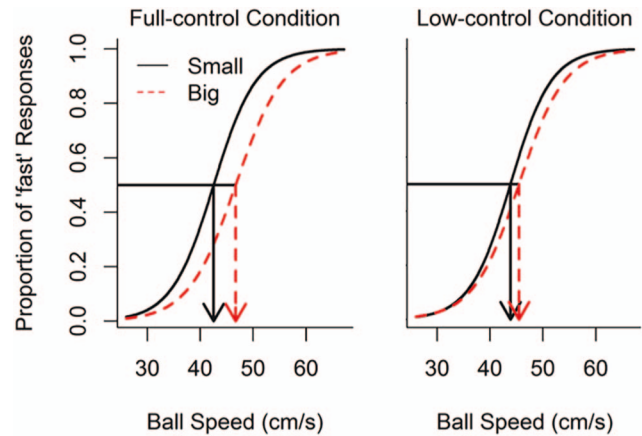


Figure 4. Proportion of “fast” responses as a function of ball speed, paddle size, and control condition for Experiment 2. Lines represent binary logistic regressions based on mean coefficients. Arrows point to the mean points of subjective equality (PSEs) for each condition. See the online article for the color version of this figure.

paddle’s movements. Participants could have estimated missed balls as fast and successfully blocked balls as slow. This tendency would have contributed to the obtained results. To assess this possibility, the data were first combined from Experiments 1 and 2, and PSEs were calculated for each paddle size and each outcome (successful block vs. miss), collapsed across control condition (in order to ensure enough trials to reach convergence in the logistic regressions). These PSEs were submitted to a repeated-measures ANOVA with paddle size and outcome as within-subjects factors. Paddle size had a significant effect on PSEs, $F(1, 78) = 125.94$, $p < .001$, $\eta_p^2 = .62$ (Small paddle: $M = 44.20$ cm/s, $SE = .51$; Big paddle: $M = 47.10$ cm/s, $SE = .57$). Outcome had a marginal effect on PSEs, $F(1, 78) = 3.88$, $p = .052$, $\eta_p^2 = .05$ (Miss: $M = 45.39$ cm/s, $SE = .54$; Block: $M = 45.91$ cm/s, $SE = .55$). Despite being marginally significant, the effect of outcome was small (approximately 0.5 cm/s). The interaction between paddle size and outcome was not significant, $F(1, 78) = 0.14$, $p = .71$, $\eta_p^2 < .01$. This suggests a small, marginally significant impact of trial outcome on speed estimates, and is therefore unlikely to account for the significant and larger effect of paddle size in the high-control condition. In addition, the role of outcome was further examined in a follow-up experiment that was similar to Experiment 1 but instead of freezing the paddle, the paddle flew off the screen and was thus ineffective at blocking the ball.

Experiment 3: Fly-Away Manipulation

Instead of the paddle freezing, in this experiment, the paddle would fly off the screen. This manipulation not only eliminated control of the paddle but also prevented any success at blocking the ball. The outcomes should help determine whether blocking success contributed to the prior results.

Method

Participants. Seventy-one students participated in exchange for course credit. As before, data was collected until a certain date,

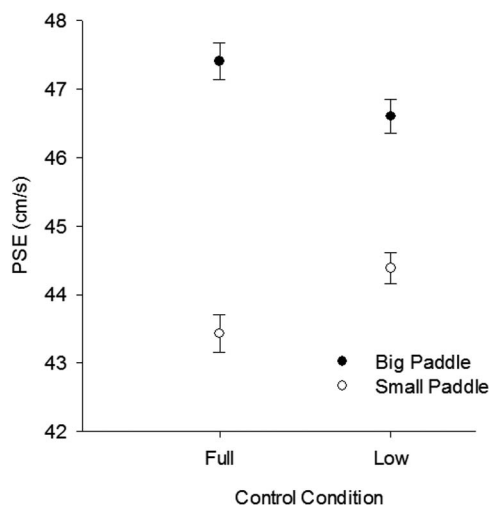


Figure 5. Points of subjective equality (PSEs) are plotted as a function of paddle size and control condition for Experiment 2. Error bars represent 1 standard error of measurement (SEM) calculated within-subjects. A lower PSE indicates the ball was judged as faster.

and the date was selected to ensure collection of at least 40 participants. Number of participants obtained was greater than had been estimated.

