Does Ease to Block a Ball Affect Perceived Ball Speed?
Examination of Alternative Hypotheses

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According to an action-specific account of perception, the perceived speed of a ball can function as a function of the ease to block the ball. Balls that are easier to stop look like they are moving slower than balls that are more difficult to stop. This was recently demonstrated with a modified version of the classic computer game Pong (Witt & Sugovic, 2010). However, alternative explanations can also explain these results without resorting to nonoptical effects on perception. To examine whether blocking ease influences perception, we conducted several experiments. We examined whether the apparent effects were due to the type of perceptual judgment, the timing of the judgment, and the effectiveness of the paddle. The results are consistent with a perceptual explanation, and help build a case that blocking ease can influence perceived speed.

Keywords: action-specific perception, affordances, perceived speed, perception-action coupling

According to an action-specific account, perception is a function of a person’s ability to perform the intended action (Witt, 2011a). For example, softball players who were hitting better than others judged the ball to be bigger (Witt & Proffitt, 2005; see also Cañal-Bruland & van der Kamp, 2009). Objects that were within reach and easier to grasp looked closer and smaller than when the same objects were beyond reach or difficult to grasp (Costantini, Ambrosini, Sinigaglia, & Gallese, 2011; Linkenauger, Witt, & Proffitt, 2011; Linkenauger, Witt, Stefanucci, Bakdash, & Proffitt, 2009; Witt & Proffitt, 2008; Witt, Proffitt, & Epstein, 2005; Witt, 2011b). Objects that were easier to pick up also appeared lighter than when the objects were more difficult to lift (Amazeen, Tseng, Valdez, & Vera, 2011; Doerrfeld, Sebanz, & Shiffrar, 2009). Hills were judged to be steeper to energy-deprived individuals compared to perceivers who had just consumed a sugary drink (Schnall, Zdra, & Proffitt, 2011). Underwater targets looked closer to more skilled swimmers, especially when they wore swimming fins (Witt, Schuck, & Taylor, 2011). Moving targets appeared faster when they were more difficult to block (Witt & Sugovic, 2010). These and other demonstrations reveal that perceptual judgments of spatial layout reflect the perceiver’s ability to act.

The action-specific perception account is rooted in Gibson’s (1979) theory of affordances. Affordances are the opportunities for, and costs associated with, various actions that can be performed in a given environment. The affordances that are available at a particular moment depend on both the environment and the perceiver. For example, the surface of water affords walking to a water bug but not to a human. As another example, a person is capable of throwing but the affordance is only available if a particular object is detached and of the right size and weight to be thrown by that person. Consequently, affordances depend on and reflect the mutual relationship between the environment and the perceiver. According to Gibson, affordances are the primary object of perception. Consistent with this claim, research has demonstrated perceptual sensitivity to affordances such as those for sitting, climbing, reaching, and grasping (e.g., Heft, 1993; Mark, 1987; Richardson, Marsh, & Baron, 2007; Warren, 1984). By perceiving affordances, perception expresses the mutual relationship between the environment and the perceiver. The action-specific perception account extends Gibson’s notion of affordances by demonstrating that affordances are detected even in seemingly basic dimensions of the environment such as distance, size, shape, slant, height, and speed.

While consistent with the theory of affordances, the action-specific account is at odds with other traditional and mainstream theories of perception including both direct1 (e.g., Gib-
son, 1979; see also Michaels & Carello, 1981) and modular (e.g., Fodor, 1983) accounts. According to the theory of direct perception, optical information fully specifies the environmental layout, and does not need to be supplemented by internal inference, cognitive knowledge, or motor abilities. According to modular accounts, perception is informationally encapsulated and thus impenetrable to influences such as action abilities. Furthermore, the notion that is inherent in most theories of perception is that perceptual processes generate a general-purpose percept that can then be used by post-perceptual processes to, for example, reason about, remember, or act on the environment. Whether implicit or explicitly stated, this description of perception is the dominant view. Thus, the claim of the action-specific approach that the same full-cue environment can look different depending on the perceiver’s ability to perform the intended action challenges the idea of a behaviorally independent, general-purpose, and/or fully specified percept.

Despite these major theoretical differences, criticisms of the action-specific approach have focused on methodological issues, rather than theoretical issues. For example, Woods and colleagues suggested that apparent action-specific effects are due to the way that participants interpret the instructions. They demonstrated that when participants were instructed to report objective or subjective distance, effort for throwing a heavy ball (cf. Witt, Proffitt, & Epstein, 2004) did not influence distance judgments. However, when participants were instructed to take into account nonoptical factors, effort for throwing did influence distance judgments (Woods, Philbeck, & Danoff, 2009). Others have emphasized the need for a range of dependent measures including action-based and indirect measures (Loomis & Philbeck, 2008). These measures are useful in testing for convergence and by reducing the potential for response bias.

Thus, it is necessary to resolve whether apparent action-specific effects are the result of action influences on perception. If so, theories of perception would need to be able to accommodate these results. However, if the effects are the result of methodological artifacts, these findings would not challenge theories of a general-purpose, fully specified perception.

Some research has examined the role of methodological artifacts in action-specific effects for perceived distance, including indirect measures (Witt, 2011b), action-based measures (Witt, Proffitt, & Epstein, 2010), and manipulations of instructions (Woods et al., 2009). However, no research has examined the potential role of methodological artifacts in apparent action-specific effects on perceived speed. Previously, we found that balls were judged to be moving faster when they were more difficult to block (Witt & Sugovic, 2010). In the current experiments, we examined three possible sources of methodological artifacts that might contribute to these effects. These include the type of response (Experiments 1–2), the possible involvement of memory-related processes (Experiments 3–4), and the influence of nonaction related factors that may have coincided with our manipulation of ability (Experiments 5–6). If apparent action-specific effects are due to methodological artifacts, then elimination of these artifacts should also eliminate the effects. However, if action-specific effects are perceptual, there should be a consistent pattern across all of the studies even as methodologies vary.

