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Perceived difficulty of a motor task affects memory but not action

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Abstract Successful motor interaction with a target changes memory of the target's size, which seems larger if the action was successful than if it was unsuccessful. This has been attributed to the effect of action on subsequent perception or memory. We asked what the action provides: Is feedback from the action necessary, or only the information provided by the action? We found that perceived difficulty alone changes the remembered goal characteristics, without changes in the stimuli, and before the motor task is executed. We gave observers a marble and showed them a hole in a box. They were told that throwing the marble into the hole was either difficult or easy, depending on the condition. The hole was then covered and its size judged. Participants who were told that the task was difficult judged the hole to be significantly smaller than it was, whereas those told that the task was easy made judgements not significantly different from veridical. When observers subsequently threw the marble, their success rates were independent of their own estimates of hole size or of what they had been told about the difficulty of the task, showing that their size estimates affected memory but not action. In a second experiment, we found that the effect disappeared if the hole was visible during the size estimation.

Keywords Goal-directed movements · Visual working memory · Short-term memory · Perception · Action

Recent research suggesting that action modifies perception has changed the current ideas about the relationship between perception and action (Witt, 2011). The new theory is that action sometimes affects perception, rather than the other way around. If this were true, the world should look different, depending on one's recent interactions with it. This view has been challenged with findings that actions modify memory for the properties of the visual world, including immediate memory, but that perception is not changed (Cooper, Sterling, Bacon, & Bridgeman, 2012).

The relationship between successful interaction with an object and subsequent perception of the properties of that object has been investigated in several experiments. For example, baseball batters who had a high batting average in a game judged the baseball to be larger than those who had a low average (Witt & Proffitt, 2005). Golfers judged a hole to be larger if they had just been successful in putting (Witt, Linkenauger, Bakdash, & Proffitt, 2008). These and similar studies (Cañal-Bruland & van der Kamp, 2009), however, tested sizes after the action had been completed and the goal object was no longer visible, leaving open the possibility that the action had modified memory rather than perception.

It is critical to test both perception and memory to differentiate the two possible influences of action, since a change in perception would also change memory, but memory could be changed without affecting perception. In a simple motor task, Cooper et al. (2012) showed that even when memory of the size of a goal is altered following motor interaction with the goal, perception remains unchanged. Thus, "action affects perception" has become "action affects memory." Furthermore, it remains an open question whether the action itself, or only the information that the observer acquires through the action, is what modifies perception or memory. We addressed this question in the present study.

Wesp, Cichello, Gracia, and Davis (2004) came close to such a test; they had observers drop a dart onto a target and then judge the size of the target while it was still visible. But their matching task failed to resolve the memory confound, since the task required the observers to look away from the target while making their judgement. Thus, the observers relied on a remembered size.

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Wesp et al. (2004) also tested the possibility that the way that an object is used will have an effect on memory of its size, whether or not the object is familiar. Their first experiment exposed observers placed in two groups to two different conditions. The first condition was called the "tedious removal condition," and the second was the "movement condition." In the first condition, the experimenter took a ladle filled with sand and used a spoon to scoop the sand out of it. The experimenters hoped that this repeated action would focus attention on the repetition, leading participants to infer that the ladle had a large volume. In the second condition, the experimenters used a larger spoon to scoop sand out of the ladle and place it in a bucket. They did this to put the focus on the "movement of sand without emphasizing a relationship between the movement and the volume of sand in the ladle" (Wesp et al., 2004). The observers were then asked to choose the correct picture from a series that depicted the size of the ladle. The results demonstrated that the observers who saw the more tedious removal of sand judged the ladle to be taller. Thus, a change in the way that the ladle was used resulted in a change in its remembered size, without the observers directly interacting with it.

Recognizing these problems, Witt et al. (2008) included a condition in which golfers estimated the size of the goal hole by reproducing its size, in an exacting task requiring the manipulation of a computer mouse to draw a circle of the desired size while the hole was visible. As soon as the golfers looked away from the hole to the computer screen, however, only memory would be available to guide the drawing task. The resolution of the retina is of course poor, except for direct fixation by the fovea. Ambiguity of the results therefore remained.

