Atten Percept Psychophys (2016) 78:1744–1754
DOI 10.3758/s13414-016-1132-5

Action-specific judgment, not perception: Fitts' law performance is related to estimates of target width only when participants are given a performance score

Howard N. Zelaznik[1] · **Laura A. Forney**[2]

Abstract Proponents of the action-specific account of perception and action posit that participants perceive their environment relative to their capabilities. For example, softball players who batted well judge the ball as being larger compared to players who did not hit as well. In the present study, we examined this issue in the context of a well-known speed-accuracy movement task that can be examined in the laboratory, repetitive Fitts aiming. In the Fitts task, a performer moved as quickly and as accurately as possible between two targets, D units of distance apart (between 2.5 and 20.0 cm) and of W width (1.0 cm or less). In the Fitts task, we posited that individuals do not have access to performance quality. Thus, we asked whether individual differences in Fitts task performance was related to perception of target width. If Fitts task performance is related to perception of target width, then the action-specific effect on perception does not require explicit knowledge of performance and, furthermore, these effects reside during on-line visual control of the task. We show that only when subjects were provided with a performance score was there a relation between Fitts task performance and target width judgment error. We interpret this result to mean that action-specific effects do not occur during perceptual processing of the task, but action-specific effects are the result of postperformance evaluation processes.

Keywords Action-specific perception · Fitts' Law · Motor control

During the past decade, a very influential set of experiments have been conducted in support of an action-specific account of perception (Witt & Proffitt, 2008; Witt & Sugovic, 2011). In the action-specific account, perception is intimately related to the capabilities and local skill potential of a performer. For example, after competing in softball or golf, performers who performed better than their counterparts reported the size of the softball or the cup in golf as being larger (Witt & Proffitt, 2005; Witt, Linkenauger, Bakdash, & Proffitt, 2008). The inference is that individuals who performed better perceived the object to be acquired directly (the softball) or indirectly (the golf cup) as larger, and this perception mediated better performance.

Since this original work, an impressive set of studies have been conducted that are consistent with the action-specific account. Tennis players unsuccessful at hitting a tennis ball judge the ball as having a greater incoming velocity compared to success in hitting the ball onto the court (Witt & Sugovic, 2011). Novices attempting to place-kick a football through a goal post view the width between the posts to be larger when they are successful compared to not being successful (Witt & Dorsch, 2009).

The action-specific view also is supported based upon results of experiments involving tool use. A tool held in the hand makes the arm functionally longer and thus makes objects to be acquired by the tool functionally closer (Witt, Proffitt, & Epstein, 2005). Individuals holding a tool report that objects are closer compared to individuals who do not hold a tool. Furthermore, the perception of the locomotor aspects of performance is related to the changing physical capabilities of the individual. Individuals wearing a weighted backpack

---

✉ Howard N. Zelaznik
hnzelaz@purdue.edu

[1] Department of Health and Kinesiology, Purdue University, West Lafayette, IN, USA

[2] Laboratory of Nutrient Sensing & Adipocyte Signaling, Pennington Biomedical Research Center, Baton Rouge, LA, USA

compared to wearing an empty backpack prior to climbing a hill view the hill as steeper (Witt & Proffitt, 2007). Individuals classified as obese judged walking distances as being farther compared to nonobese individuals (Sugovic & Witt, 2011).

In the action-specific account, having perception scale to capabilities serves a functional evolutionary role. Attempting actions that are not within the capabilities of the person should be avoided. For example, a hill is less climbable when carrying a heavy backpack and thus perceptual mechanisms make the hill appear to be steeper. Thus, the action-specific account links the quality of perception to the nature of the affordances in the environment (Proffitt, 2006). Durgin and colleagues (Durgin et al., 2009, Durgin, Hajnal, Li, Tonge, & Stigliani, 2010), on the other hand, argue that in the perception of hill steepness, research participants discover the purpose of the experiment and thus conform to the demand characteristics of the task (see Firestone, 2013, for a detailed description of this argument). Woods, Philbeck, and Danoff (2009) were not able to replicate the effort-distance perception effect found by Proffitt, Stefanucci, Banton, and Epstein (2003), Woods and colleagues infer that the action-specific effects are the results of participants recalibrating their decisions about distance because they are sensitive to the context of the experimental situation. Both the work of Durgin and Woods, coupled with the theorizing by Firestone (2013), led us to infer that the locus of the action-specific effects are post on-line visual processing.

Gibson (1979) posited that the environment provides direct visual information about affordances. An affordance can be considered to be an interaction between the capacities of the individual and the visual information in the environment. A tree is climbable for a squirrel but is not climbable for an elderly individual. When holding a tool, the functionality of the arm has changed, and thus our perception of near perceptual space changes accordingly. When the tool can be used for reaching or touching, objects to be touched are functionally closer. The distance estimate captures the changed affordance. Similar logic is used to explain the softball and golf studies. Performers who did a better job hitting the softball or getting the golf ball in the cup perceived the better affordance on that particular day and, thus, did perceive the ball as more hittable and thus larger, or the putt as more sinkable and thus the golf cup as larger. Taking a Gibsonian approach leads to the idea that the affordance is directly perceived and then translated into a judgment.

The studies conducted in the action-specific framework, without exception, utilize tasks in which an affordance is directly related to task performance. In other words, performers, based upon their success or failure, or based upon their individual physical capacities, perceive the affordance. The affordance changes, but we argue that the online visual control of action is unaffected. In the present study, we were interested in whether the perception–performance relation found in studies such as golf, field-goal kicking, tennis, and softball batting would be seen in a task in which a subject does not know how well or poorly she performed, and thus the affordance of the task is not easily discernible.

When performing many tasks, a participant directly knows success. Furthermore, because of experience in or knowledge of the sport, a performer also has a reasonable idea how well her performance scales to understood norms. However, if action-specific effects reside in a real-time relation between perception and action capabilities, then the action-specific effect should be observed in "novel" tasks in which a performer does not know how well she performed. Thus, knowledge about performance should not affect the relation between action success and perception and thus should not affect the affordance–judgment relation.

The question investigated is pivotal for the action-specific account. In an action-specific view, performing well on a particular day modifies the perception of the performer. Durgin et al. (2009) and Firestone (2013), on the other hand, believe that a significant number of participants in these experiments figure out the purpose of the experiment and thus are responsive to the demand effects (Firestone, 2013) and provide results that are consistent with the investigators' hypotheses.