### Experiment 1: Speed Ratings

In previous experiments (Witt & Sugovic, 2010), participants rated the speed of the ball by performing a speed bisection task. This task was modeled after typical duration bisection tasks (e.g., Penney, Gibbon, & Meck, 2008), and participants judged whether each ball moved more like the fast speed or more like the slow speed. In the current experiment, we used a different perceptual judgment to examine if the effect generalizes beyond a specific type of response. Participants rated the speed of each ball on a scale from 1 to 7.

#### Method

**Participants.** Eleven students (three females, eight males) participated for course credit. All provided informed consent. This and all following experiments were approved by the university’s IRB committee.

**Stimuli and apparatus.** Stimuli were presented on a projection screen. The projected area was 168 cm × 95.4 cm. The background was black. Participants sat approximately 5.4 m from the screen. A joystick and a numbered keypad were placed on the table directly in front of them. The ball was a white circle, which, due to distortion from the projector, was 8.1 cm wide and 5.5 cm tall. A white rectangle, which served as the paddle, was only visible on test trials. The paddle was always 3 cm wide and positioned 12 cm from the right edge of the projection area. The height of the paddle was set to one of three heights (6, 18.5, or 37 cm). The paddle was placed on top of a white bar that was 3 cm wide and 95.4 cm tall, so it covered the entire height of the display. Thus, the paddle size was specified by the separation between two black horizontal lines that were the outline at the top and bottom of the paddle (see Figure 1). This was done to help minimize optical differences across paddle sizes such as luminance contrast.

**Procedure.** First, participants were exposed to speeds 1 and 7. Prior to each exposure, text on the screen said “This is speed 1” or “This is speed 7”. Then the ball traveled from left to right across the screen at 0.82 m/second (speed 1) or 3.28 m/s (speed 7). During training, the ball moved horizontally with no vertical displacement. Each speed was shown three times, and the order was randomized. Then participants were tested to ensure that they could discriminate between the slow and fast speeds. Each speed

![Figure 1. Sample display from Experiments 1, 3, 4, and 5. Black and white are reversed here compared to what the participant saw, and there was no border around the outside of the display.](image-url)
was shown three times (order was randomized) and participants indicated its speed by pressing the corresponding number on the keypad.

On each test trial, the ball appeared on the left side of the screen and the paddle appeared on the right. To begin the trial, participants pressed the trigger on the joystick and the ball traveled across the screen. The ball traveled at 1 of 6 possible test speeds ranging from 1.16–2.99 m/s. The ball moved along a diagonal. The ball was displaced 2 pixels vertically and 2–7 pixels horizontally every 4 ms. The initial vertical direction (up or down) was randomized. The vertical direction reversed whenever it reached the top or the bottom of the display, and reversed at random, which made the task of blocking the ball more difficult. Every 4 ms, the ball had a 5% chance of reversing vertical directions.

Participants used the joystick to control the paddle with their dominant hand. The movement of the joystick and paddle were compatible such that forward movement of the joystick resulted in upward movement of the paddle and backward movement of the joystick resulted in downward movement of the paddle on the screen. When participants successfully positioned the paddle to stop the ball, the ball stopped on the paddle. When they missed, the ball continued beyond the edge of the display. Then the participant estimated the speed of the ball by pressing a number between 1 and 7 on the keypad. Each block of trials contained two repetitions of the six speeds with each of the three paddle sizes for a total of 36 trials per block. Speed and paddle size were randomized within each block. Participants completed eight blocks of trials.

Results and Discussion

As expected, participants were better at blocking the ball when they played with the bigger paddle, $F(2, 20) = 207.18, p < .001$, $\eta_p^2 = .95$ (see Table 1). Importantly, participants judged the ball to be moving slower as the size of the paddle increased (see Figure 2). This was confirmed with a 3 (paddle size) × 6 (speed) repeated-measures ANOVA with speed judgments as the dependent variable. Paddle size significantly influenced speed judgments, $F(2, 20) = 13.29, p < .001$, $\eta_p^2 = .57$. The effect of speed was also significant, $F(5, 50) = 315.75, p < .001$, $\eta_p^2 = .97$. The interaction between speed and paddle size was not significant, $F(10, 100) = 0.84, p > .59$. These results match those found with the speed-bisection task (Witt & Sugovic, 2010), and demonstrate that the effect of paddle size generalizes to multiple types of perceptual judgments of speed. Even when the ball was moving at the same speed, participants judged it to be moving faster when they played with the smaller, less effective paddle.

| Paddle Size Across Experiments 1–4. All Standard Errors Were Less Than .03 |
|-----------------|-----------------|-----------------|-----------------|
| Experiment 1 |
| 1 | 2 | 3 | 4 |
| Small | .49 | .47 | .53 | .50 |
| Medium | .83 | .81 | .84 | .85 |
| Big | .96 | .96 | .94 | .96 |

We also examined whether performance on individual trials influenced estimated speed. We could not conduct a repeated-measures ANOVA with trial performance (hit vs. miss) as a factor because participants did not miss many balls when playing with the big paddle (see Table 1). Instead, we conducted paired-samples $t$ tests for each paddle size for each speed on estimated speed when participants missed the ball compared to when they successfully blocked the ball. This test was a very liberal test to determine if trial-by-trial performance influenced estimated speed, yet none of these $t$ tests revealed significant effects, $p$s > .10. Thus, even with this liberal test, trial-by-trial performance did not influence estimated speed. Instead, estimated speed seems to be a function of task-specific ability.2

Experiment 2: Visual Comparisons

We examined whether the effect would also generalize to a third type of perceptual judgment. Participants viewed two simultaneously presented speeds and judged which speed was faster. Thus, participants did not have to label the speed. Instead they visually compared two speeds and determined which speed is faster.

Method

Participants. Ten students (three female, seven male) participated in exchange for course credit. All provided informed consent.

