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Embodied Valuation: Directional Action is Associated with Item Values

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ABBREVIATED TITLE: Embodied valuation

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Abstract

We have a lifetime of experience interacting with objects we value. Although many economic theories represent valuation as a purely cognitive process independent of the sensorimotor system, embodied cognitive theory suggests that our memories for items' value should be linked to actions we use to obtain them. Here we investigated whether the value of real items was associated with specific directional movements toward or away from the body. Participants priced a set of food items to determine their values; they then used directional actions to classify each item as high- or low-value. To determine if value is linked to specific action mappings, movements were referenced either with respect to the object (push toward high-value items; pull away from low-value items) or the self (pull high-value items toward self; push low-value items away). Participants who were assigned (Experiment 1) or chose (Experiment 2) to use an object-referenced action mapping were faster than those using a self-referenced mapping. A control experiment (Experiment 3) using left/right movements found no such difference when action mappings were not toward/away from the body. These results indicate that directional actions towards items are associated with the representation of their value, suggesting an embodied component to economic choice.

(200/200 words)

Key words: Decision-Making, Economic Choice, Embodied Cognition, Valuation, Action

Introduction

According to economic theories of decision making, a decision maker faced with a set of available options makes choices depending on the relative values placed on those options (e.g., Samuelson, 1938). These values can be influenced by a number of factors including risk, delay, quantity, and previous experience. However, because economic models often consider valuation wholly cognitive in nature, one factor often excluded is the body and its actions (e.g., Padoa-Schioppa, 2011; but see Cisek & Kalaska, 2010).

In "good-based" models of economic choice (e.g., Padoa-Schioppa, 2011), the decision maker compares cognitive representations of the options, or goods, in terms of intrinsic properties including sensory, affective, and conceptual dimensions. For example, when choosing among candy bars, a decision maker might make a selection based on integrating the value of the different ingredients, flavors, and size. The outcome of the decision is sent to the sensorimotor system which implements the choice. Importantly, computations integrating object properties and comparing item values occur within the representational space of the goods, which is independent of the action space. Thus, in good-based models of choice, physical actions do not influence value perception, judgments, or choice because they are only involved in executing the outcome of the decision.

In contrast, embodied cognition frameworks in psychology propose that motor and sensory inputs are integral components of the representations of objects and their values (Kiefer & Pulvermüller, 2012; Wilson, 2002). Cognitive processes are inseparable from the sensorimotor contexts in which they occur. Thus, actions performed concurrently with mental processes can affect the resulting representation in memory (Barsalou, 1999). When actions are performed in conjunction with certain mental concepts repeatedly over a lifetime, those actions become inextricably linked to those concepts. As a result, actions alone can activate the mental concepts through long-term associations (Barsalou, 1999; Garcia & Ibáñez, 2016). Contrary to good-based models of economic choice, embodied cognitive theory suggests that our choices can be affected by the actions we use to implement them. Thus, mental concepts of value are linked to the specific actions we use to interact with valued objects. In embodied decision-making, action is both a method of decision execution and a factor that can influence the cognitive process of choice (Reimann et al., 2012).

Are concepts of value linked to specific action mappings, as suggested by embodied cognitive theory? Or is valuation independent of sensorimotor systems, as represented in economic models? Few studies have investigated explicitly whether object representations include both their value and the actions associated with choosing those objects. Of note, Schonberg and colleagues (2014) recently demonstrated a connection between stimulus-motor response associations and subsequent item preference. Participants priced a set of food images and then performed an associated go/no-go task in which each food item was presented on the screen with or without a tone cue; participants pressed a button only when a tone cue was presented. Finally, in a two-alternative forced–choice task, participants selected their preferred choice among item pairs that had been equally valued in the first task. Items with a tone-action association were chosen more frequently in the forced-choice task, suggesting that the multisensory association of tone-plus-action with an item affected preference for that item. This effect was specific to the incorporation of action because when a similar experiment was performed with only the tone cue but no corresponding button press action, there were no choice preferences for the tone-cued items. Thus, item preference is enhanced when an item has been previously paired with an irrelevant motor response.

Although Schonberg and colleagues demonstrated that motor responses can affect choice for food items, this paradigm did not clarify whether action of any type can influence preferences or whether specific types of directional action used in everyday interactions with valued objects have differential effects. If any action concurrent with stimulus presentation can change valuation of that stimulus, valuation may not necessarily be embodied. Instead, action could influence valuation by modulating attention, leading to deeper processing of the item (Schonberg et al., 2014). Alternatively, if a lifetime of interacting with valued items creates value-action associations, specific actions that are used to obtain valued items may make the representation of value more accessible.

