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Behavioral Sensitivity to Reward Is Reduced for Far Objects

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Abstract
Many studies have demonstrated that people will adjust their behavioral response to a reward on the basis of the time taken to receive the reward. Yet despite growing evidence that time and space are not mentally independent, there has been no examination of whether spatial distance may also affect the way people respond to rewarding objects. We examined speeded binary decisions about objects associated with high, low, or no reward for correct responses. Using a 3-D display, we varied perceived spatial distance so that objects appeared at distances near to or far from participants. Both the speed and the accuracy of responses were better for high-reward objects compared with low- and no-reward objects, but this difference occurred only when the objects appeared at near distance to participants. These results demonstrate that when people respond to rewarding objects, they show sensitivity to spatial-distance information even if the information is irrelevant to the task.

Keywords
rewards, distance perception, decision making, values, perception

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Are people's behavioral responses to identical rewarding objects influenced by whether the objects are presented in near or far space? A notion commonly posited in economics and behavioral sciences is that the value of an object is discounted as the waiting time to receive it (temporal distance) increases (Ainslie, 1975; Loewenstein & Prelec, 1992). There is some evidence that this tendency also occurs as spatial distance increases. For example, marmoset monkeys have shown preferences for smaller, nearer rewards compared with larger, more distant rewards (Stevens, Rosati, Ross, & Hauser, 2005). However, researchers have not investigated whether humans respond differently to rewarding objects as a function of the objects' spatial proximity.

The potential for behavioral parallels between temporal and spatial domains is supported by a growing body of evidence that the two domains are not independent (Bonato, Zorzi, & Umiltà, 2012). Numerous researchers have proposed that time is represented mentally as a spatial construct (Boroditsky & Ramscar, 2002; Ishihara, Keller, Rossetti, & Prinz, 2008; Oliveri, Magnani, Filipelli, Avanzi, & Frassinetti, 2013; Vallesi, Binns, & Shallice, 2008; Vallesi, McIntosh, & Stuss, 2011; Williams, Huang, & Bargh, 2009). For instance, people are unable to ignore irrelevant spatial information when they make judgments about temporal duration (Casasanto & Boroditsky, 2008). Indeed, drawing on the idea that cortical maps can be recycled (Dehaene & Cohen, 2007), some have argued that a brain region implicated in the representation of information related to physical space in primates (posterior parietal cortex) has expanded its functional range in humans to accommodate higher-order concepts, such as time (Yamazaki, Hashimoto, & Iriki, 2009).

Given this apparent mental coupling of space and time, we tested whether there was a spatial analogue for the tendency in the temporal domain to discount the value of rewarding objects as distance increases. To do this, we examined changes in participants' response

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speed and accuracy during two-alternative forced-choice decisions about objects in both near and far space. We manipulated spatial distance by presenting objects stereoscopically on a 3-D screen within a Ponzo-illusion depth cue (Li & Guo, 1995; see Fig. 1 for example screenshots). Only when participants' decisions were sufficiently rapid did correct choices result in reward feedback conveying a monetary value. The magnitude of reward feedback was associated with object color—red objects earned a high reward of 0.50 Australian dollars (AUD), blue objects earned a low reward of AUD$0.05, and green objects earned no reward (AUD$0.00). We hypothesized that to maximize rewards, participants would make faster and more accurate decisions for objects associated with high reward; however, this improvement would be diminished for the same objects when they were presented in far space compared with when they were presented in near space.