Apparatus and stimuli. This experiment took place in a different room than Experiment 1, so there were variations in experimental set-up. Experiments 1, 3, and 4 took place in one room (and thus, had the same experimental set-up as each other),

2 The literature on action-specific effects suggests that many aspects of ability influence perceptual judgments. These include general abilities such as overall fitness, task-specific skills such as swimming, task-specific difficulties such as wearing ankle weights, and moment-to-moment performance such as kicking well (see Witt, 2011a). However, more research is needed to determine answers to remaining questions such as if these various aspects of ability interact with each other, depend on subjective ratings of ability (but see Witt et al., 2008), change over time (and if so, determine the time-scale of these changes), and influence perceptual reports of all aspects of the environment.
and Experiments 2, 5, and 6 took place in the other room (and thus had the same experimental set-up as each other).

In this experiment, the stimuli were presented on a projection screen that was 109 cm by 80.5 cm. A white circle (5 cm in diameter) served as the ball. The ball always started on the left side of the screen and traveled right. Another white circle (also 5 cm in diameter) served as the comparison circle. The comparison circle started 1 cm to the right of the paddle and 38.4 cm above the bottom of the projected area. The comparison circle always moved downward (see Figure 3).

**Procedure.** Participants pressed the trigger on the joystick to initiate each trial. Simultaneously, the ball moved across the screen at 1 of 6 speeds ranging from 0.75 m/s to 1.94 m/s, and the comparison circle moved downward at one of four speeds relative to each ball speed (see Table 2). The comparison circle always moved downward, and disappeared at the bottom of the screen. The comparison circle always disappeared before the ball reached the paddle.

Participants used the joystick to control the paddle. Then they estimated whether the ball moved slower or faster than the comparison circle by pressing the buttons labeled “slow” and “fast” on the joystick. Each block contained 72 trials (3 paddle sizes × 6 comparison speeds). Participants completed four blocks. The first 10 trials served as practice.

**Results and Discussion**

Participants blocked the ball more successfully as paddle size increased, $F(2, 18) = 355.94, p < .001, \eta_p^2 = .98$ (see Table 1). Perceptual judgments were submitted to a 3 (paddle size) × 4 (comparison speed) × 6 (ball speed) repeated-measures ANOVA with proportion of trials that participants judged the ball to be moving faster as the dependent factor. Paddle size significantly influenced perceptual judgments, $F(2, 18) = 3.78, p < .05, \eta_p^2 = .30$ (see Figure 4). Participants judged the ball to be moving faster than the comparison circle more frequently when they played with the smaller paddle.

There was a main effect of speed, $F(5, 45) = 6.76, p < .001, \eta_p^2 = .43$. Participants were more likely to judge the ball as faster than the comparison speed as the speed of the ball increased. There was a main effect of comparison speed, $F(3, 27) = 8.22, p < .001, \eta_p^2 = .48$, and a significant interaction between ball speed and comparison speed, $F(15, 135) = 2.62, p < .01, \eta_p^2 = .23$ (see Figure 5). As the ball moved faster, participants were more likely to select the ball as moving faster than the comparison circle. The interaction between paddle size and speed was not significant, $F(10, 90) = 1.66, p = .10, \eta_p^2 = .16$ (see Figure 6). All other interactions were not significant, $Fs < 1$. As is apparent in Figure 5, participants struggled with this task, especially as ball speed increased. However, their judgments were still a function of differences in speed between the ball and the comparison circle for nearly all of the speeds (see Figure 5). This result suggests that they were not simply guessing but rather had some ability to differentiate the speeds. Importantly, despite the difficulties with the perceptual comparison task, ease to block the ball (due to paddle size) still influenced their perceptual judgments.

We also analyzed estimated speed on successful trials compared to unsuccessful trials. Paired-samples $t$ tests revealed no significant differences for any of the paddles at any of the speeds, $ps > .10$.  

**Table 2**  

<table>
<thead>
<tr>
<th>Ball speed (m/s)</th>
<th>-2</th>
<th>-1</th>
<th>+1</th>
<th>+2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.75</td>
<td>0.26</td>
<td>0.52</td>
<td>0.79</td>
<td>1.05</td>
</tr>
<tr>
<td>0.96</td>
<td>0.52</td>
<td>0.79</td>
<td>1.05</td>
<td>1.31</td>
</tr>
<tr>
<td>1.19</td>
<td>0.79</td>
<td>1.05</td>
<td>1.31</td>
<td>1.57</td>
</tr>
<tr>
<td>1.43</td>
<td>1.05</td>
<td>1.31</td>
<td>1.57</td>
<td>1.83</td>
</tr>
<tr>
<td>1.68</td>
<td>1.31</td>
<td>1.57</td>
<td>1.83</td>
<td>2.10</td>
</tr>
<tr>
<td>1.94</td>
<td>1.57</td>
<td>1.83</td>
<td>2.10</td>
<td>2.36</td>
</tr>
</tbody>
</table>

*Figure 3.* Sample display from Experiment 2. Black and white are reversed here relative to what participants viewed, and there was no border around the display. The circle on the left was the ball, and the circle on the right was the comparison circle. The comparison circle moved straight downwards, as indicated by the solid arrow. The ball moved along a diagonal to the right. A sample path is depicted by the dashed arrow.

*Figure 4.* Results from Experiment 2. Proportion of trials in which participants judged the ball to be moving faster than the comparison circle as a function of paddle size. A higher value indicates that the balls were judged as moving faster. Error bars represent 1 SEM calculated within-subjects.
The results from Experiments 1 and 2 demonstrate that the previously found effect of paddle size on judged speed generalizes to multiple types of judgments. Specifically, three types of responses (speed bisection, speed ratings, and visual comparisons) demonstrate effects of paddle size on estimated speed. These findings suggest that the results are not an artifact of the type of response. Such a result is predicted by a perceptual account of these action-specific effects. However, other methodological artifacts could still explain these results. In particular, in previous experiments, participants judged the speed of the ball after the ball had stopped moving. Thus, these effects could be due to an influence from memory-based processes. Participants might have seen the ball similarly but remembered, and then judged, it as moving a different speed.