To our knowledge, the relation between action and item value *per se* has not been specifically explored. However, approach/avoidance behavior may be relevant to this question because, in some circumstances, it *can* reflect the interaction of action and valuation. That is, people tend to approach things that are of high value and avoid things that are of negative value to them (Carver, 2006; Eliot, 2006).

Approach/avoidance behavior has been studied extensively with respect to emotionally valenced words (for a review, see Garcia & Ibanez, 2016), but fewer studies have looked specifically at the link between emotional words and directional action. Chen and Bargh (1999) asked participants to push or pull a lever in response to negative and positive words, respectively; the avoidance response was defined as pushing the lever away and the approach response was defined as pulling the lever toward the body. Positive words elicited faster responses using the pulling action; negative words elicited faster responses using the pushing action. They argued that emotionally valenced words activate specific motor patterns associated with approach and avoidance.

Nonetheless, the specificity of action direction to approach/avoidance has been questioned by Wentura and colleagues (2000). In their task, participants either pressed or released a button located on the computer screen in response to positive and negative words. Button presses involving arm extension (i.e., reaching out) were defined as an approach movement. Button releases involving arm flexion (i.e., pulling arm towards the body) were defined as an avoidance movement. Contrary to the results of Chen and Bargh (1999), positive words elicited faster responses when paired with arm extension (button presses) rather than arm flexion (button releases). Therefore, these studies raise questions about whether specific movement directions are linked directly to approach versus avoidance behaviors.

One reason that specific actions may not be tightly coupled with negative and positive words or concepts is that the cognitive system may flexibly adapt the action response to the reference frame of the situation. Actions can be conceptualized with respect to the object being acted on ("object reference"), or the end state for the organism ("self reference"). Reaching can be described in terms of moving toward the object or bringing the object toward oneself. Supporting this idea, Seibt and colleagues (2008) manipulated the action reference point for classifying emotional words: participants moved a joystick either with respect to the self or the object to classify words as positive or negative. Participants who received self-referenced instructions (i.e., pull the words toward yourself; push the words away from yourself) were faster to categorize positive words by pulling (flexing the arm) and negative words by pushing (extending the arm). Alternatively, a different set of participants who received object-referenced instructions (i.e., move toward the object; pull away from the object) were faster to categorize positive words by moving toward the object (extending the arm) and negative words by pulling away from the object (flexing the arm). These findings suggest that emotion-action associations can be manipulated by changing the action reference point through instructions.

In addition to the frame of reference for directing actions, the consequences of actions may also be important in determining approach/avoidance action mapping. Van Dantzig and colleagues (2008) argued that depending on environmental feedback, any action response can become associated with positive or negative stimuli. Participants viewed either emotionally valenced words (e.g., “peace” or “funeral”) or neutral words (e.g., “clock”) and indicated whether the words were emotional or neutral using keypresses. To link a response with a consequence, one response key implemented a simulated approach with the word growing larger on the screen as if it were moving toward the participant, and the other key simulated avoidance with the word growing smaller as if it were moving away from the participant. Responses were faster when the valence of the word led to the congruent approach or avoidance stimulus movement (i.e., positive words moving toward the participant, negative words moving away from the participant) than the incongruent stimulus movement. They concluded that neutral actions (keypresses) can become associated with specific mental states through repeated concurrent presentation and that it is the context, or feedback from the environment, that determines which actions constitute “approach” and “avoidance.”

Collectively, the above studies support a connection between action history and affective processing, but their conflicting results preclude strong conclusions about action type and direction with emotional valence. Relevant to our study, the differences in tasks, stimuli, and instructions provide no consensus regarding which types of actions, if any, can be associated with concepts of item value. For example, many studies use key presses or other movements that are not associated with directional, real-world object interactions. This leaves open the question of whether certain actions, through a lifetime of association with specific objects, are a component of those objects' conceptual representations. Also, although object words evoke affordances, images offer more direct information about how the body can interact with the depicted objects (Myachykov et al., 2013; Zhang et al., 2016).