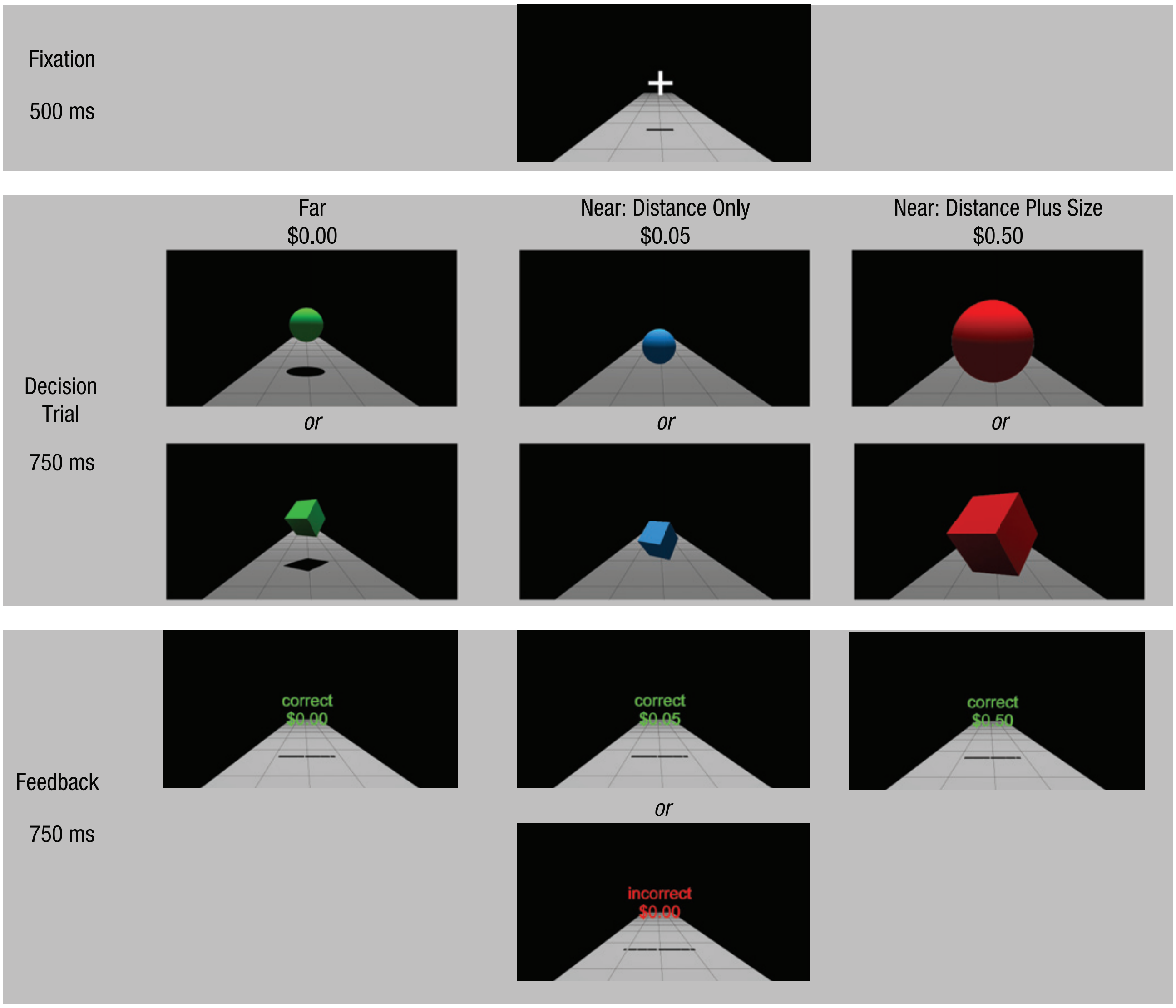

Fig. 1. Schematic showing the sequence of trials and example decision-trial and reward-feedback screenshots. On each trial, after fixation, participants were shown an object—either a cube or a sphere—that was green, blue, or red. Participants were required to rapidly decide whether the object was a cube or a sphere and to indicate their choice by pressing one of two preassigned keys. Correct decisions resulted in reward feedback that showed the monetary amount (in Australian dollars, AUD) associated with the color of the trial object (AUD$0.00 for green objects, AUD$0.05 for blue objects, and AUD$0.50 for red objects). Retinal size for objects presented in the distance-plus-size task condition was increased when the objects were presented at near distance. In the distance-only task condition, the retinal size of objects was kept the same for objects presented at near and far distances.

Method

Participants

A total of 27 participants (56% female and 44% male) were recruited through research advertisements posted in the School of Psychological Sciences at the University of Melbourne. In addition to task-related payment, all participants received AUD$10 upon completion of the research session.