**Experiment 3: Speed Ratings While Ball Is Still Moving**

To test whether these effects were due to exaggerations in memory, we replicated the previous findings but instructed participants to estimate speed while the ball was still moving. If the effects are dependent on memory-based processes, then paddle size will not influence judgments when the ball is still in motion. However, if ease to block the ball influences perceived speed, then paddle size will influence speed judgments even when the ball is still moving.

**Method**

**Participants.** Fourteen students (four females, 10 males) participated for course credit or for payment. All provided informed consent.

**Stimuli, apparatus, and procedure.** Everything was the same as in Experiment 1 except for the following changes. Most importantly, participants judged the speed of the ball while the ball was still moving. There were also two changes to the training session. Participants viewed six initial exposures to speed 1 and speed 7, and the speed labeled as 7 was 4.10 m/s (rather than 3.28 m/s, as in Experiment 1). These changes were not intentional. The speeds at test were the same as in Experiment 1 (1.16–2.99 m/s). Participants made their judgment on a scale from 1 to 7, and said their judgment aloud. An experimenter recorded their estimate and also recorded if they made their judgment after the ball was no longer moving.

**Results and Discussion**

Trials in which participants judged the speed after the ball stopped moving were removed from the analysis. This constituted 6.7% of the trials, although the pattern of results was the same when these trials were included.

Participants had better blocking success as paddle size increased, $F(2, 26) = 189.23, p < .001, \eta_p^2 = .94$ (see Table 1). In addition, participants judged the ball to be moving slower as the size of the paddle increased (see Figure 7). Paddle size significantly influenced speed judgments, $F(2, 26) = 11.33, p < .001, \eta_p^2 = .47$. The effect of speed was significant, $F(5, 65) = 325.24, p < .001, \eta_p^2 = .96$. The interaction between speed and paddle size was significant, $F(10, 130) = 2.61, p < .01, \eta_p^2 = .17$ (see Figure 8). Paddle size significantly affected perceptual judgments of speed at the three fastest speeds ($ps < .01$) and the third slowest speed ($p = .078$) but not at the two slowest speeds ($ps > .50$). Given that paddle size significantly influenced blocking performance at each speed ($Fs(2, 26) > 23.65, ps < .001$), we had expected that paddle size would also influence perceived speed at each speed. Inconsistent with this prediction, we found that paddle size did not influence perceived speed at the two slowest speeds.
We are unclear as to why there was no effect at the slow speeds, and future work will need to consider why perception seems to be sensitive to blocking ability at the higher speeds but not at the lower speeds.

The current results demonstrate that the effect of paddle size on perceptual judgments is not just an effect on remembered speed. However, such a conclusion does not preclude the possibility that action-specific effects also occur in memory. Thus, we combined the data from Experiments 1 and 3 to test if ability also influences remembered speed. The interaction between paddle size and experiment was not significant, $F(2, 46) = 1.93, p = .16, \eta^2_p = .08$. There was a slight trend for paddle size to have a bigger effect when judgments were made from immediate memory than when they were made while the ball was still moving. Such a result would suggest that action-specific effects get exaggerated in memory. There was a main effect of experiment, $F(1, 23) = 8.21, p < .01$, likely because we (unintentionally) used different training speeds between the two experiments, so speed 7 was faster in Experiment 3 than in Experiment 1. The possibility that memory might exaggerate original differences in perception is an intriguing idea, although our data are inconclusive as to whether such exaggeration exists.

**Experiment 4:**

**Speed Bisection While Ball Is Still Moving**

We replicated Experiment 3 using a speed bisection task. Participants judged the ball’s speed while the ball was still moving, thus, perceptual information about speed was available at the time participants made their judgments.

**Method**

**Participants.** Nine students (six females, three males) participated for course credit or payment. All provided informed consent.

**Stimuli and apparatus.** The stimuli were similar to the stimuli in Experiments 1 and 3 except that the training speeds were introduced as the “slow” speed and the “fast” speed.

**Procedure.** Participants were first exposed to the slow (0.82 m/s) and fast (3.28 m/s) speeds. Each speed was shown three times, and order was randomized. Then participants were tested to ensure that they could discriminate between the slow and fast speeds. Each speed was shown three times again (order was randomized) and participants indicated the ball’s speed by pressing the button labeled “slow” or the button labeled “fast” on the joystick.

On each test trial, the ball appeared on the left side of the screen and the paddle appeared on the right. To begin the trial, participants pressed the trigger on the joystick and the ball traveled across the screen. Participants used the joystick to control the paddle with their dominant hand. Participants were instructed to indicate the speed of the ball while the ball was still moving. To indicate the speed of the ball, participants performed a speed-bisection task in which they judged whether the speed of the ball was more like the slow speed or more like the fast speed. This speed-bisection task was modeled after typical duration bisection tasks (e.g., Penney et al., 2008) and was used in previous studies (Witt & Sugovic, 2010). In this experiment, participants’ task was to determine, while the ball was still in motion, if the ball traveled more like the slow speed or more like the fast speed. Participants said “slow” or “fast” aloud, and an experimenter recorded their response. If the participant responded after either blocking or missing the ball, the experimenter still recorded their response but also recorded that the response was late and instructed them to respond sooner. If participants successfully positioned the paddle to stop the ball, the ball stopped on the paddle. If they missed, the ball continued beyond the paddle. Participants completed eight blocks of trials. Each block contained two repetitions of each of six
speeds with each paddle size for a total of 36 trials per block. Speed and paddle size were randomized within each block.

Results and Discussion

Participants judged the speed too late on 6.6% of trials, which were excluded prior to analysis, although the pattern of results was the same when these trials were included.