Förster (2004) addressed part, but not all, of this problem in a study investigating how the performance of directional arm movements might influence evaluation. Förster defined food items *a priori* as having either positive (e.g., candy and pizza) or negative (e.g., beef lung and pig tongue) values. Participants were grouped into one of two action groups: push down on a table (arm extension) or pull up on the underside of a table (arm flexion). While performing the assigned action, food images were presented on a screen and participants rated how much they liked each food item and how much they would like to buy the item. Förster found that participants who flexed their arms liked positive-value foods more than those who extended their arms, and participants who extended their arms disliked negative-value food more strongly than those who flexed their arms.

Although this study demonstrated a connection between images of real food items, action, and evaluation, the ecological validity of this type of movement in relation to the food and its valenced context is questionable. The action directions were not what one would perform if one were actually choosing or rejecting a food item: i.e., up and down rather than to or from the body. Further, the results of this study may be biased because pushing down on a table may be motorically easier compared to pulling up on a table, which could influence liking scores (Niedenthal, Winkielman, Mondillon, & Vermeulen, 2009). Finally, given that the experimenters, not the participants, determined which foods were positive and negative in value, it is unclear how the actions related to individuals' own food item valuations.

Thus, the relationship between sensorimotor output and economic value remains an open question. Specifically, do representations of object value include associations with common reaching or grasping actions (like reaching and pulling) used to interact with those objects? In this study, we examine directly how real object representations are connected with information about their value and the actions we commonly use to interact with them. Specifically, we investigate whether an item's value is represented independently of its associated real-world actions, as suggested by typical economic models, or whether associations between value and action are formed through repeated real-world interactions, as theorized in the embodied cognition framework.

In three experiments, we first asked participants to perform an item pricing task to indicate how much they would pay for real-world food items, shown in full-color photographs, and then to perform a classification task in which they used a directional joystick movement to indicate whether each item was previously priced as having low or high value. The pricing task allowed us to assess each participant's individual valuation of each item, whereas the classification task with its directional action manipulation compared the effect of action-direction mappings in mnemonic representations of item value. To determine if specific directional actions were associated with item value, we included a within-subject reversal manipulation in which we changed the value-action mapping halfway through the trials and assessed whether any performance changes were associated with switching between action-value mappings. If value is associated with a specific action mapping (e.g., moving towards a high-value item), switching to an incongruent mapping should impair performance; likewise, switching from a mapping that is inconsistent with value-action representations to a mapping that is in line with the representations should improve performance. However, if conceptual representations of value are independent of action, participants should perform equally well with any value-action mappings, as in Seibt et al. (2008). Directional actions towards and away from the body have been conceptualized in terms of either object-referenced (e.g., movement towards objects) or self-referenced (e.g., movement towards the body) frameworks. In Experiments 1 and 2, we compared performance using assigned versus self-selected value-action mappings for movements directed towards the viewed objects or towards the self. To ensure that the measured effects reflect meaningful actions associated with movement towards/away from the body, in Experiment 3 we further tested actions without a meaningful object- or self-referenced framework (e.g., left/right movements).

Experiment 1

As discussed above, previous studies have provided mixed evidence regarding whether value-action mapping should favor an object- or self-referenced framework and whether such mappings can be flexibly reassigned through instruction. Thus, in Experiment 1, we assigned equal numbers of participants to two instruction groups: an “object-referenced” group and a “self-referenced” group. The *object-referenced* group was instructed to push the joy stick to “reach” toward items remembered as having high value and to “pull” away from low-value items, whereas the *self-referenced* group was told to “push” low-value items away and “pull” high-value items toward themselves. To dissociate the relative effects of value-action mappings via experimental instruction vs. long-term value-action direction associations, after participants had categorized half of the items we reversed the instructions (e.g., changed “push” to “pull”) for the remaining stimuli (i.e., there was no repetition of items between blocks). If participants can adapt flexibly to instructed value-action mappings, both groups should be equally fast and accurate, and there should be no change in performance for reversing the value-action mapping instructions. However, if directional actions are associated with item values, as claimed by embodied theories, then performance should be relatively worse when the instructions violate these associations and relatively better when they are consistent with the appropriate coupling.

Methods

Participants. Fifty-nine undergraduate participants (41 female; ages 18-23; 54 right-handed) volunteered for partial course credit in introductory psychology courses. Participants were randomly assigned to one of two instructed value-action mapping groups: an "object-referenced" group in which participants were asked to initially move a joystick toward high-value items on the computer screen, or a "self-referenced" group in which participants were asked to initially move a joystick toward themselves when they viewed high-value items on the computer screen.