Stimuli and procedure

In the present study, for each trial, participants were instructed to report their decision about whether the shape presented on a screen was a sphere or a cube by pressing a preassigned key with the index or middle finger of their dominant hand. Stimuli were presented on a 117-cm 3-D display monitor from which participants were positioned at a viewing distance of 100 cm. On each trial, a fixation point was presented followed by a colored object—a cube or a sphere (see Fig. 1). The two types of objects were presented in an unpredictable order and divided equally among trials. Red, green, and blue objects could appear with equal probability.

To modulate proximity, we presented objects with equal probability at distances near to and far from the participant. Near objects were intended to appear within a "reachable" distance of less than 50 cm from the viewer, whereas far objects were intended to appear approximately 300 cm from the viewer. To simulate perception of distance, we created stereographic images using Autodesk 3ds Max 2010 (Autodesk Inc., San Rafael, CA) with a Render 3D plug-in. Participants viewed 3-D images through circular polarized passive eyewear, and objects were displayed stereoscopically using a horizontal-interlace 3-D format. To maintain distance perception throughout experimental blocks, we presented intertrial feedback information and the fixation image stereoscopically. We further simulated distance by displaying all trial-related information within the context of a Ponzo illusion. Each object was presented for 750 ms and was followed by a feedback screen of the same duration. Fixation screens were presented for 500 ms. The experiment comprised four blocks of 60 trials each.

To approximate realistic changes in object information across spatial distance, we employed an ecologically valid design in which retinal size of objects increased appropriately for proximal presentation. However, because size and distance are inherently related in perception, this design gave rise to the possibility that any reported changes in performance might occur as the result of size rather than distance (Amit, Mehoudar, Trope, & Yovel, 2012). To address this potential confound, we also administered a distance-only version of the task, which maintained consistent retinal size of objects across spatial-distance manipulations. Thus, although objects presented at near and far distances in this task condition occupied the same area of the observer's visual field, the degree of binocular disparity varied such that one image was consistent with a far object, whereas the other image was consistent with a near object.

Blocks were divided equally between distance-plus-size and distance-only conditions and were preceded by an initial training block that included no distance or size manipulations and thereby enabled participants to learn the associations between the stimuli and rewards. We used feedback to discourage responses that were excessively slow (> 500 ms) or fast (< 100 ms, to prevent arbitrary key presses); the feedback consisted of messages presented on-screen ("**too slow** respond faster" or "**too fast** respond slower," respectively). For correct responses made within these time constraints, feedback informed participants of their correct decision and the reward amount. Reward amount was contingent on stimulus color, as described earlier. At the end of each block, participants were informed of the total amount earned for each color from the block as well as the total amount earned during the task. After completion of the task, participants received 5% of their total task earnings. In sum, the task design allowed for a repeated measures analysis of variance (ANOVA) of participants' response speed and accuracy with three within-subjects factors: task condition (distance plus size and distance only), distance (near and far), and reward feedback as connoted by target color (red, AUD$0.50; blue, AUD$0.05; and green, AUD$0.00).

Results

Figures 2a and 2b present mean response times (RTs) for near and far objects as a function of reward feedback for both task conditions. A 2 (task condition) × 2 (distance) × 2 (reward feedback) ANOVA of RTs yielded a significant interaction between distance and reward outcome, $F(2, 52) = 8.80$, $p = .001$, $\eta_p^2 = .25$. There was a significant main effect of task condition, $F(1, 26) = 4.72$, $p = .039$, $\eta_p^2 = .15$ (distance plus size: M = 384 ms; distance only: M = 379 ms); however, task condition did not exert any significant interactive effects on RTs, $F(2, 52) = 1.32$, $p = .270$, $\eta_p^2 = .05$.