Blocking performance increased as paddle size increased, $F(2, 16) = 289.74, p < .001$, $\eta^2_p = .97$ (see Table 1). Participants judged the balls to be moving slower as the size of the paddle increased (see Figure 9). The point of subjective equality (PSE) was calculated for each person for each paddle size from the slopes and intercepts from binary logistic regressions. Paddle size significantly influenced PSE, $F(2, 16) = 9.04, p < .005$, $\eta^2_p = .53$. When playing with the smaller paddle, participants judged faster speeds as being equally fast and slow. This pattern of results matches what was previously found when participants estimated speed after the ball had stopped moving (Witt & Sugovic, 2010).

In the current experiment, the ball was still visible and moving when participants made their speed judgments. If the previous effect of paddle size had been due to an effect on remembered speed, paddle size would not have affected estimated speed when the ball was still moving. Thus, the current results suggest that the effect of paddle size on perceptual judgments does not just reflect an effect in remembered speed.

We also examined if initially seeing the ball as slower influenced subsequent blocking performance. One prediction is that seeing the ball as moving slower might give participants confidence and help improve performance, but another prediction is that seeing the ball as slower might cause the participant to miss, and blocking performance would decrease. We compared blocking performance when participants rated the ball’s speed as “slow” to blocking performance when participants rated the ball’s speed as “fast” for each paddle size for the two middle speeds. Initial speed judgment did not influence subsequent blocking success, $F(1, 8) = 0.04$. The interaction between paddle size and initial speed judgment also did not significantly influence subsequent blocking success, $F(2, 16) = 0.23$. We conducted a similar analysis for the data from Experiment 3. We performed a median split on perceptual judgment for each participant, speed, and paddle size, and compared performance on trials in which participants gave lower estimates to trials in which participants gave higher estimates. Speed judgments did not influence subsequent performance, $F(1, 13) = 0.27$, but there was a slight trend with the small paddle. When playing with the small paddle, participants tended to have more blocking success on trials when they judged the ball to be moving slower rather than faster, $t(13) = 1.61, p = .13$ (perceptually judged to be slower: $M = 56.1\%, SD = .12$; perceptually judged to be faster: $M = 50.9\%, SD = .14$). Just as with people kicking field goals (Witt & Dorsch, 2009), performance influenced perceptual judgments, but initial perceptual judgments did not influence subsequent performance.

The current results suggest that the effect of paddle size on judged speed does not just reflect an effect in remembered speed. Thus far, the results from Experiments 1–4 are consistent with an action-specific perception account. The results demonstrate that these effects generalize to multiple types of speed estimates (and thus are not likely dependent on postperceptual processes that generate specific responses) and that the effects persist when removing the methodological artifact of having participants make their judgments after visual information about speed was no longer available. However, even if these effects are perceptual, we still need to examine if the effects are specifically due to differences in blocking ability. For example, one possibility is that the visual differences between the paddle sizes caused these effects. In this case, even though the effects may be perceptual, they are not the result of changes in ability but rather to visual factors. The possible finding that these effects are entirely driven by visual differences and that ability does not contribute to perceived speed would be inconsistent with and evidence against an action-specific perception account.

Experiment 5: Predictable Ball Paths

According to the action-specific perception account, paddle size influences perceived speed because paddle size affects ease to block the ball, which influences perceived speed. To further evaluate this claim, we conducted an experiment in which paddle size was more relevant or less relevant for blocking success. As before, participants attempted to block the ball with different sized paddles. However, in some blocks of trials, the ball moved horizontally with no vertical displacement. This made the task of blocking the ball much easier, and thus, reduced the effect that paddle size had on blocking ease.

Method

Participants. Ten students (three female, seven male) participated in exchange for course credit. All provided informed consent.

Apparatus and stimuli. A white circle, 5 cm in diameter, served as the ball. The paddle was always 2 cm wide, and was set to one of three lengths (5.33, 16, or 32 cm tall).

![Figure 9](image-url) The PSE between slow and fast speeds as a function of paddle size. A lower PSE indicates that the balls were judged as moving faster. Error bars represent 1 SEM calculated within-subjects.
Procedure. Participants were initially trained on the slow (0.53 m/s) and fast (2.13 m/s) speeds. They viewed six initial exposures, and were tested to ensure they could discriminate these two speeds on six additional exposures.

After training, participants completed four blocks of test trials. Two of these blocks contained “Unpredictable” trials, and two contained “Predictable” trials. Block order was randomized, and trials within each block were also randomized. Blocks with Unpredictable trials began with instructions displayed on the screen telling participants that the ball would bounce up and down. Blocks with Predictable trials started with instructions that stated the ball would only move horizontally and would not bounce.

To initiate each trial, participants pressed the trigger and the ball moved across the screen from left to right. During Unpredictable trials, the ball started halfway up the display and moved along a diagonal, as in the previous experiments. On each trial, the ball’s speed was set to one of six possible speeds (0.75–1.94 m/s). During Predictable trials, the ball started halfway up the display and moved horizontally with no vertical displacement. The ball moved at one of six possible speeds (0.53–1.86 m/s). (These speeds were equated for horizontal displacement, but programming limitations did not permit us to match the speeds exactly). Participants controlled the paddle by moving the joystick. After they successfully blocked or missed the ball, they estimated the speed of the ball by performing the speed bisection task (as in Experiment 4). Each block contained 72 trials (3 paddle sizes × 6 speeds × 4 repetitions).

Results and Discussion

First, we analyzed blocking performance as a function of predictability (Predictable or Unpredictable) and paddle size (see Table 3). Proportion of trials successfully blocked was significantly influenced by predictability, $F(1, 9) = 282.23$, $p < .001$, $\eta_p^2 = .97$, and by paddle size, $F(2, 18) = 258.56$, $p < .001$, $\eta_p^2 = .97$. Critically, the interaction between predictability and paddle size was also significant, $F(2, 18) = 142.03$, $p < .001$, $\eta_p^2 = .94$. Paddle size had a bigger effect on blocking ability during Unpredictable trials than during Predictable trials. Separate repeated-measures ANOVAs for each type of trial revealed a significant effect of paddle size on blocking success during Unpredictable trials, $F(2, 18) = 200.67$, $p < .001$, $\eta_p^2 = .96$. However, despite the small differences, paddle size also significantly affected blocking success during Predictable trials, $F(2, 18) = 7.72$, $p < .01$, $\eta_p^2 = .46$. Follow-up $t$ tests revealed that participants were significantly worse at blocking predictable balls with the smaller paddle than the medium or the big paddles ($p < .05$). Even though paddle size still had an effect on blocking performance in the Predictable trials, the effect was significantly smaller than for the Unpredictable trials. Thus, we can examine whether or not paddle size has a bigger effect on estimated speed when paddle size also has a bigger effect on blocking ease.