Procedure. Everything was the same as in Experiment 1 except as follows. In Experiments 1 and 2, when the paddle froze, it simply stopped moving from its current location. In Experiment 3, rather than freezing, the paddle flew off the screen by moving up until it was no longer visible (or, if the paddle was already located on the bottom half of the display at the time control was cut-off, the paddle moved down until it was no longer visible). When the paddle flew off the screen, it always moved at 64.6 cm/s, and the ball was never successfully blocked. As in the other experiments, paddle color indicated whether the paddle had a 20% or 80% likelihood of flying away, and color assignment was randomly determined for each participant. Participants completed 8 blocks of trials, and each block contained 48 trials (2 paddle sizes $\times$ 2 fly away conditions $\times$ 6 ball speeds $\times$ 2 repetitions) in which order was randomized.

Results and Discussion

PSEs were calculated as before. Five participants were identified as outliers because they had at least 1 PSE that was 3 times greater than the interquartile range or at least 2 PSEs that were 1.5 times greater than the interquartile range. These participants were removed from the analysis, although their removal did not change the pattern of outcomes.

PSEs were submitted to a repeated-measures ANOVA with paddle size and control condition as within-subjects factors. Paddle size significantly influenced the PSEs, $F(1, 65) = 84.84$, $p < .001$, $\eta_p^2 = .57$. Participants estimated the ball as moving faster when the paddle was small than when the paddle was big. Control condition significantly influenced the PSEs, $F(1, 65) = 17.85$, $p < .001$, $\eta_p^2 = .22$. Unlike in the first two experiments, participants estimated the ball as moving faster when the paddle was likely to fly away than when the paddle remained under control. This result

was not anticipated given that one might expect the ball to be seen as moving faster when one needs to act on it than when action is not permitted, as has been shown previously when performing the Pong task compared to watching someone else perform the task (Witt, Sugovic, & Taylor, 2012). However, it is possible that the paddle flying away drew attention toward the paddle and away from the ball, and it is known that the ball will appear to move faster when looking off to the side than when fixating the ball itself, a phenomenon known as the Aubert-Fleischl illusion (Aubert, 1886; Fleischl, 1882). In other words, the increase in overall perceived speed in the low-control condition may relate to attentional factors rather than action-based factors.

As in the first two experiments, there was a significant interaction between paddle size and control condition, $F(1, 65) = 7.40$, $p = .008$, $\eta_p^2 = .10$ (see Figures 6 and 7). Paddle size had a larger impact on PSEs when participants anticipated full control than when they anticipated the paddle flying away. Paired-samples t tests revealed significant effects of paddle size for the high-control condition, $t(65) = 7.95$, $p < .001$, $d_{RM} = .73$, $M_{diff} = 4.37$ cm/s, and for the low-control condition, $t(65) = 7.76$, $p < .001$, $d_{RM} = .56$, $M_{diff} = 2.98$ cm/s. These results closely match those found in Experiments 1 and 2. The results suggest that the previously found effect of paddle size in the low-control conditions was not due to differential outcomes across paddle sizes of successful blocks versus misses given that no balls were blocked when the paddle flew away. Instead, it is likely that there was still some anticipation of the impact of the paddle when it was under control. The results are consistent with the claim that control is a moderating factor for the paddle effect.

Experiment 4: Timing of Loss of Control

If control is a moderating factor, the timing of when control is lost should be relevant. When control over the paddle is lost earlier in the trial, it should have a reduced effect on perceived ball speed than when control is lost later in the trial. There were not enough data to calculate PSEs depending on when control was lost, so in

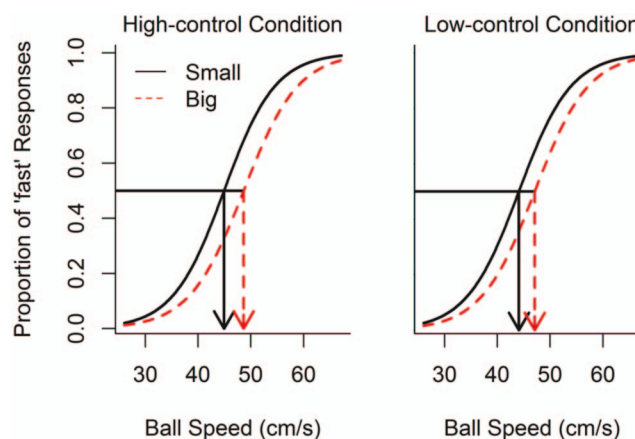


Figure 6. Proportion of "fast" responses as a function of ball speed, paddle size, and control condition for Experiment 3. Lines represent binary logistic regressions based on mean coefficients. Arrows point to the mean points of subjective equality (PSEs) for each condition. See the online article for the color version of this figure.