Post hoc comparisons (Bonferroni corrected) indicated that responses for high-reward objects (M = 374 ms) were significantly faster than were responses for low-reward (M = 387 ms) and no-reward (M = 384 ms) objects, but this result held only when objects were presented at near distance—high reward versus low reward: $d = -0.54$, $p < .001$; high reward versus no reward: $d = -0.39$, $p = .005$. There were no significant differences in response speeds for objects presented at far distance

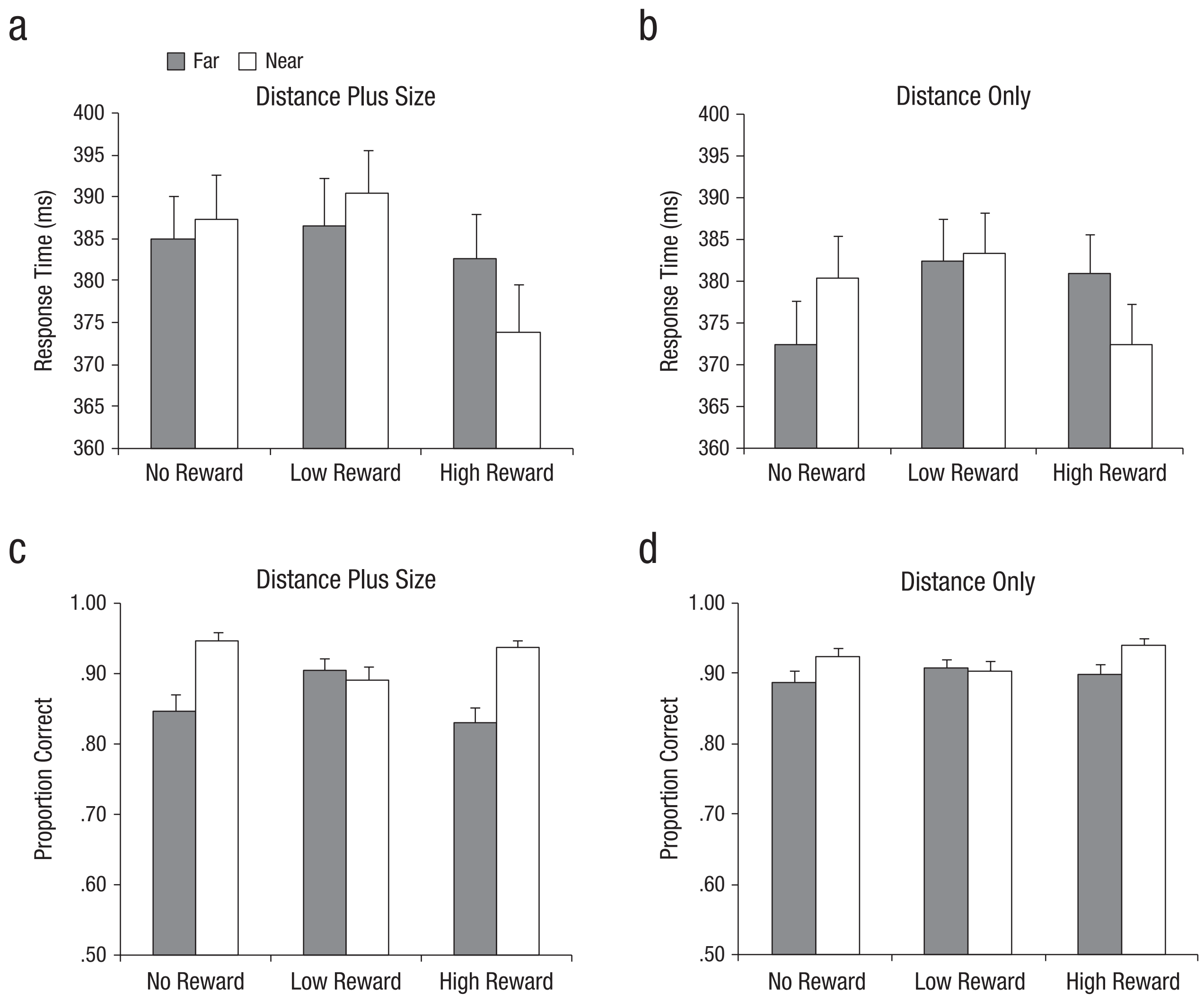

Fig. 2. Mean response time as a function of object distance and reward, shown separately for the (a) distance-plus-size and (b) distance-only task conditions, and decision accuracy (mean proportion of correct responses) as a function of object distance and reward feedback, shown separately for the (c) distance-plus-size and (d) distance-only task conditions. Error bars represent +1 *SD*.