As predicted by the action-specific perception account, we found that paddle size had a bigger effect on estimated speed during the Unpredictable trials than during Predictable trials (see Figure 10). PSEs were calculated as in Experiment 4 and submitted to 2 (predictability) × 3 (paddle size) repeated-measures ANOVA. Critically, the interaction between trial type and paddle size was significant, $F(2, 18) = 4.16$, $p < .05$, $\eta_p^2 = .32$. As is apparent in Figure 10, paddle size had a bigger effect on estimated speed when the ball moved along a less predictable path than when it moved along a predictable path. This result confirms the prediction of the action-specific perception account because it demonstrates that when paddle size had a bigger effect on blocking performance, paddle size also had a bigger effect on perceptual speed judgments.

We conducted two separate repeated-measures ANOVAs for each of the predictability conditions. During Unpredictable trials, paddle size significantly influenced estimated speed, $F(2, 18) = 16.22$, $p < .001$, $\eta_p^2 = .64$. However, during Predictable trials, paddle size also influenced estimated speed, $F(2, 18) = 3.67$, $p < .05$, $\eta_p^2 = .29$. Thus, even when the task was really easy, paddle size still influenced estimated speed.

Initially, the action-specific perception account made no prediction either way as to whether an effect would occur in the predictable case. The reason is that the action-specific perception account does not deny that visual influences can affect perceived speed. Indeed, previous research has demonstrated influences of object size on speed perception (Chen, Bedell, & Frishman, 1998; Diener, Wist, Dichgans, & Brandt, 1976; Werkhoven & Koenderink, 1993). While no research to date has examined the effect of nearby object size on perceived speed, this is certainly a valid possibility. However, given that paddle size did influence blocking performance in the predictable condition, the action-specific account would have predicted an effect of paddle size on speed judgments. The result raises an interesting, and unanswered, question of how much difference in ability is necessary in order for perception to reflect these dissimilarities. To date, nearly all manipulations of ability have been fairly substantial; such as wearing a heavy backpack while viewing a big, steep hill (e.g., Bhalla & Proffitt, 1999, but see General Discussion in Durgin, Hajnal, Li, Tonge, & Stiglini, 2010; see also Proffitt & Zadra, 2011) or reaching with a long, rather than short, tool (e.g., Witt et al., 2005). Little to no research has examined if more subtle manipulations of ability would also produce detectable effects in perception.

One finding that is inconsistent with the action-specific perception account is that there was not a main effect of predictability, $F(1, 9) < 1$. Given that it was much easier to successfully block the ball when its path was predictable, we had expected the ball to look like it was moving slower in the predictable condition than in the unpredictable condition. More research will be needed to fully understand this pattern of results. For this experiment, there are a few factors to consider. First, although participants were trained on the same initial anchor speeds, due to programming limitations, the range of ball speeds used during predictable blocks was slower ($M = 1.20$ m/s) than the range of speeds used during unpredictable blocks ($M = 1.35$ m/s). Second, a factor that needs to be considered is which aspect of task difficulty is relevant. Within predictable blocks, positioning the smaller paddle to be in the right place

<table>
<thead>
<tr>
<th>Predictable</th>
<th>Unpredictable</th>
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<tbody>
<tr>
<td>Small</td>
<td>.972 (.008)</td>
</tr>
<tr>
<td>Medium</td>
<td>.996 (.003)</td>
</tr>
<tr>
<td>Big</td>
<td>.998 (.002)</td>
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to block the ball was significantly more difficult (as revealed by significantly worse performance), and likely required much more precision in positioning the small paddle than the medium or big paddles, although we did not measure this. Thus, relative to the other two paddle conditions within the predictable blocks, the small paddle was significantly more difficult. However, if we compare across types of trials, performance was better when controlling a small paddle during predictable blocks than when controlling a big paddle during unpredictable blocks. Thus, an open question is whether difficulty is assessed relative to individual task types or if difficulty is assessed across different task types.

Although there are some inconclusive results, the significant interaction confirms the key prediction of the action-specific perception account, which was that paddle size would have a bigger effect on perceptual speed judgments when paddle size also had a bigger effect on blocking success. This result suggests that the ability to block the ball—and not (just) visual differences across paddle sizes— influences perception.

**Experiment 6: Multiple Paddle Sizes**

In this experiment, participants played with a larger range of paddle sizes, and we determined if the same psychometric function would fit both performance and perceptual judgments.

**Method**

**Participants.** Ten students (three female, seven male) participated in exchange for course credit and provided informed consent.

**Apparatus and stimuli.** A white circle, 5 cm in diameter, served as the ball. The paddle was always 2 cm wide, and was set to one of six heights ranging from 5.24 cm to 31.45 cm. In this experiment, there was no white bar behind the paddle.

**Procedure.** Participants were initially trained on the slow (0.53 m/s) and fast (2.13 m/s) speeds. They viewed six initial exposures, and were tested to ensure they could discriminate these two speeds on six additional exposures.

Participants initiated each trial by pressing the trigger on the joystick. The ball moved across the screen, and the participant attempted to block the ball with the paddle. Then, the participant judged the speed of the ball by performing the speed bisection task in which they determined whether the ball moved more like the slow speed or more like the fast speed. Each block of trials contained 36 trials (6 paddle sizes 6 ball speeds). Participants completed eight blocks.