In another attempt to distinguish perceptual from memory effects, Witt and Dorsch (2009) had observers reconstruct the proportions of an American football goal post on a handheld plastic model before and after attempting to kick a football at the goal post. The football goal post consisted of a pair of parallel vertical bars supported by a horizontal bar that in turn was mounted on a vertical post. The dimensions of the goal post model after the observers adjusted it varied with success in kicking, with the model being set larger with success in kicking. Lateral misses resulted in the model being set with a narrower space between the side bars of the goal post, and undershoots resulted in the supporting post being set longer than it was by those who succeeded. Since the observers were facing the real goal post while manipulating the model, the authors concluded that the effect was perceptual rather than memory-based.

Some ambiguities still remained in the interpretation of the Witt and Dorsch (2009) result, however. First, if observers were truly paying attention to both the real and model goal posts simultaneously, they would have simply matched the model against the real post by superimposition and come up with no errors. In order to have errors, the observers must have looked away from the real goal to set the model, a task involving visually controlled action on a handheld object distant from the real goal post. We know from the literature on inattentional blindness and attention that people can generally attend to only one object at a time. Second, the observers set the model both before and after their kicks. The request to set the model again, after they had already set it before kicking, would have informed them that some sort of change was expected. Otherwise, there would be no point in obtaining a second setting. Thus, a demand characteristic was established. If the authors asked their observers about their opinion of the purpose of the experiment, they did not report it.

To cleanly separate perception from memory, it was necessary to have observers estimate goal size with a task that did not require visual perception of both the goal and the comparison standard at the same time. For example, observers could verbally decide which of several goal sizes matched the currently perceived one, or give a haptic estimate with unseen hands to show size while fixating the target and performing no visually guided task. Thus, the issue of the information needed or used to inform memory of the goal objects remained unresolved; what was required, was a task that could allow direct visual fixation of the goal while a nonvisual measure of its size was recorded.

Cooper et al. (2012) met this requirement by having observers attempt to throw a marble through a hole and then judge the size of the hole. This task was chosen to avoid the confounds from previous experience with football goals, golf holes, and so forth. In one condition, observers judged the size after a curtain had obscured the hole (memory condition), whereas in another condition they judged the size while still looking at the hole (perception condition). Two measures were used: either estimating the size of the hole on the basis of a set of numbered and memorized alternatives or indicating the hole size with hidden fingers. With either measure, the accuracy in indicating the size of the still-visible hole was independent of motor success. When the curtain obscured the hole, though, estimates were larger when the most recent toss had been successful. Thus, the memory condition replicated the results of Witt and Proffitt (2005), Wesp et al. (2004), and others that have shown an influence of motor success on size estimates, but the lack of an effect in the perception condition suggests that the action affected memory rather than perception: Participants made a judgment based on their memory of the perceived hole, informed by their experience in the marble-toss task.

The Cooper et al. (2012) result challenged the thesis that action affects perception. Their data show that the second part of the thesis is incorrect: Rather, action affects *memory.*

In this study, we approach the first part of the new thesis: whether action is needed in active-participation paradigms. It remains an open question whether the action itself, or only the information that the observer acquires through the action, is what modifies perception or memory. It has been known since

Bartlett (1932) that long-term memory is systematically distorted by experiences and expectations. In our study, however, we investigated very short-term working memory, which must hold information about a stimulus for only a few seconds.

If action influences memory for the size of an object, a question arises as to what sort of information is necessary to affect memory. Is active interaction with the goal object or observation of an active interaction necessary, or can symbolic information alone influence the object's remembered size? Here, we tested for the presence of a memory effect on size judgment using the simple task of throwing a marble through a hole, while manipulating the perceived difficulty of the task. Observers used a combination of their memory of looking at the hole without throwing and the suggested difficulty of the task, based on the verbal instructions, to make their size estimates.

Experiment 1

Methods

Participants

A total of 98 undergraduate students at the University of California, Santa Cruz (78 female, 20 male), volunteered to participate in exchange for course credit.