However, if the action-specific effect is the result of postperceptual processes, then knowledge about performance should be critical to perceptual judgments about task attributes. To examine this issue we chose a task that exhibits the most robust relation in motor behavior, such that it has "law" status. This is the Fitts' law task (Fitts, 1954).

In the Fitts task (Fitts, 1954; Fitts & Peterson, 1964), a participant moves from one location to a target, D units of distance away. The width of the target, W, and D are manipulated. The goal is to move as quickly as possible to the target without sacrificing accuracy, usually defined as less than a 5 % error rate. In the continuous (repetitive) version, described in the original Fitts (1954) paper, two targets of fixed width, W, are D units of distance apart (center to center distance). The participant moves repetitively, without pause, from one target to the other, under the speed-accuracy constraints described above. (An example of the Fitts task is shown in Fig. 1.) Fitts discovered a robust linear relation between average movement time, T, and the logarithm of the ratio of distance to target width, T =

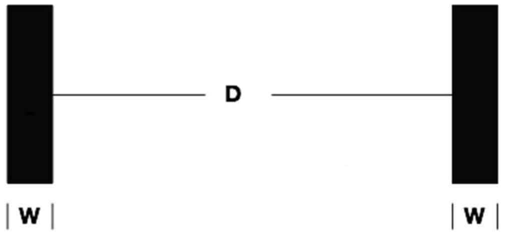

Fig. 1 Depiction of the target sheets in a typical Fitts' task. Two targets of width, W, are place D units apart (measured from the target center). Participant moves finger or an implement into one target, then the other, in a repetitive, continuous fashion, attempting to move as quickly as possible, without missing each target

$\underline{a} + \underline{b}\ \mathrm{Log}_2$ (2D/W), known as Fitts' law. Fitts' law is one of the most robust relations in all of human performance (Keele, 1968; Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979). Although slope and intercept values vary across different population samples, the relation between Log_2 (2D/W) and T is strongly linear (correlation values typically greater than 0.90). Thus, we assumed that the Fitts task would provide a robust laboratory task to examine whether action-specific effects require direct knowledge of performance or whether on-line perception during task performance can also account for this effect.

We believe that a participant does not have access to his or her level of performance. In order to know how well he or she performed, a participant must be capable to estimate their index of performance, defined as the ratio of the obtained index of difficulty and average T. Imagine that a participant could estimate her observed index of performance. For example, what is the meaning of an estimated IP of 11 bits/second? Thus, unless the individual understands the performance norms, we believe an individual will not know the relative standing of her performance. However, we posit that performance individual differences in the Fitts task will be observed. Thus, if perception and performance are inextricably linked, we still should observe an action-specific effect—that better Fitts task performers will report having a wider (larger) target width.

Experiment 1

Participants executed a continuous Fitts task in each of eight conditions. After each condition was performed, the participant judged the width of the target. We were interested in determining whether the level of performance on the Fitts task was related to the judgment of the width of the target.

Method

Participants Thirty-five college undergraduate students served as research participants. Participants received credit for participation in introductory psychology. The Purdue University Institutional Review Board approved all recruitment, informed consent, and experimental procedures.

Tasks Two tasks were performed. In the Fitts task, a participant moved a hand-held pencil in the medial-lateral dimension (left to right) and superior-inferior (up and down) from one target to another. In other words, the participant left the plane of the tabletop, moved laterally toward the next target, touched down on the target, and reversed direction to the other target. The targets were the same width, W, and were D cm apart. The values of W were 0.5 and 1.0 cm (the length of each target was 10.0 cm), and the values of D were 2.5, 5.0, 10.0 and 20.0 cm. The values of ID (Log_2(2D/W)) ranged from 2.32 to 6.32 bits.

The second task was a perceptual judgment of target width. On a sheet of standard 8.5 × 11-inch paper, 11 rectangles were placed. The rectangles were 10.0 cm in length. Width varied between 9.0 mm to 11.0 mm in 0.2 mm steps for the 1.0 cm targets, or from 4.5 to 5.5 mm in 0.1 mm steps for the 0.5 cm targets. The resolution of target width was equal to .002 cm (1,200 dots per inch). Each rectangle was randomly positioned on the paper. Each rectangle was randomly assigned a unique number, from 1 to 11. The rectangle number was unrelated to the width of the rectangle. Figure 2 shows one of the sheets used in the experiment. The number "007" in the upper right-hand corner identified the target sheet. The experimenters did not know the relation between the number of the rectangle and the width of the target. Thus, neither the participant nor the experimenter knew which numbered rectangle was the correct one. The participant verbally reported the rectangle number believed to be the correct target width.[1]

Apparatus A receiver from a Polhemus Liberty motion-capture system (2.30 x 1.27 x 1.14 cm) was taped to a standard HB wooden pencil. The tip of this unsharpened pencil was covered with a rubberized tip used in common ear buds for headphones. The targets for the Fitts task were centered in landscape orientation on standard 8.5 × 11-inch paper and secured with drafting tape to the surface of a 79-cm-high table. The perceptual judgment sheets were taped to the outside of a manila folder, so that the paper stayed flat during the judgment task. The participant could not view the judgment tasks except when presented by the experimenter.

Procedure Upon entering the laboratory, a participant was seated in front of the table. Upon providing informed consent, data collection commenced. The participant held the pencil between the index finger and thumb of the dominant hand. The participant placed the rubber tip of the pencil in the right- or left-most target, depending upon whether the participant was right- or left-handed. The experimenter asked whether the participant was "ready" and then initiated the trial by having a Windows-based PC system produce an 800 Hz, 100 ms duration tone. The participant moved from one target to the next, as quickly as possible, without missing the target. The participant moved for 22 seconds, and the end of the trial was signaled by a subsequent 800 Hz 100 ms duration tone. There was a 20-s intertrial interval during which a participant rested the arm on the tabletop. At the completion of five trials, the participant released the pencil; the experimenter covered the

---

[1] As we are not concerned with the psycho-physics of the judgment of target width, we used the same procedure utilized by Witt and colleagues. The participant was given a set of targets and produced a single judgment; we then recorded the judgment error.