**Results and Discussion**

Proportion of balls successfully blocked was submitted to a repeated-measures ANOVA with paddle size as the within-subjects factor. Paddle size significantly influenced the proportion of balls blocked, $F(4, 45) = 72.93, p < .001, n_p^2 = .89$ (see Figure 11). The linear contrast was most significant, $F(1, 9) = 295.70,$
p < .001, $\eta^2_p = .97$, the quadratic contrast was also significant, $F(1, 9) = 45.04, p < .001, \eta^2_p = .83$, and no other contrasts were significant. In a second analysis, PSEs were calculated as before and submitted to a repeated-measures ANOVA with paddle size as the within-subjects factor. Paddle size significantly influenced PSEs, $F(5, 45) = 5.54, p < .001, \eta^2_p = .38$ (see Figure 11). As with blocking performance, the linear contrast was most significant, $F(1, 9) = 17.15, p < .01, \eta^2_p = .66$, and the quadratic contrast was also significant, $F(1, 9) = 7.98, p < .05, \eta^2_p = .47$. No other contrasts were significant. Thus, the same contrasts best accounted for both perceptual judgments and performance. This finding is consistent with the claim that blocking ease influences perceived speed. We also analyzed the correlation between blocking success and PSEs by entering the data for each participant for each paddle size. There was a significant correlation between blocking success and PSEs, $r(59) = .37, p < .01$. This result also suggests a relationship between blocking ease and perceived speed.

## General Discussion

According to most theoretical accounts, perception provides behaviorally independent and general-purpose information about the environment, which can then be used for a variety of reasons including the selection, planning, and execution of actions. In contrast, the action-specific perception account claims that perceivers see the surrounding environment in terms of their ability to perform the intended action. For example, tall walls look shorter to perceivers who are trained in parkour and have developed the skills to jump up the wall compared with perceivers who do not have these skills (Taylor, Witt, & Sugovic, 2011). Just as Gibson (1979) theorized in his notion of affordances, the action-specific account proposes that perception expresses the mutual relationship between the environment and the perceiver.

The action-specific perception account is not the first time that traditional and mainstream views of perception have been challenged. Indeed, there is a history of research on ostensibly nonoptical perceptual effects. For example, according to the “New Look” approach, perception is a function of value and need. In one study, coins that were worth more looked bigger, and coins looked bigger to poorer children, presumably because they valued the coins more (Bruner & Goodman, 1947). At the time, these findings challenged the mainstream notions of perception. However, the results were not able to withstand methodological criticisms. For example, in the coin study, the size of the coin was correlated with its value. When size and value were decoupled, perceived size was a function of physical size, rather than value (Carter & Schooner, 1949). In addition, many other methodological inconsistencies were raised and later found to be relevant (Pastore, 1949). The New Look approach failed, in part, because the findings could not withstand changes to the methodologies.

Like the New Look approach, the action-specific perception approach is also challenged on methodological grounds (e.g., Loomis & Philbeck, 2008; Woods et al., 2009). Given the methodologically induced downfall of the New Look approach, it is critical to examine the potential role of methodological artifacts as determining factors for action-specific effects. With the current experiments, we examined the potential role of methodological artifacts in the effects of blocking ability on perceptual speed judgments. In Experiments 1 and 2, we found that the effects generalized to multiple types of perceptual judgments. This generalization is important because it suggests that the effects occur on a process that is common to all of the responses (such as perception) rather than on postperceptual processes that generate individual responses (see Foley, 1977; Loomis & Philbeck, 2008; Philbeck & Loomis, 1997). In Experiments 3 and 4, we found the effects of paddle size on perceptual judgments when the ball was still visibly in motion. These results rule out the possibility that the effect was dependent on an influence on remembered speed (although it is possible that initial differences in perceived speed could get exaggerated in memory). In Experiments 5 and 6, we evaluated whether changes in apparent speed were due to ability (as we had intended) or to nonaction-related factors that were incidentally manipulated. Experiment 5 demonstrated that when paddle size had a bigger effect on blocking ease, paddle size also had a bigger effect on estimated speed. Experiment 6 demonstrated similar functions for paddle size on estimated speed and on blocking ability as paddle size increased. Both sets of results suggest that the effects were driven by manipulations of ability.

Taken together, the current studies help build a case that blocking ease influences perceived speed. Whereas the New Look results failed to replicate with varying methodologies, and thus, ultimately failed as a theoretical account of perception, the action-specific result of blocking ability on apparent speed persists within a similar range of methodologically varying experiments.

While the current studies rule out several methodological artifacts as an explanation of action-specific effects, other alternative nonperceptual explanations are still possible. These can be divided into two categories: preperceptual and postperceptual. According to a preperceptual explanation, various levels of ability could direct attention differently, and this could lead to action-specific effects. This explanation is most sensible in the cases in which intention was manipulated (e.g., Witt et al., 2004, 2010) because perceivers who intend to throw may focus on different aspects of the environment compared with perceivers who intend to walk. However, little-to-no research to date has investigated this potential mechanism of action-specific effects.

Instead, most criticisms focus on the possibility of a postperceptual explanation such that differences in ability affect the postperceptual processes that generate the response, rather than perception itself. The particular difficulty in determining if an effect is perceptual or not arises from the fact that perception cannot be measured directly. Researchers can only measure behavioral responses and must infer perceptual processes from these behavioral responses. Because these responses are a function of both perceptual and postperceptual processes, it is difficult to determine the locus of the effect. Classic examples of influences on postperceptual processes are cases of response bias and misattribution. In the case of response bias, participants see the target similarly, but they adjust their responses to conform to their impressions of experimenter or social expectations (e.g., Asch’s, 1955 conformity studies). In the case of misattribution, participants also perceive the target similarly, but their perceptual reports are contaminated by their sense of some other aspect of the stimuli such as prior exposure (e.g., Jacoby, Allan, Collins, & Larwill, 1988).