Apparatus

A white wooden box presented a surface in the seated observer's frontal plane. A 58-mm-diameter hole in the surface was centered 86.5 cm from the floor, 109 cm from the observer's corneas. This placed the hole at shoulder height. A black felt curtain hung in front of the box concealed the box from view. A hole-sizing chart depicting seven circles was displayed in view to the left of the chair; the circles represented hole sizes ordered by increasing size, in increments of 3 mm. Hole 1, at the bottom of the chart, measured 49 mm in diameter, and hole size 7, at the top of the chart, measured 67 mm. Thus, the hole in the box was identified as number 4, leaving equal numbers of circle sizes that were larger and smaller than the actual hole. The difference between the successive hole size choices was adjusted in pilot work to be small enough to result in some estimation errors, but large enough to offer a wide range of possibilities.

Procedure

Since Cooper et al. (2012) had found that action affects memory but not perception, we tested only memory. Haptic (finger span) and verbal measures had produced similar patterns of results in that study, so we were able to get a complete picture with a verbal measure. New in our study was a different source of information about task difficulty: Rather than observers using information from their own motor success, the information was provided in the form of instructions regarding the task difficulty.

Observers sat in front of a black felt curtain, keeping their backs against the rear seat cushion of their chair (Fig. 1). They were handed a standard marble 14 mm in diameter before receiving oral instructions. While holding the marble, the observers were given instructions in one of two conditions. In the "easy" condition, the participants were told, "Your task will be to throw the marble through the hole (which was then revealed by lifting the curtain). This is an easy task, 90% of subjects succeed. But first we would like you to estimate the size of the hole." The procedure in the "hard" condition was the same, except that the observers were told "This is a hard task, 90% of subjects miss."

After this instruction, the hole and box were covered while the observer judged which of the seven circle alternatives was the same size as the hole in the box. The curtain was then raised again, and the observer was allowed three chances to throw the marble through the hole with the dominant hand. The results were recorded. Observers were assigned alternately to the two conditions (the first observer ran in the easy condition, the second in the hard condition, the third in the easy condition, etc.).

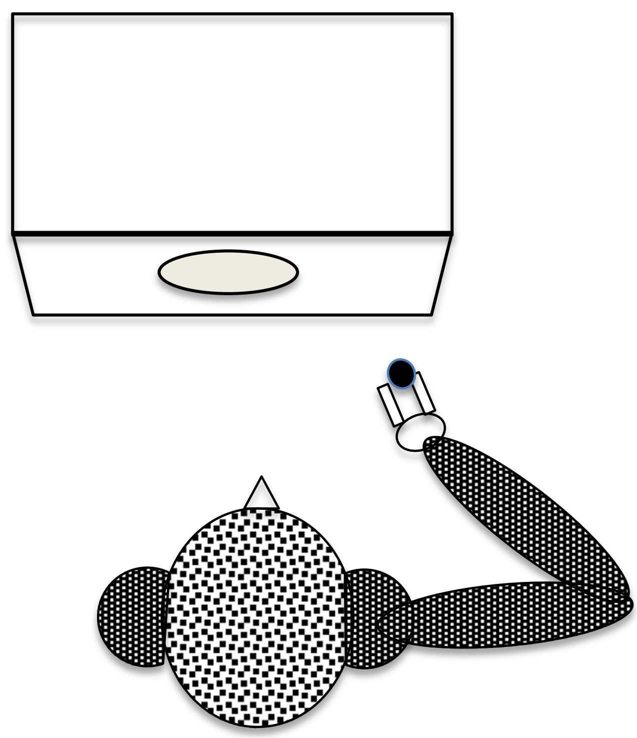

Fig. 1 Apparatus, viewed from above. The observers threw the marble with the preferred hand after estimating the hole size. The box was obscured by a curtain during the estimate in Experiment 1, but remained visible in Experiment 2

Following their participation, observers were asked two questions: First, they were asked their opinions about the purpose of the experiment; second, they were asked whether these opinions had occurred during the experiment or afterward. They were then debriefed on the purpose of the experiment and thanked for their participation.