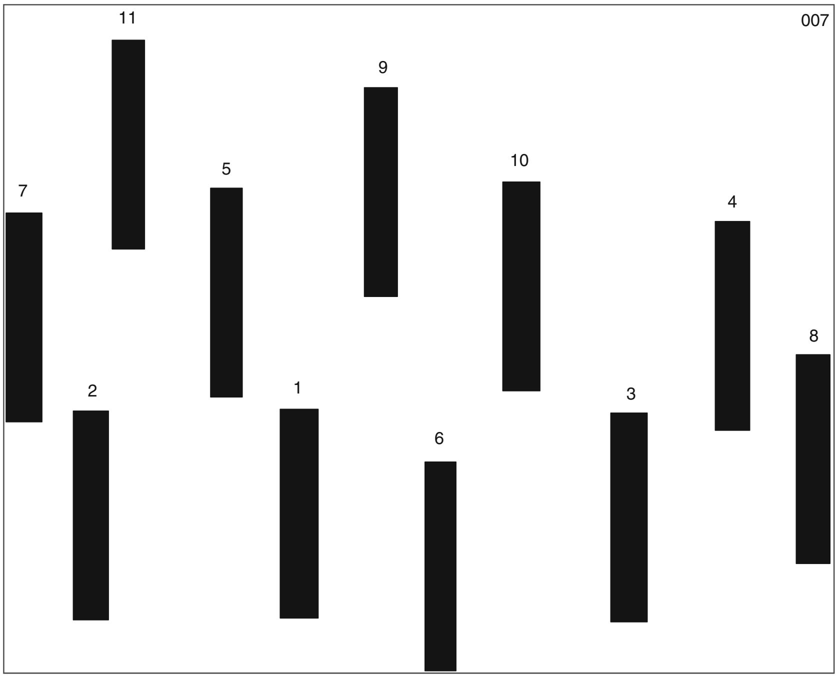

Fig. 2 A typical perceptual judgment of rectangle width sheet. These sheets were used in each of the experiments reported

Fitts' task target sheet with a manila folder and then presented the perception target sheet. The participant was not allowed to put his or her finger on the judgment sheet. Within 15 seconds the participant reported the number of the rectangle that was judged to be the exact same width as the target on the previous five trials. Following the verbal response, the experimenter removed the judgment sheet and replaced the Fitts' task target sheet with the sheet to be used on the next set of five trials. Performance of the eight Fitts conditions and the eight perceptual judgments of rectangle width required a total of 50 minutes.

Data collection and computations Kinematic data about the location of the pencil tip were collected with the Liberty Pohlemus system at 240 Hz. The medial-lateral dimension was utilized to compute movement time and movement distance. Medial-lateral data were low-pass filtered at 12 Hz with a fifth-order Butterworth filter, in the forward and backward direction. Velocity was computed with a three-point central-difference technique. Movement reversal was computed as a change in sign of velocity. Movement time was determined as the time interval from one reversal point to the next. The onset of the initial movement in the series was determined to be the first velocity value that was 3 % of the peak velocity value for that first movement.

Results

Fitts' law behavior For each subject, in each condition, the average distance, standard deviation in distance, and average movement time for each of the last four trials in each condition were computed. These computations allowed for the calculation of the effective index of difficulty, defined as the logarithm to the base two of the ratio of twice the average obtained distance and four times the standard deviation in distance. This latter term can be thought of as the actual target width, as four times the standard deviation in movement distance, as plus or minus two standard deviation units encompasses 95 percent of movement endpoints. In Fig. 3, the relation between the effective ID and movement time is shown for each subject in each D-W condition. Overall there was a strong linear relation between effective ID and T, with the correlation being equal to 0.75. When the effective ID was averaged across all 35 participants within each combination of D and W, the correlation was 0.97. Thus, Fitts' law was observed.

Judgment of target width In order to examine the relation between Fitts' law performance and perception of target width, we first calculated the index of performance (IP) described by Fitts (1954). The IP is the rate of information transmission (bits/second). It is the effective ID divided by the average movement time. The obtained IP served as the motor performance individual difference variable. In Fig. 4a and b, we present the relation between the IP and the percentage of rectangle width judgment error for the 0.5-cm and the 1.0-cm target-width conditions, respectively.

As is clearly depicted in the two panels, there was no relationship between Fitts-task performance and error of

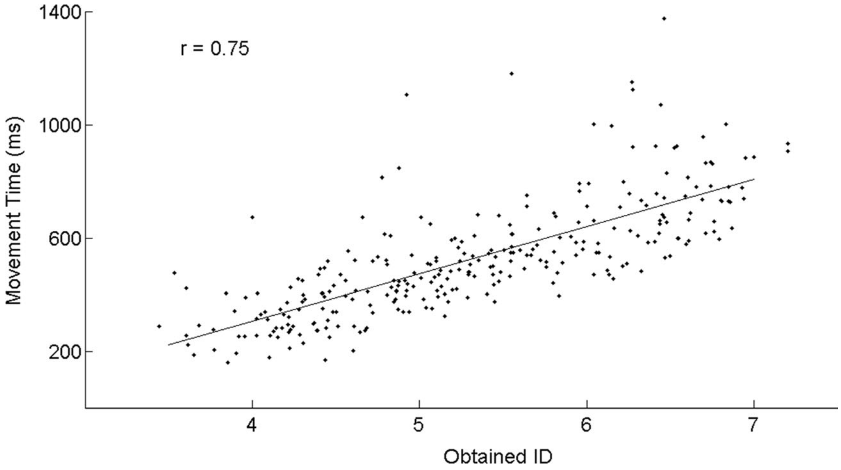

Fig. 3 Relation between obtained index of difficulty (ID) and movement time not averaged across subjects in Experiment 1

target width judgment. The correlations were -0.18 and 0.04 in the 0.5 and 1.0 cm target width conditions, respectively. These results do not support the action-specific perception effect in a Fitts' law task.