(high reward: M = 382 ms; low reward: M = 385 ms; no reward: M = 379 ms)—high reward versus low reward: $d = -0.11$, $p = 1.0$; high reward versus no reward: $d = 0.12$, $p = .684$. A further comparison showed that participants responded significantly faster to high-reward objects when the objects were presented at near distance (M = 374 ms) compared with when they were presented at far distance (M = 382 ms), $d = -0.31$, $p = .004$. More unexpectedly, responses to no-reward objects at far distance (M = 379 ms) were faster than were responses both to low-reward objects presented at far distance (M = 385 ms), $d = -0.23$, $p = .030$, and to no-reward objects presented at near distance (M = 384 ms), $d = -0.19$, $p = .018$.

Figures 2c and 2d present decision-accuracy results for near and far objects as a function of reward feedback for both task conditions. A 2 (task condition) × 2 (distance) × 2 (reward feedback) ANOVA of correct-response proportions yielded a significant interaction between distance and reward outcome, $F(2, 52) = 10.20$, $p = .004$, $\eta_p^2 = .280$. Task condition (distance only vs. distance plus size) did not exert a significant influence on correct-response proportion of variance, $F(2, 52) = 2.12$, $p = .120$, $\eta_p^2 = .07$. Results also showed a significant main effect of distance, $F(1, 26) = 37.1$, $p < .001$, $\eta_p^2 = .59$ (near distance: M = .92; far distance: M = .88).

Post hoc comparisons (Bonferroni corrected) indicated that correct-response proportions for high-reward objects were greater than for low-reward objects, but only when objects were presented at near distance (high reward: M = .94; low reward: M = .89; no reward:

M = .94)—high reward versus low reward: d = 0.79, p = .02; high reward versus no reward: d = 0.00, p = 1.0. At far distance, this pattern was reversed (high reward: M = .86; low reward: M = .90; no reward: M = .86)—high reward versus low reward: d = −0.57, p = .008; high reward versus no reward: d = 0.00, p = 1.0. A further comparison showed that demonstrated improvements in RTs for near high-reward objects, compared with far high-reward objects, were also allied with a concurrent increase in correct responses (near object, high reward: M = .94; far object, high reward: M = .86), d = 1.29, p < .001. However, faster RTs for far no-reward objects, compared with near no-reward objects, were associated with a concurrent decrease in correct responses (far object, no reward: M = .87; near object, no reward: M = .94), d = −0.99, p < .001. Wilcoxon signed-rank tests of scores collapsed across task conditions also showed a significant increase in correct-response proportions for near versus far high-reward objects, z = −3.80, p < .001, and a decrease in correct-response proportions for far versus near no-reward objects, z = −4.18, p < .001.

These results demonstrate that responses to high-reward objects, compared with low- and no-reward objects, were significantly faster, but only when these objects were presented at near distance. This improvement in processing speed was supported by a concurrent increase in proportion of correct responses. Response speeds were also faster for no-reward objects presented at far distance. However, claims that this difference represents an improvement in processing efficiency must be qualified by the finding of a corresponding decrease in the proportion of correct responses when objects were presented in far space. The absence of a significant influence of task condition on RT variance implicates spatial distance as the primary modulator of performance rather than object size.

Discussion

In the current study, we found evidence that behavioral responses to identical rewarding objects were influenced by whether the objects were presented in near or far space. Specifically, participants made faster and more accurate decisions for objects associated with high reward; however, this improvement was diminished when the same objects were presented in far space.