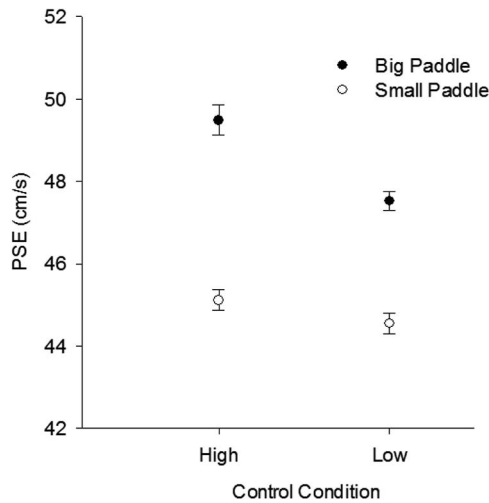


Figure 7. Points of subjective equality (PSEs) are plotted as a function of paddle size and control condition for Experiment 3. Error bars represent 1 standard error of measurement (SEM) calculated within-subjects. A lower PSE indicates the ball was judged as faster.

Experiment 4, ball speed was estimated using a magnitude estimation task instead.

Method

Twenty-seven students participated in exchange for course credit. As before, a date was selected to stop data-collection. The experiment was the same as Experiment 1 except for the following changes. During training, the anchor speeds were introduced as Speed 1 and Speed 7. During test trials, participants rated each speed on a scale of 1 to 7 and entered their response on the keyboard. Two participants did not understand the instructions and entered only 1 or 7 (rather than 1 through 7) during the experiment and were excluded from the analyses.

Results and Discussion

Because not all trials were needed to fit logistic regressions, only trials for which the freeze outcome matched the control condition were included (i.e., high-control trials when the paddle did not freeze and low-control trials when the paddle did freeze). Perceptual judgments were calculated as speed judgment minus ball speed. Mean perceptual judgments were calculated for each participant across all speeds for each combination of paddle size, control condition, and whether or not the ball was set to freeze

Table 2
Mean Ball Blocking Success (and Standard Deviation in Parentheses) as a Function of Paddle Size, Control Condition, and Early Versus Late Control Loss

Condition	Small		Big	
	Early	Late	Early	Late
High control	.47 (.13)	.45 (.10)	.89 (.13)	.89 (.14)
Low control	.11 (.03)	.21 (.07)	.39 (.08)	.62 (.11)

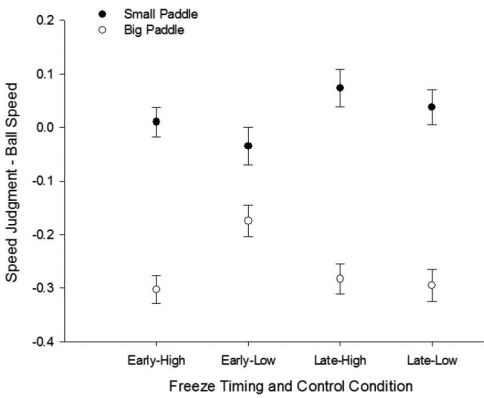


Figure 8. Perceptual judgments (calculated as speed judgment minus ball speed) are plotted as a function of paddle size (small and big), control condition (low and high), and whether the paddle froze early or late in the trial for Experiment 4. Error bars represent 1 standard error of measurement (SEM) calculated within-subjects. A higher perceptual judgment indicates the ball was judged as faster.

before or after the halfway point of where the ball could freeze. No participants were identified as outliers. Ball blocking performance is shown in Table 2.