In Experiment 2 we examine the possibility that individuals did not perceive any differences between the widths of the rectangles. In other words, the plus–minus 10 % target width ranges were not discriminable. Thus, in Experiment 1 it could

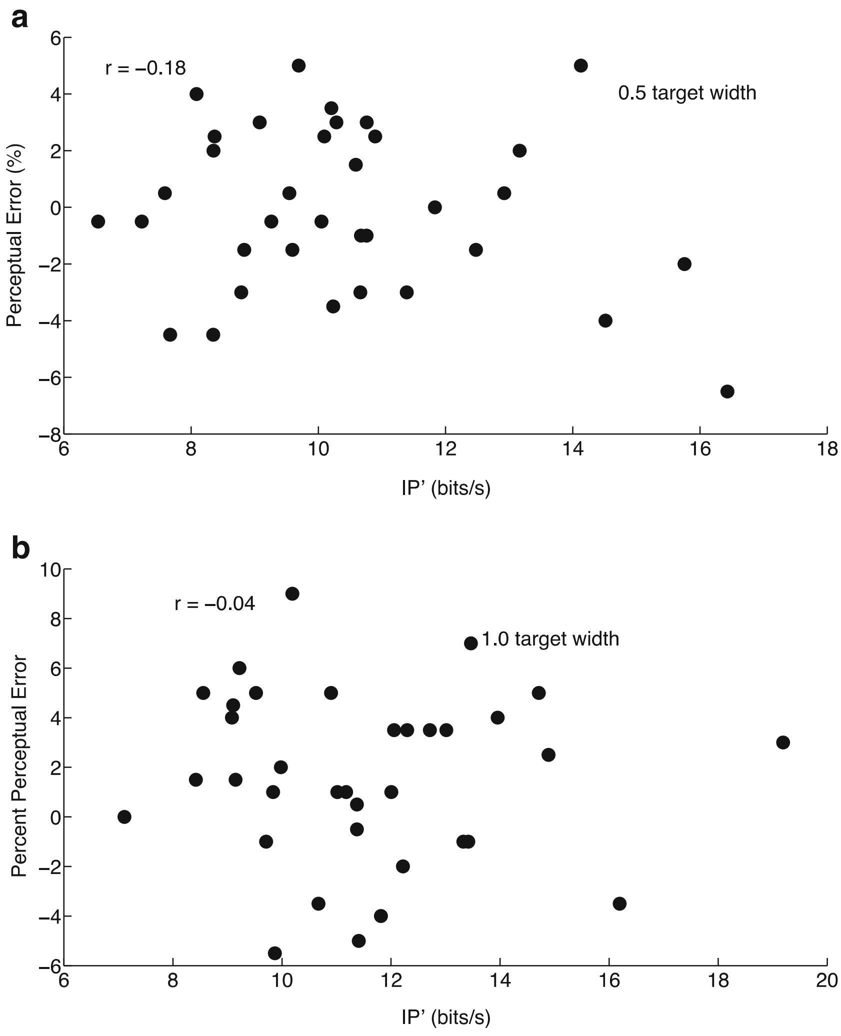

Fig. 4 Relation between index of performance and judgment of rectangle width in Experiment 1

be that we did not provide a fair evaluation of the action-specific account of perception and action.

Experiment 2

One possible explanation for the lack of a relation between performance and perception of target width concerns the very small range in width (plus or minus 1.0 mm) for the 1.0 cm target-width perception task. To examine this issue, we took the target perception sheets to locations in which students, individually, would be present, and showed them the 1.0 cm width target. Then the participant was presented the target judgment sheet, in which the target widths ranged from plus or minus 10 % of the width 9.0 mm–11.0 mm, or plus or minus 20 %, 8.0 mm–12.0 mm (this was a between-subjects variable). There still were 11 widths on each sheet, and each rectangle was located randomly, ordered, and numbered randomly, as in the first experiment.

Method

Participants One hundred and eighty (180), undergraduate students served as subjects. The Purdue University IRB deemed this study exempt from review and informed consent requirements.

Procedure An experimenter walked around campus and asked individual students sitting either indoors or outdoors to participate in a less than 2-minute perception task. The subjects, in agreement, looked at the 1.0-cm target-width rectangle for 15 seconds and then was presented with one of 20 randomly selected perceptual target judgment sheets. The participant chose the rectangle he or she believed matched the rectangle that was just viewed. Half of the participants viewed the judgment sheets that were plus or minus 10 % of the 1.0-cm width, and the other participants viewed a set of sheets that were plus or minus 20 %.

Results We are concerned with the discriminability of the 0.2 mm gradations in width (10 % case) and the 0.4-mm gradations (20 % case). We posit that if these widths are discriminable and not too easy, then we expect that the frequency of choosing a particular rectangle width will be distributed normally. As one can see in Fig. 5, the 20 % rectangle width sheets did produce a clear, normal looking distribution, but the 10 % sheets production was less so. However, a Kolmogorov-Smirnov test (with MATLAB) was performed, and it was determined that the 10 % and 20 % frequency distributions did not fail the normal distribution test. Thus, despite the visual appearance differences between the distributions, each could be considered to have a normal distribution.

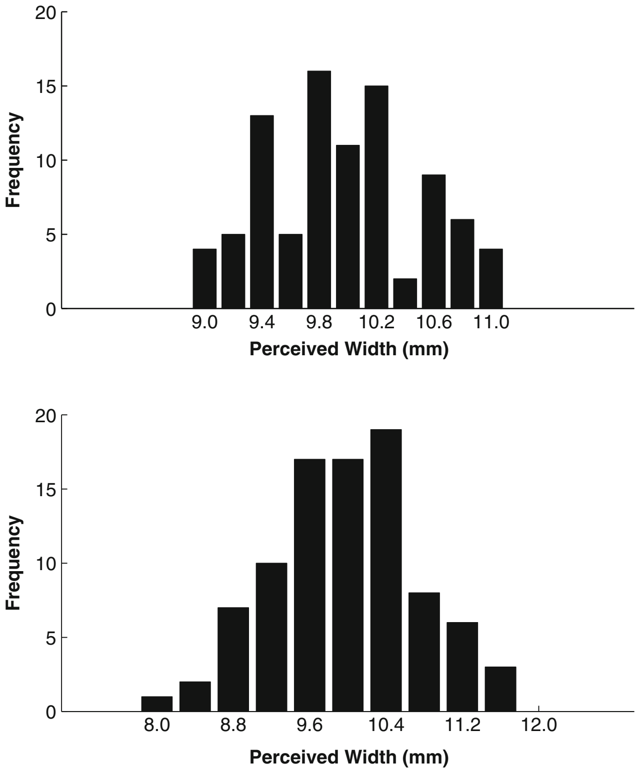

Fig. 5 Frequency distributions for the 10 % (a) and 20 % (b) target judgment tasks in Experiment 2

To further investigate target-width judgment accuracy, the average absolute error in each group was computed. As the range of errors in absolute millimeters for the 20 % group should be twice that of the 10 % group, the rectangle width values were normalized to a -100 % to +100 % scale. For the 10 % group the average absolute error in judgment was 43.2 %, and this value was 30.2 % for the 20 % group. This difference was significant, $t(178) = 34.7, p < .001$. Based upon the less-than-normal-looking distribution for the 10 % group, as well as the clearly greater errors in judgment, we infer that the 20 % range of rectangle widths would have provided a fairer examination of the action-specific framework in a laboratory task.