This result suggests that there is a spatial influence on value assignment that may be analogous to the phenomenon of temporal discounting, in which rewarding objects are discounted as a function of their temporal distance (Ainslie, 1975; Loewenstein & Prelec, 1992). However, an important distinction between the task used in our study and tasks that have previously been used to examine behavior in relation to temporal discounting is that modulations of temporal distance are typically explicit and relevant to decisions. In temporal-discounting tasks, participants generally are asked to make choices between two items that differ both in value and in the time point at which the items will be received. In our task, modulations of spatial distance were implicit and completely irrelevant to decisions made by participants. Indeed, there was no monetary advantage to improved behavioral responding to rewarding objects in near space. Despite this, participants still demonstrated changes in behavioral response that were, first, indicative of a use of irrelevant spatial-distance information and, second, suggestive of a bias for high-reward objects presented in near space. Nonetheless, as a result of the multiple differences between studies of temporal discounting and the current study, further research comparing the two effects more directly is needed to systematically assess the speculated association between the effects of space and time on reward processing.

Given the novelty of our findings and the noted differences between the present paradigm and those used to investigate temporal discounting, we can only speculate about the underlying mechanisms generating reported effects and outline further steps that could be taken in future research. One possible interpretation is based on a study from the field of behavioral economics that showed that the physical presence of an actual appetitive item, compared with an image or text display, led to a 40% to 60% increase in participants' willingness to pay for the item (Bushong, King, Camerer, & Rangel, 2010). This real-exposure effect on object valuation has been explained with the argument that the physical presence of an appetitive item can trigger a valuation system composed of Pavlovian consummatory processes that facilitate approach behavior toward the rewarding object (Balleine, 2005; Balleine, Daw, & O'Doherty, 2008; Bushong et al., 2010). Our findings suggest that the magnitude of such an approach response to an appetitive item may be modulated by the item's position in space. This supposition is logical given the consideration that, in reality, distant appetitive items are less frequently associated with subsequent consumption than are spatially proximate appetitive items. It will be important for future studies to explicitly test whether the real-exposure effect diminishes with increasing spatial distance and whether participants' willingness to pay for items is indeed affected by spatial proximity.

Assuming that the effect of the Pavlovian valuation system diminishes with distance, we believe it is also possible that our results reflect the involvement of a goal-directed valuation system, which is sensitive to contingencies between actions and outcomes and directs responses to the most valued outcome (Bushong et al., 2010; Rangel, Camerer, & Montague, 2008). Whereas the Pavlovian valuation system is thought to influence behaviors, such as choosing immediate rewards at the expense of delayed rewards (Balleine, 2005; Balleine et al., 2008; Dayan, Niv, Seymour, & Daw, 2006), the goal-directed system can represent outcomes related to broader goals. For instance, whereas the Pavlovian system would assign a high value to an appetitive item, such as a chocolate bar, the goal-directed system would compute the item's potential negative health outcomes. When an individual is forced to choose among multiple potential actions, these conflicting value systems are thought to compete (Rangel et al., 2008).

Given these considerations, we can speculate that this level of competition would vary as a function of spatial distance. It will be interesting to see whether future studies can identify the extent to which our findings reflect the influence of this type of goal-directed valuation system. The use of a task that requires participants to make explicit choices between appetitive items at varying distances from the viewer could be informative in this case. Such a paradigm could also be used to explore alternative perspectives, such as construal-level theory, which proposes that the mental representations of objects change as a function of their distance from the viewer (Liberman & Trope, 2008; Trope & Liberman, 2010).

The findings reported here offer a new and potentially important insight into the way humans assign value to objects. Future research could extend our results by more formally characterizing behavioral responses to reward across space in the same way that behavioral economists have modeled the influence of time on decision making (Frederick, Loewenstein, O'Donoghue, 2002; Loewenstein & Prelec, 1992). Only through a more detailed understanding of the nature of the relationship between space and value will it be possible to better understand how these effects fit within the broader theoretical concepts associated with action selection and mental representation. Overall, these results support the notion that behavioral responses to rewarding objects are influenced by their position in near or far space and substantiate Hume's (1789/2010) contention that we "yield to the solicitations of our passions, which always plead in favour of whatever is near and contiguous" (p. 396).

Author Contributions

D. A. O'Connor developed the original concept and methodology, collected and analyzed the data, and drafted the manuscript. B. Meade assisted with the 3-D image-delivery technology. S. Rossiter collected data. R. Hester, O. Carter, and S. Rossiter critically revised the manuscript. All authors contributed to the study design and approved the final version of the manuscript for submission.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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