Misattribution is a possible explanation for action-specific effects. Participants could perceive the speed of the ball similarly but misattribute their difficulty in blocking the ball to the ball’s speed.
For example, they might misattribute the increased difficulty to block the ball when playing with the small paddle as being due to increased speed of the ball. However, our own view is that perception and action systems are integrated, so it is to be expected that they would influence each other. In the case of integrated systems, multimodal effects are illustrative. For example, the perceived loudness of a note played on the marimba is influenced by the perceived height of the stroke that created the sound (Schutz & Kubovy, 2009; Schutz & Lipscomb, 2007). In this case, visual information influences auditory information (see also the classic McGurk effect; McGurk & MacDonald, 1976). As another example, in the size-weight illusion, the perceived weight of an object is influenced by its perceived size. These effects are considered to be due to multimodal interactions on perception, rather than to misattribution. In contrast, when semantic knowledge or prior exposure influences judgments of, for example, loudness (e.g., Jacoby et al., 1988), these effects are considered to be due to misattribution, rather than to changes in perception.

In our view, action-specific effects are more like the multimodal effects than like the misattribution effects. Just as sensory systems are integrated and thus influence each other, we think that perception and action systems are integrated and also influence each other. The claim that these systems are integrated has been proposed and demonstrated by a number of different approaches including the common-coding approach (e.g., Grosjean, Zwikel, & Prinz, 2009; Müsseler & Hommel, 1997), the selection-for-action account (e.g., Bekkering & Neggers, 2002; Gutting, Kenemans, & Neggers, 2011), accounts of biological motion (e.g., Jacobs & Shiffrar, 2005; Shiffrar & Freyd, 1990), and accounts of action observation (Grosjean, Shiffrar, & Knoblich, 2007; Serino et al., 2009). Thus, just as there are interactions between integrated sensory systems, so are there interactions between integrated perception and action systems.

We propose that action-specific effects are also like multimodal sensory effects in that information about the environment and information about the perceiver’s ability to act are being detected online. In other words, information about anticipated action ability is perceived or detected at the time that the perceiver views the target with the intention to act, rather than being stored and retrieved from memory (see Witt & Proffitt, 2008; Witt & Riley, submitted\(^3\)). In this case, detecting information about one’s own ability to act is similar to detecting information about weight, loudness, or speed. According to our view, information about one’s ability to act is integrated with information about the target, and this integration leads to action-specific effects.

However, it is difficult to determine whether a given effect such as the McGurk effect or action-specific effects are due to changes in perception or to misattribution. More broadly, it is difficult to determine if a given effect on perceptual judgments is due to a change in the perception or to a change in the responses. Several strategies have been developed to determine if an effect is perceptual or response-based. One strategy is to demonstrate convergence (Foley, 1977). Such convergence needs to include multiple types of direct and indirect measures. The current studies demonstrate some convergence by showing a consistent pattern of results across many direct measures including speed bisection, speed ratings, and visual comparisons. Future work should continue to examine convergence by looking at indirect measures of perceived speed (as explicitly suggested by Loomis & Philbeck, 2008, and as has been done with respect to perceived distance by Witt, 2011b). Investigations using indirect measures of perceived speed would be useful for examining possible effects of response bias and misattribution.

Another strategy is to remove experimenter-based artifacts (e.g., Durgin et al., 2010; Woods et al., 2009). In the current studies, the experimenter made no mention of the size of the paddle, instructions were objective such that participants were told to rate the speed of the ball (rather than the apparent or subjective speed of the ball), and once the test trials began, the experimenter did not interact further with the participant. Furthermore, the idea that action-specific effects are the result of experimenter-based artifacts fails to account for the functional specificity typically found in these effects. Functional specificity has been documented in three ways. One type of specificity that has been examined is intentional specificity. Data suggest that only ability for the intended action—but not for unintended actions—influences perceptual judgments (Witt et al., 2004, 2005, 2010). Another is directional specificity where better ability leads to judging some objects—specifically target objects—as bigger (e.g., Cañal-Bruland & van der Kamp, 2009; Wesp, Cichello, Gracia, & Davis, 2004; Witt & Dorsch, 2009; Witt, Linkenauger, Bakdash, & Proffitt, 2008; Witt & Proffitt, 2005) but other objects—specifically obstacles—as smaller (Taylor et al., 2011; Witt & Sugovic, 2010). A third type of specificity examined is whether the effects generalize to spaces that do not afford action. Results demonstrate that ability only affects judgments for objects that can be acted on but not objects that are too big to be grasped (Linkenauger, Ramenzi, & Proffitt, 2010; Linkenauger, Witt, & Proffitt, 2011) or jumped across (Lessard, Linkenauger, & Proffitt, 2009). These patterns of results undermine accounts that action-specific effects are due to task demands or response bias. Similar investigations of functional specificity with respect to perceived speed would be useful for determining if a person’s ability to block a ball truly influences the perceived speed of the ball, as claimed here.

**Summary**

Like Gibson’s (1979) theory of affordances, the action-specific perception account calls for a theoretical conceptualization of perception as a process that expresses the relationship between the perceiver and the environment. This conceptualization challenges current mainstream approaches that conceptualize perception as a behaviorally neutral, general-purpose, and optically specified process. However, the action-specific perception account has been challenged on methodological grounds, with claims that methodological artifacts led to effects on the judgments, rather than on perception. Here, we examined a number of potential methodological artifacts. Unlike the New Look approach to perception, the

\(^3\)This notion of action-specific effects as being like multimodal effects also has the consequence that action-specific effects would not challenge certain notions of direct perception. In particular, Stoffregen and Bardy (2001) have argued that perception is based on a global array that is based on information across the optic array, the acoustic array, etc... If we extend their notion of the global array to include proprioceptive and interoceptive arrays, then information about the perceiver’s ability to act would be incorporated into the global array, and this information could be detected directly (Witt & Riley, submitted).
action-specific effect of blocking ability on apparent speed persisted despite changes in the methodology. The current experiments point to a perceptual locus with respect to the effect of blocking ability on estimated speed. We propose that perception is behaviorally relevant and action-specific.

References


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