Experiment 3

Given the difficulty of the 10 % target width judgment task utilized in Experiment 1, in the present experiment the nature of the perceptual judgment (10 % vs. 20 % width range) was examined. We were interested in determining whether there would be support for the action-specific framework in the 20 % judgment task and not in the 10 % task. Target width was kept constant at 1.0 cm, and only one perceptual judgment was made at the end of performance of only two Fitts' law tasks. This latter change made this experiment similar to the procedures used in the sport-task studies, in which only one perceptual judgment was made.

Method

Participants Seventy undergraduate male and female students participated in the experiment as part of an introductory psychology class research option.

Task and apparatus The Fitts tasks and the perceptual judgment task were identical to those used in Experiment 1. The 10 % and 20 % judgment task utilized the judgment sheets from Experiment 2. The two Fitts tasks were 10.0 cm and 20.0 cm in distance to a 1.0 cm target.

Procedures Procedures for the Fitts tasks and the judgment task were identical to those of Experiment 1. Each distance condition was performed for eight trials. At the conclusion of all of the Fitts task trials, the participant made a single judgment of the target width.

Results In the 10-cm distance conditions, average movement time was 411 and 381 ms in the 10 % and 20 % groups, respectively. In the 20-cm distance conditions, average movement time was 509 and 468 ms in the 10 % and 20 % groups, respectively.

The index of performance (effective difficulty / movement time, in bits/s) essentially was constant across the four conditions; in the 10 % group, index of performance was 12.0 and 11.4 bits/s in the 10 and 20 cm distance conditions, and in the 20-percent group these values were 12.2 and 11.7. Thus, the rate of information transmission was constant, as expected because of adherence to Fitts' Law. Thus, the movement time difference between the 10 % and 20 % groups is due to the fact that the 20 % subjects exhibited increased distance variability with a smaller movement time, but with similar IP values.

We present the relation between judgment of rectangle width and the mean index of performance for each of the four conditions in Fig. 6. As can be seen in the four scatter plots, the relation between the index of performance in each of the four tasks and perception of rectangle width was not strong. Furthermore, counter to the action-specific account, the relation was negative, such that the higher values of the index of performance were related to judgments of a smaller width, but not significantly so.

Discussion

The results from this experiment support the original results found in Experiment 1. Regardless of whether the Fitts target width judgment task was difficult (10 % condition) or easier (20 % condition), there was no significant relationship between performance and target width judgment. Thus, we infer that in a laboratory task, no support for action-specific perception was evident.

However, there is one major difference in the Fitts' law task compared to the softball and golf tasks utilized by Witt (Witt et al., 2008; Witt & Proffitt, 2005). In those sports tasks, performers know and, we argue, understand the performance metrics. Performers also might be aware of the sport folklore concerning the nature of being in the zone (Gallwey, 1997) and thus assume that they should be influenced by how they performed. In fact, Firestone (2013) posited that this demand effect explains many of the action-specific effects (but see Proffitt, 2013, for a rejoinder).

In the fourth and final experiment, knowledge about performance is provided concerning the Fitts aiming task. In addition, we explained the performance scale so that participants would believe that their performance was equal to, above, or below average. If knowledge about performance is necessary to produce the relation between performance (in this case, perceived performance) and judgment, then we should now observe the action-specific relation instantiated for the easier judgment task.

Experiment 4

The results from Experiments 1 and 3 lead us to infer that performance on the Fitts task does not affect judgment of target width. As such, the use of vision in movement control during movement planning and movement execution is not supporting action-specific effects. Performance on the Fitts task does not produce an outcome that is readily available to the performer. In particular, good or bad performance needs to be relative to a standard. In the Witt golf and softball studies, performers knew their outcome, and, we assume, clearly knew how their performance compared to their own average and/or any arbitrary standards. As judgments were made following performance, it is possible that judgments were biased. In Experiment 4, we provided a performance score after completion of the Fitts task prior to participants making a target-width judgment so that a performance standard that would have the potential to be used by a participant was provided. We expected this information would lead to an action-specific effect on perception of target width.

Participants performed two Fitts tasks for eight trials each. At the start of the testing session, participants were informed that at the end of the 16 trials that an index of performance", analogous to a motoric IQ (of course, this was a cover story, and participants were fully debriefed after the experiment) would be provided. These scores had a population average of 100 and ranged from 50 (*really poor performance*) to 150 (*a motor virtuoso*). After receiving their performance score, the average from their eight trials, the participant then made