Results

The mean estimate of hole size was larger by 0.7 hole sizes for the easy than for the hard group. A two-tailed *t* test revealed a statistically significant difference between the size estimates by the two groups, $t(96) = 2.50$, $p = .014$, 95% confidence interval = 0.14 to 1.25 (all results are given in units of hole size, the units used in the observers' estimates). The modal response was the accurate estimate of Hole 4 (Fig. 2) for the easy group, but Hole 2 was preferred by the hard group. In the easy condition, 11 observers underestimated the goal size, 19 were accurate, and 20 overestimated it. In the hard condition, 23 observers underestimated the goal size, 12 were accurate, and 13 overestimated it (Fig. 2).

One-sample *t* tests comparing group performance against the actual hole size of 4 showed that the estimates of the easy group, at 4.26, were not significantly different from the actual hole size, $t(49) = 0.16$, NS, whereas the hard group found the hole, at 3.56, to be smaller than its actual size, $t(47) = 2.06$, $p = .045$.

Success in the subsequent marble toss, however, was nearly identical in the two groups, $t(96) = 0.61$, n.s. The number of males in the study was too small to accurately estimate a gender difference in successful marble tosses. Averaging over the two conditions, the actual overall failure rate (proportion of observers who failed on all three tosses) was 40 observers out of 98, or 41%. The most common success rate was one out of three; this was the case for 45% of our observers. Another 12% succeeded in two tosses out of three. Only 2% succeeded in all three throws. The task was thus closer to hard than to easy.

A further question concerned the relationship between estimated hole size and success in the throwing task. Would those who remembered a larger hole size have greater success in throwing? For this question, the hard and easy groups were combined. Correlating the hole size estimate and success rate for each participant showed no significant relationship between the two variables, Pearson $r = .137$, $F(1, 96) = 1.82$, $p = .18$. Thus, those who rated the hole as being large did no better in the marble toss task than those who rated the hole as being small.

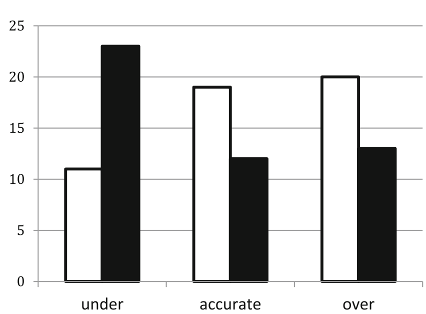

Fig. 2 Numbers of observers in Experiment 1 by condition who underestimated, accurately estimated, or overestimated the hole size. Solid bars: Easy condition. Open bars: Hard condition

Most observers reported that they had no opinion about the purpose of the experiment, even when asked directly. Only one of the observers guessed correctly.

Discussion

A question remained whether the verbal suggestion of task difficulty might affect size estimates even when the goal hole was visible. If this were the case, the result above might simply be an effect of suggestion, unrelated to either perception or memory. To test this proposal, we ran a second experiment in a condition identical to those of the experimental groups above, except that the curtain remained up while the observers made their estimates. Thus, we were testing perception rather than memory.

A lack of difference between the easy and hard groups would replicate Cooper et al. (2012), with verbal suggestion rather than motor success being the source of difficulty information, whereas a significant difference between the two groups would indicate that observers relied on the experimenters' verbal suggestions in reporting the size of the goal.

Experiment 2

Methods

Fifty-four observers were included, who were undergraduate students at the University of California, Santa Cruz: 27 in the easy condition and 27 in the hard condition. The apparatus and procedures were the same as in Experiment 1, except that the goal hole remained visible while the observers made their size judgments.

Results

A *t* test indicated no difference between the size estimates of the two groups, $t(47) = 0.86$, n.s. Perception remained stable despite our instructions, since the means of the two groups differed only by 0.06 hole units (<0.2 mm). By advance agreement, we excluded observers who gave estimates at the extremes of our range, because of range ambiguity. An estimate of 7, for instance, might mean that the hole was perceived as being even larger than 7, but that estimate was given because it was the largest available alternative. This resulted in eliminating three observers from the "easy" condition and two from the "hard" condition, all of whom provided estimates of 7.

Including these observers in the sample did not change the conclusion.

Again, the two groups did not differ in subsequent throwing success, $t(47) = 0.26$, n.s.