Control condition had differential effects on the influence of paddle size depending on whether control was lost early versus late (see Figure 8). When control was lost early, there was a significant interaction between paddle size and control condition, $F(1, 24) = 5.76, p = .025, \eta_p^2 = .19$. In contrast, when control was lost during the second half of the display, the interaction was not significant, $F(1, 24) = 0.75, p = .75, \eta_p^2 = .004$. (Note: the three-way interaction between freeze location, control condition, and paddle size did not reach significance, $F(1, 24) = 1.60, p = .22, \eta_p^2 = .06$. This may be due to low power given that desired number of 40 participants was not achieved in timeframe expected). For each combination of control condition and freeze location, the paddle effect was still significant (early and low control: $t(24) = 2.65, p = .014, d_{RM} = .27$; all other conditions, $t(24)s > 6.53, ps < .001, d_{RM} > .63$). Difference scores were created as the mean perceptual judgments with the small paddle minus the mean judgments with the big paddle. Paired-samples t tests indicated that the difference score for the condition for which control was lost early was significantly smaller than all other conditions, $t(24)s > 2.29, ps < .031, d_{RM} > .74$ (see Figure 8).

The obtained pattern of results with PSEs match the obtained pattern of results with ball blocking success. Therefore, it could be that the PSEs are a function of likelihood of successfully blocking the ball without an impact of control. However, Experiment 3 provided evidence against this possibility. The data are consistent with the claims that the paddle effect can be modulated and that control is a relevant factor. Furthermore, the earlier that control was lost, the less effect paddle size had on perceived speed. This suggests a dynamic weighting of information related to action.

General Discussion

The action-specific account of perception—that perceivers see the spatial layout of the environment relative to their ability to

act—is supported by many empirical demonstrations but lacks a satisfactory mechanistic explanation. Much research on action-specific effects have been devoted to documenting that the effects exist, identifying the scope of action-specific effects, and exploring whether or not the effects reflect genuine influences on perception (Firestone & Scholl, 2016; Philbeck & Witt, 2015). In contrast, less research has been devoted to exploring the mechanism. One reason for the lack of this research is that it would be premature to explore a perceptual mechanism before determining that the effect is indeed perceptual. Given that this is an ongoing debate, much research focuses on answering the question of perception first. However, in the case of the paddle effect, evidence already provides strong support for a perceptual account (Witt, 2016; Witt, Sugovic, Tenhundfeld, et al., 2016). As a reminder, the paddle effect is the phenomenon whereby balls that are easier to catch (by using a bigger, more effective paddle) appear slower than balls that are more difficult to catch (by using a smaller, less effective paddle). In addition, previous research demonstrates that the paddle effect is independent of attention (Witt, Sugovic, & Dodd, 2016), prompting the need for another mechanistic explanation.

One potential mechanism is that action-specific effects are like a multimodal effect. For multimodal effects, information detected from one sensory system can influence perception within another sensory system. For example, in the classic McGurk effect, seeing a face saying *ga* when coupled with auditory sound of *ba* leads to the perception of the syllable *da*. As another example, the presentation of two auditory beeps can make a single visual flash appear as if it were two flashes (Shams, Kamitani, & Shimojo, 2000). One possibility is that action-specific effects are also like multimodal effects, but instead of information being detected from a sensory system, the information is detected from systems that monitor aspects of the body and its potential for action (such as proprioceptors or interoceptors, Witt & Riley, 2014).

A characteristic of multimodal effects is that each source of information is weighted, and this weight dictates the extent to which that source of information exerts an influence over the resulting perceptual experience. If action-specific effects are like multimodal effects, there should be evidence that information about action can be weighted. This predicts that partial action-specific effects should be possible. To explore this possibility, the current experiments involved the manipulation of control. Given that action is about volitional control over one's movements to bring about a goal state, the idea was that the weight given to information about action would be reduced when the action was no longer under control. The data supported this prediction. Ease to block the ball (as a function of paddle size) had a stronger effect on perceived ball speed when participants anticipated having control over the paddle than when they anticipated losing control. This is the first reported instance of a partial or moderated action-specific effect. Moderated effects are consistent with the proposal that information about action is weighted as it exerts its influence on perception.

Partial, moderated effects are predicted by conceptualizing action-specific effects as being like a multimodal effect. Does this finding rule out other kinds of mechanisms? One potential mechanism is that action-specific effects are driven by a common coding mechanism. According to the common coding approach, there are shared representations between action and their corresponding percepts (Hommel, Musseler, Aschersleben, & Prinz,

2001; Prinz, 1990). This shared representation provides a mechanism to allow actions to influence perception; for example, moving left can bias perception of a leftward-facing object such as an arrow. The common coding framework discusses representations as being shared without mention of the information (e.g., action or perception) as being weighted. This does not mean the theory of common coding cannot explain a modulated effect, but it does not predict one.