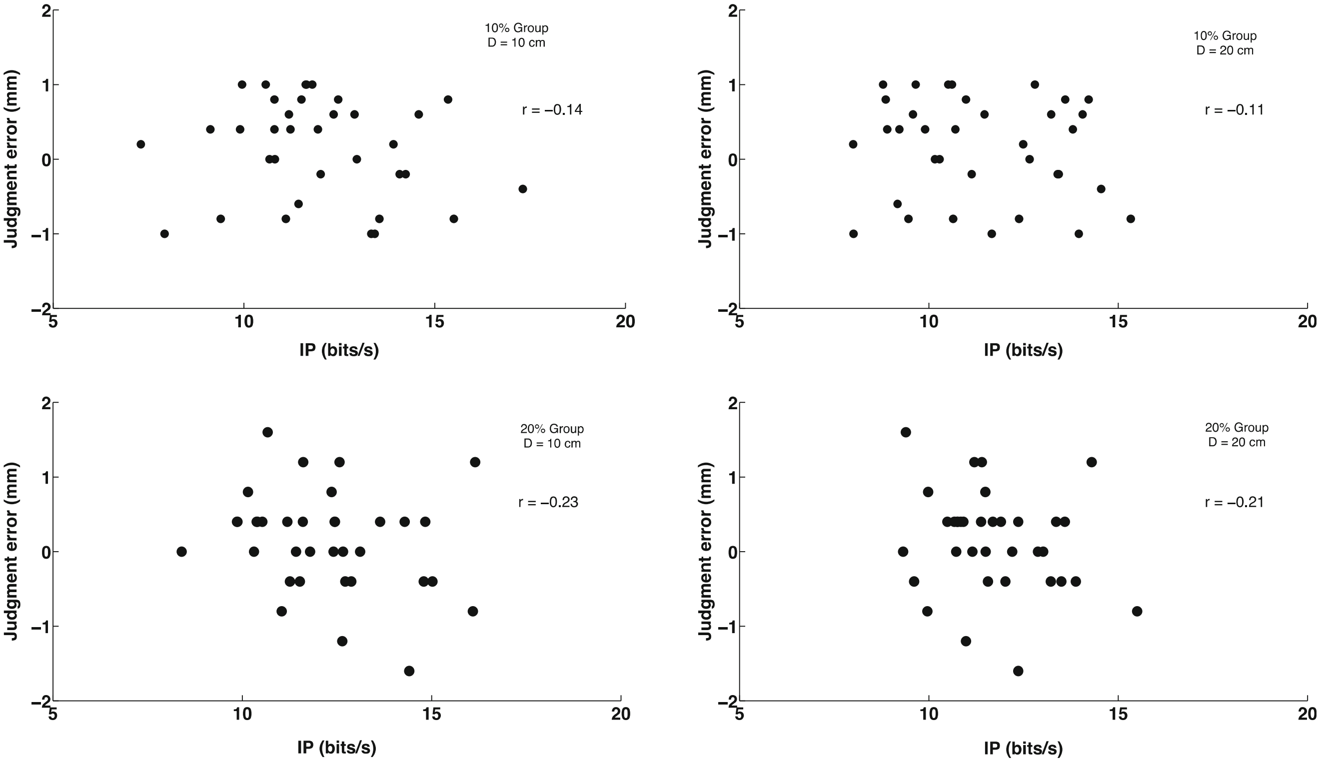

Fig. 6 Relation between index of performance (IP) and judgment of target width for the 10 % and 20 % judgment groups in the 10-cm and 20-cm distance conditions in Experiment 3

the perceptual judgment of target width, identical to those in the first three studies.

We used the Fitts task performance from previous experiments to generate a normal distribution of IP values. The mean of this distribution was 11.7 bits/s (this value is very close to the average IP in the Fitts, 1954, paper) with a standard deviation of 2.33. Then we assigned a Motor IQ to the subject's performance by taking their average IP, converting to a *Z,* score and using the following sigmoidal relation:

$$MotorIQ = 50 + 100/\left(1 + e^{-Z/.43}\right) \qquad (1)$$

Equation 1 produces a set of scores ranging from 50 to 150, but will accentuate the extremes. We did not want the scores to be segregated around 100, in order to provide a good range of IQ scores.

Method

Participants Thirty-six male and female participants from introductory psychology volunteered for course credit. Nineteen participants performed in the 10 % judgment task. There were 10 females in the 10 % group and nine females in the 20 % group. All participants were right-handed, with no known neurological impairments, and had normal or corrected-to-normal vision.

Apparatus and tasks The two Fitts' law tasks were 10.0 and 20.0 cm distance, each with a 1.0 cm target width. The perceptual judgment of target width was either a 10 % or 20 % condition. Each of these tasks was performed identically to those in Experiments 1 and 3.

Procedure During the instructions and informed consent procedures, participants were informed that the speed and accuracy of their performance would be calculated and compared to that of all undergraduates that have performed on these tasks over the last 5 years. They were informed that average performance produced a score of 100, and that exceptionally excellent performance would produce a score close to 150 and very poor performance would exhibit a score close to 50. Finally, it is important to note that the experimenters were under the belief that these Motor IQ scores were drawn at random, and thus we minimized, if not eliminated, the possibility of an experimenter biasing the judgment task.

The Fitts tasks and the judgment task were performed identically to those in Experiments 1 and 3. Upon completion of the last trial in the Fitts task, the experimenter provided the subject with their Motor IQ score and was reminded that the population average score was 100. The participant then performed the judgment task, exactly as described in Experiments 1 and 3.

Upon completion of the target-width judgment task, the participant was debriefed and informed that the Fitts task, as far as anyone knows, is unrelated to motor performance in other tasks.

The judgment task (10 % vs. 20 % range of target width) was a between-subjects factor, and distance was within subjects. The order of distances was counterbalanced across subjects.

Results

Descriptive results For the 10 % participants, average movement time values were 477 and 585 ms, in the 10-cm and 20-cm distance conditions, respectively. For the 20 % participants, average movement time values were 533 and 660 ms, in the 10-cm and 20-cm distance conditions, respectively. Index of performance values were 14.3, 13.2, and 13.1 and 12.0 for the 10 % and 20 % groups in the 10-cm and 20-cm distance conditions, respectively.

Relation between index of performance and judgment In Fig. 7, the relation between the index of performance score and perceptual judgment error is presented for the 10 % group (top panel) and the 20 % group (bottom panel). As can be seen in the figure, there was no relation between judgment and performance in the 10 % judgment task (r = -0.27). On the other hand, for the 20 % judgment task, a fairly strong relation between index of performance and target-width judgment was observed (r = 0.54, $p < .05$).

Discussion

When participants were provided with a score that was believed to reflect their performance on the Fitts' law task, the expected action-specific effect was observed only when the perception task was discriminable (20 % judgment task). This result, we believe, supports the notion that action-specific effects require knowledge of performance and, perhaps, an understanding of the norms or standards of performance.

General discussion

We examined the generalizability of the action-specific view of perception in a laboratory task. Specifically, would individual differences in Fitts task performance predict judgment of target width? In the first experiment, with a 10 % judgement task, the answer was no. Experiment 2 demonstrated that the 10 % perceptual judgment task used in Experiment 1 was too difficult. Therefore, in Experiment 3 we examined the action-specific perception-action account in Fitts' law performance, with a plus or minus 10 % and plus or minus 20 % perceptual-judgment condition. We found the same results as in the first experiment. The level of performance on the Fitts task, as captured by the index of performance, was unrelated to target-width judgment.