General discussion

Informing observers about the difficulty of performing a task affects their memory of the goal of that task, even if the information is incorrect. If observers about to throw a marble into a hole are told that the task is difficult, they judge the hole to be smaller than do other observers who are told that the task is easy. Moreover, the "easy" group judges the hole size more accurately than the "hard" group, who tend to judge the hole to be smaller than it really is. We can conclude that lower perceived difficulty elicits a more conservative memory of goal size, even if the difficulty is only anticipated and is in fact deceptive. The task required a sequential process, in which participants perceived a hole size, remembered it, and then reported the memory. Between perception and memory, the influence of the instructions intervened. When the target remained visible in Experiment 2 the instruction effect disappeared, replicating and extending the results of Cooper et al. (2012).

The instructions modified the memory of hole size, but did not change the success of participants' actions. Whether they were informed that the task was hard or easy, the observers in both conditions experienced the same level of motor success, and their estimates of the size of the hole were unrelated to their success in the marble toss task.

The results of this study also show that, contrary to the dominant explanations in the literature, action is not necessary to induce changes in the remembered properties of a target object. Rather, the *information that the action provides* about task difficulty is what affects judgments. Since memory necessarily contains less information than the perception that informs it, there is more room for distortions in memory than in perception.

The information must be salient to the observers, however, as has been demonstrated by the influence of a heavy backpack on the perceived slope of a hill (Bhalla & Proffitt, 1999). Wearing a heavier backpack correlated with a steeper estimate of slope among observers standing in front of a hill. The result was reinterpreted by Durgin et al. (2009), who had their observers wear a backpack of similar weight, but explained that it was a mobile device to measure the posture of the legs and feet. The weight of the backpack under this condition had no influence on the perceived slope of a board in front of the observer, implying that the original result had been contaminated by demand characteristics (Michael, Garry, & Kirsch, 2012). Loomis and Philbeck (2008) also interpreted such results as reflecting a response bias. The Durgin et al. (2009) result has been criticized because the slope to be estimated was of a short board rather than a long hill that would require a significant effort to be scaled (Proffitt, 2009). Recently, however, Durgin et al. (2012) extended their result to a real hill, with similar results. The fact that only one of our participants guessed the true purpose of the experiment in our postexperiment questionnaire indicates that response bias based on the participants' expected outcome could not have affected their judgments.

In these slope experiments, perception (or memory) of slope was affected by passive support requirements, not action, and no interaction with the hill was involved. Our action-oriented results simply go one step further, to show that the information provided by either active or passive interaction with a goal, and not the interaction itself, is sufficient to bias memory. The information in our experiments was not provided by perception or action, showing that bias in memory preceding an anticipated action can stem from any of a number of influences that bias the interpretation of a sensory situation. This does not diminish the importance of previous studies of the effects of action on perception; it only reinterprets them by showing that, in light of our results, the effects of action and of prior information on memory are equally important.

It remains unclear how much our results can generalize to other action-oriented situations, such as sinking a golf putt or hitting a baseball, but the similarity of the results in those situations to ours suggests that in the absence of further direct tests, the more consistent conclusion would be that action provides information that in turn biases memory for the physical properties of a goal. Our task intentionally included similarities to the tasks in experiments on baseball, golf, football, and so forth: It required a ballistic action toward a visible target.

Other studies have been aimed more explicitly at the effect of action, or potential action, on memory. Archers remember their target to be larger if they are more accurate, even if the target and the arrow's trajectory are obscured (Lee, Lee, Carello, & Turvey, 2012). Here the information provided by the archer's own motor activity is what signals a "good shot," and subsequently leads to both greater accuracy and a larger remembered goal.

Our results also show the potentially large effects of intentionally distorted information on memory of previously viewed target properties, even when the memory lasts only a few seconds. Action may be necessary to affect memory or perception in other tasks, however. Specifically, there may be a difference between the coding of exocentric variables, such as goal size, and egocentric variables, such as the distance to a target.

In summary, earlier experiments had changed "action affects perception" to "action affects memory." The present experiments modify the first part of the current idea by removing the necessity of action from the equation, resulting in "information affects memory." This final version is less dramatic, but more reflective of what happens in the real world.

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