Another possibility relates to the perceptual ruler mechanism proposed by Proffitt and Linkenauger (2013). According to their theory, action provides a ruler with which to scale incoming visual information into conscious percepts. Visual information takes the form of visual angles, so it must be scaled into the units that are perceived. Proffitt and Linkenauger (2013) propose that the transformation function used to perform this scaling relates to the body and its abilities to act. Their theory builds off of research showing that eye height can be used to scale visual angles to perceive object distance and object height (Sedgwick, 1986; Wraga, 1999). While the theory extends nicely to action-based effects related to morphology (e.g., objects look smaller when the hand is rendered in virtual reality as bigger, Linkenauger et al., 2013), the theory is underspecified with respect to performance-based effects such as the paddle effect. One possibility is that eye movements provide a ruler with which to scale information about optically specified ball speed. However, previous research has shown that eliminating eye movements does not reduce the paddle effect (Witt, Sugovic, & Dodd, 2016), suggesting that saccades do not play this kind of role. Proffitt and Linkenauger have postulated that performance-based effects depend on rulers that are sensitive to the variability surrounding successful outcomes. Good performance means that performance is more consistently accurate, whereas bad performance means that performance is less consistently accurate. It is not immediately obvious how this idea maps on to the paddle effect, and more specifically, how it could explain the reduced paddle effect in the low control conditions. It is possible that when control is likely to be severed, the hypothetical ruler might change, and that is why the effect is reduced. The details surrounding this theory, and how it could be used to explain the current data, need further exploration. There are many different types of action-based effects, and it is possible that each category of effects is driven by different mechanisms. Morphology-based action-specific effects may be the result of a perceptual ruler-type mechanism, whereas performance-based action-specific effects may rely on other processes such as weighted integration. Nevertheless, while the current data are predicted by an integration account, they are not predicted by a perceptual ruler account.

According to an affordance-based account, the factor that should be relevant is whether the ball is likely to be blocked. Thus, when participants lose control of the paddle and this degrades performance, the ball should be seen as less-blockable and should therefore be reported as faster. This account predicts a main effect of control, but not the interaction between control and paddle size. The data are therefore inconsistent with an affordance-based mechanism.

The current results reveal two main findings. As just discussed, one finding is that partial action-specific effects are possible. This is predicted by the integration account but not by the perceptual

ruler account and is inconsistent with an affordance-based mechanism. The other finding is that the factor that reduced the paddle effect related to control. This is relevant because a subsequent question for future research is to determine the exact nature by which the weights on the various sources of information are determined.

One possibility is that the weights are determined or influenced by attention (Gogel & Sharkey, 1989; Gogel & Tietz, 1977). The paddle could be better attended when perceivers have control and this increased attention toward the paddle could strengthen the weight on information related to blocking ease. A second possibility is that the weights are determined by the reliability of the source of information (e.g., Ernst & Banks, 2002). Reliability relates to the precision of the information. In the case of the paddle effect, the information concerns the likelihood that the ball will be successfully blocked. Anticipating the likelihood of ball blocking success could be more reliable when the perceiver has control over the paddle. Thus, losing control could reduce the reliability of information related to action, and this could weaken the weight for this source of information. For example, if the source of information about the ease to block the ball comes from a forward model, the forward model might be more engaged when perceivers have control than when they lose control. This increased engagement could strengthen the impact of the outcome of the forward model on perceived ball speed.

Conclusion

In summary, the paddle effect is an example of a genuinely perceptual action-specific effect for which a person's potential for action related to blocking a ball influences perceived ball speed. To further advance the action-specific approach, it is necessary to understand the underlying mechanisms. The current experiments provide initial support for the idea that the paddle effect involves weighted integration between action-based and optical information. According to an integration model, each source of information is weighted and the weights determine the relevant impact of each source. When perceivers can control their actions, the weight is stronger, so action has a bigger effect on perception, than when control is lost. This mechanism likens action-specific effects to multimodal effects. However, whereas multimodal effects are driven by integration of sensory systems that detect information about the external environment, action-specific effects involve integration of systems that detect both the external environment and the internal environment, including the body and its potential for action. Because of this integration, perception expresses the external environment as it relates to action.

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Received September 2, 2016

Revision received March 22, 2017

Accepted April 16, 2017 ■