In the fourth experiment we demonstrated that when knowledge of performance was provided in conjunction with the 20 % target width judgment task, an action-specific effect like those found in sport-skill studies (Witt et al., 2008; Witt et al., 2005) was observed. Thus, we claim that the relation between motor performance and/or motor capabilities and perception of task-relevant information does not reside in the perception of this information during actual task performance but is biased toward action-specific effects in postperformance judgment. Firestone (2013) describes these types of effects as "demand" effects.

A traditional framework that can be used to understand these "demand" effects is signal-detection theory (Green & Swets, 1966), in which the sensitivity of the perceptual mechanism parameter, d', and response bias, β, determine the rates of percentage corrects, misses, false alarms, and incorrect rejections. Based upon our results, we infer that our perceptual effects in the fourth experiment are most likely because of a change in sensitivity with performance but instead because knowledge of performance affects the bias to choose a larger size target.

Of course, it is also the case that in the sports studies previously cited, the performer experiences a much more discrete event (a base hit in softball, as well as the ball in the hole in fewer strokes in golf) that might be more easily influence perceptual performance. In the timing domain, Zelaznik, Spencer, and Ivry (2002) have shown that individuals who are better timers in a discrete timing task also are better at perceptual judgments of time. However, this relation breaks down for continuous timing tasks. In the present work, we used the continuous (repetitive) version of the Fitts tasks, and thus it might be the case that a discrete Fitts task in which performers see discrete hits and misses of the target will exhibit robust action-specific effects. However, in the viewing of Fitts' law tasks, observers show that individuals can perceive the quality of Fitts' law performance in continuous Fitts tasks (Grosjean, Shiffer, & Knoblich, 2007). Thus, we do not believe that continuous tasks provide an exception to the action-specific account. Furthermore, we produced the action-specific effect when participants were provided with a contrived Motor IQ score, even though the Fitts task was performed repetitively.

A stronger test of the notion that performance knowledge is a cause of the action-specific effect would be to provide a Motor IQ score selected at random. Thus, the score is unrelated to objective performance. In this scenario, we also predict a linear relation of IP score to judgment of target width.

Similar to the account of Firestone (2013), we attribute the action-specific effect to a postperformance bias

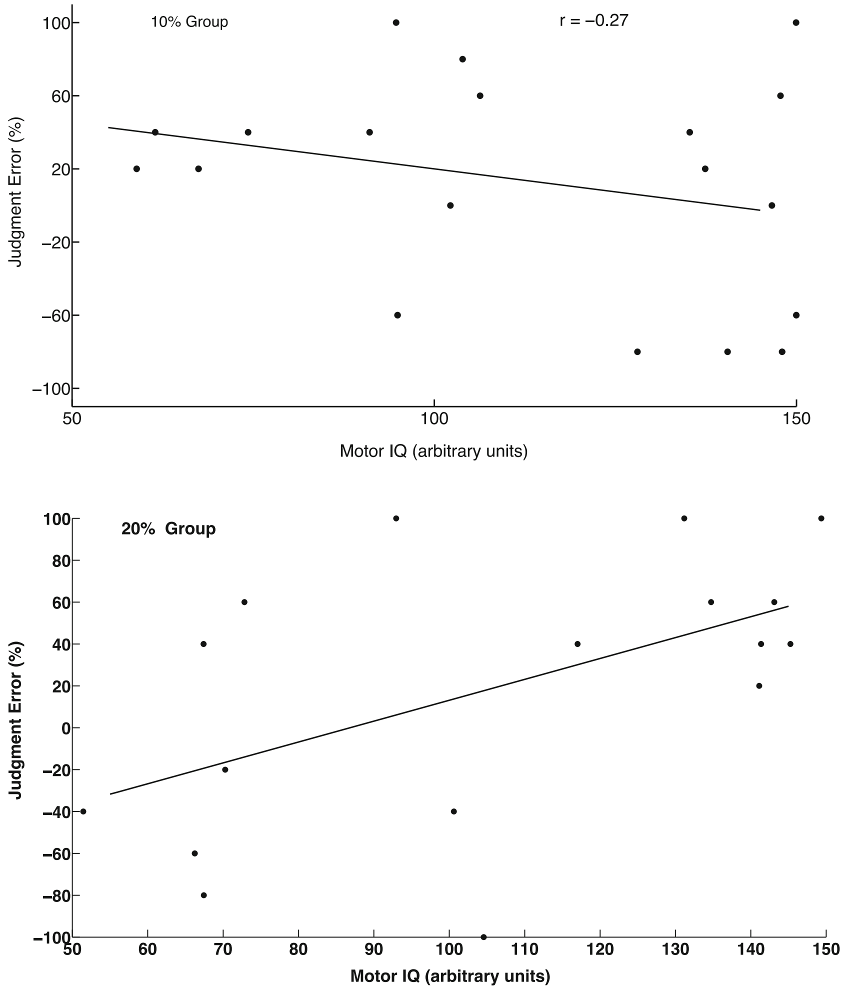

Fig. 7 Relation between Motor IQ and target width judgment in the 10 % and 20 % groups in Experiment 4

produced by knowledge of performance, and thus judgment was biased, but not online perception. Of course, we are not arguing that individuals do not perceive the world in terms of affordances (see Gibson, 1979). However, we believe individuals should perceive the world relative to the information that affords successful performance. The perception of distance, slant, and size collected in most experiments are judgments that people make that they then provide an explicit response to an experimenter. These judgments are influenced by many factors, one of which can be the physical capability of the individual.

Clearly, our participants were far from being expert performers in making width judgments. However, the judgment of hill angle (Witt & Proffitt, 2007) did not use expert subjects, and city league softball players and weekend golfers also are far from experts. However, in those three studies, individuals, without any help from the experimenter understood how well they performed or that it would be harder to climb a hill while wearing a heavy backpack (see Durgin et al., 2009). Thus, the demand effects proffered by Firestone (2013) could come into play.

In Fig. 8 we present the Fitts' performance as measured by the IP with the confidence interval for 10 % and 20 % conditions in the third and fourth experiment. These confidence intervals overlap, and thus we consider that there was not any sampling bias in Fitts performance across the judgment conditions and the level of Fitts' performance. For example it could have been the case that the range of Fitts performance

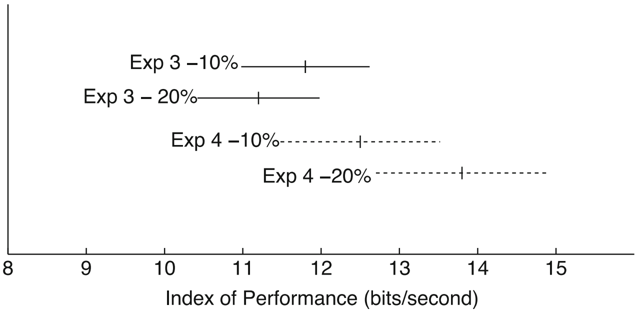

Fig. 8 Obtained average index of performance (bits/second) for each judgment condition in Experiments 3 and 4. Horizontal lines represent plus and minus two standard errors

differences was too narrow to provide an opportunity to show performance-judgment relations. As the confidence intervals shown in Fig. 8 are essentially equivalent and the scatter plots of IP to judgment show, the value of the correlation coefficients are not dependent upon unique distributions of one or both sets of scores. Thus, we are quite confident that our results are not due to differences in IP performance in the Fitts task across experiments.

Proffitt and Witt have produced an impressive set of experiments that clearly show the individuals making judgments about the state of their world are affected by their chronic and/or acute physical capabilities (see Proffitt, 2013, and/or Firestone, 2013, for a very brief review). Although we did not directly examine these issues, we claim that these effects are not perceptual but are due to biased judgments.

Author notes The authors thank J. K. Witt for discussions concerning the work in the first two experiments. Dennis Proffitt, David Rosenbaum, and Chaz Firestone provided helpful comments on previous versions of the manuscript. H. N. Z. was involved in all aspects of this research. L. F. was involved in the design of the Experiments 1, 2, and 3, as well as in the writing of the manuscript. The authors have no competing interests.

References

Durgin, F. H., Baird, J. A., Greenburg, M., Russell, R., Shaughnessy, K., & Waymouth, S. (2009). Who is being deceived? The experimental demands of wearing a backpack. *Psychonomic Bulletin & Review, 16*(5), 964–968. doi:10.3758/pbr.16.5.964

Durgin, F. H., Hajnal, A., Li, Z., Tonge, N., & Stigliani, A. (2010). Palm boards are not action measures: An alternative to the two-systems theory of geographical slant perception. *Acta Psychologica, 134*(2), 182–197. doi:10.1016/j.actpsy.2010.01.009

Firestone, C. (2013). How "paternalistic" is spatial perception? Why wearing a heavy backpack doesn't—and couldn't—make hills look steeper. *Perspectives on Psychological Science, 8*(4), 455–473.

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology, 47,* 381–391.

Fitts, P. M., & Peterson, J. R. (1964). Information capacity of discrete motor responses. *Journal of Experimental Psychology, 67,* 103–112.

Gallwey, W. T. (1997). *The inner game of tennis: The classic guide to the mental side of peak performance (Rev. ed.)*. New York, NY: Random House.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston, MA: Houghton Mifflin.

Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics* (Vol. 1974). New York, NY: Wiley.

Grosjean, M., Shiffrar, M., & Knoblich, G. (2007). Fitts' Law holds for action perception. *Psychological Science, 18*(2), 95–99.

Keele, S. W. (1968). Movement control in skilled motor performance. *Psychological Bulletin, 70,* 387–403.

Proffitt, D. R. (2006). Embodied Perception and the Economy of Action. *Perspectives on Psychological Science, 1*(2), 110–122. doi:10.1111/j.1745-6916.2006.00008.x

Proffitt, D. R. (2013). An embodied approach to perception: By what units are visual perceptions scaled? *Perspectives on Psychological Science, 8*(4), 474–483. doi:10.1177/1745691613489837

Proffitt, D. R., Stefanucci, J., Banton, T., & Epstein, W. (2003). The role of effort in perceiving distance. *Psychological Science, 14*(2), 106–112. doi:10.1111/1467-9280.t01-1-01427

Schmidt, R. A., Zelaznik, H., Hawkins, B., Frank, J. S., & Quinn, J. T. (1979). Motor-output variability: A theory for the accuracy of rapid motor acts. *Psychological Review, 86*(5), 415–451.

Sugovic, M., & Witt, J. K. (2011). Perception in obesity: Does physical or perceived body size affect perceived distance? *Visual Cognition, 19*(10), 1323–1326.

Witt, J. K., & Dorsch, T. E. (2009). Kicking to bigger uprights: Field goal kicking performance influences perceived size. *Perception, 38*(9), 1328–1340. doi:10.1068/p6325

Witt, J. K., Linkenauger, S. A., Bakdash, J. Z., & Proffitt, D. R. (2008). Putting to a bigger hole: Golf performance relates to perceived size. *Psychonomic Bulletin & Review, 15*(3), 581–585.

Witt, J. K., & Proffitt, D. R. (2005). See the ball, hit the ball: Apparent ball size is correlated with batting average. *Psychological Science, 16*(12), 937–938.

Witt, J. K., & Proffitt, D. R. (2007). Perceived slant: A dissociation between perception and action. *Perception, 36,* 249–257.

Witt, J. K., & Proffitt, D. R. (2008). Action-specific influences on distance perception: A role for motor simulation. *Journal of Experimental Psychology: Human Perception and Performance, 34*(6), 1479–1492. doi:10.1037/a0010781

Witt, J. K., Proffitt, D. R., & Epstein, W. (2005). Tool use affects perceived distance, but only when you intend to use it. *Journal of Experimental Psychology: Human Perception and Performance, 31*(5), 880–888. doi:10.1037/0096-1523.31.5.880

Witt, J. K., & Sugovic, M. (2011). Performance and ease influence perceived speed. *Perception, 39*(10), 1341–1353.

Woods, A. J., Philbeck, J. W., & Danoff, J. V. (2009). The various perceptions of distance: An alternative view of how effort affects distance judgments. *Journal of Experimental Psychology: Human Perception and Performance, 35*(4), 1104–1117. doi:10.1037/a0013622

Zelaznik, H. N., Spencer, R. M. C., & Ivry, R. B. (2002). Dissociation of explicit and implicit timing in repetitive tapping and drawing movements. *Journal of Experimental Psychology: Human Perception and Performance, 28*(3), 575–588. doi:10.1037//0096-1523.28.3.575