Ten participants were excluded from the reported analyses for failing to follow instructions (*n* = 4), exhibiting poor performance (e.g., 3 standard deviations from the overall participant mean RT; *n* = 4), or atypical value distributions (e.g., rated most items with negative values; *n* = 2). Thus, 49 participants (27 in the object-referenced group, 22 in the self-referenced group) were included in the analyses below.

Stimuli. The stimuli were 250 color photographs of common foods or beverages with a black background (576 × 432 pixels). These food images have been demonstrated to elicit a wide range of desirability ratings, from typically appetitive items such as candy bars to typically aversive items such as canned meats (Harris, Adolphs, Camerer & Rangel, 2011). The tasks were programmed using Psychophysics Toolbox (Brainard, 1997; Kleiner et al., 2007) in

MATLAB (MathWorks Inc., Natick, MA) and the images were presented on a 19” LCD monitor.

Procedure. All participants were tested individually. Participants were asked to fast for two hours prior to the experiment to motivate their attention to the food images. The experiment consisted of three tasks: 1) item pricing task, 2) value categorization task with original instructions, and 3) value categorization task with reverse instructions (Figure 1A-C). Participants began with the *pricing task* (Harris et al., 2011; Plassmann et al., 2010) to establish each participant’s individual valuation of each food item; these values were then used to classify items as low or high value items for the subsequent value categorization tasks. In the *pricing task*, they viewed images of individual food items with a price number line with values ranging between -$2.00 and $2.00 (e.g., -$2, -$1, $0, +$1, and +$2) presented horizontally at the bottom of the computer screen so that it was perpendicular to the axis of movement in the categorization task. Participants indicated how much they would pay for each item in dollar amounts using button presses on a keyboard; item images remained on the screen until the participant made a response. Participants were instructed to price items so that positive dollar amounts would indicate how much they would be willing to pay for the item, and negative dollar values indicated how much they would need to be paid to eat that item. This elicitation has been used in previous studies to quantify the degree to which individuals find food items appetitive or aversive (Harris et al., 2011; Plassmann et al., 2010). A response of $0 meant that participants would consume the item if they were hungry and it was free.

To prevent the rehearsal of item value responses in the pricing task, participants completed a 5-10 minute filler task, Part 1 of The Shipley Institute of Living Scale (Shipley, 1940), which was not scored. Next, participants completed the two-part *value categorization* *task*. To implement the value categorization task, a computer program was used to sort the images into high-value and low-value categories based on each participant's values from the pricing task. Half of the high- and low-value items were then randomly selected for use in the first part/block of the value categorization task, and the other 50% of each category in the second part/block. Thus, there was no item repetition in the two blocks of the value categorization task. Because the scale used in the pricing task spanned from negative to positive values, prices reflected both emotional valence, indexed by the sign of the item price (Plassmann et al., 2007), and arousal, based on whether the price was high or low (Litt et al., 2011). To ensure that arousal and valence were well-matched across conditions, the item selection procedure for the value categorization task allocated equal numbers of both positive/negative and high/low prices.

In the value categorization task, each food image was presented individually, and participants were told to categorize that food item as a high-value or low-value item based on their responses in the pricing task. Participants were instructed to treat items that they previously priced above $0 as high-value items, whereas items priced or below $0 were considered low-value. $0 items were included in the low-value category to produce approximately equal numbers of push vs. pull movements in the value categorization tasks, reducing the risk of directional response bias. However, because $0 items fall into a murky conceptual category in terms of value, these foods were excluded from subsequent analyses.

Participants categorized each item as high or low value using a Logitech Extreme 3D Pro joystick, holding the top of the joystick with the palm of their dominant hand and moving it in the specified direction (either pushing or pulling) to indicate item value. To determine which direction they should move the joystick to indicate item value, participants were randomly assigned to either the object-referenced group or the self-referenced group. The object-referenced group was instructed to move the joystick toward the food image (as if to reach out to grab it) when its remembered value was high, and to pull the joystick toward their bodies when the item's remembered value was low. The self-referenced group was instructed to move the joystick toward their body (as if pulling the item toward them) when the item's remembered value was high, and to move the joystick toward the food image (as if to push the item away) when the item's value was low. A fixation cross was presented for 1000 ms between trials. Participants were instructed to respond as fast and as accurately as possible, and were told that they might receive a candy treat at the end of the experiment for their compliance. Following the first block of the categorization task, participants completed another short filler task, Part 2 of The Shipley Institute of Living Scale (Shipley, 1940), which was not scored.

Next, for the second block of the value categorization task participants were told to reverse the value-action mapping. Specifically, the object-referenced group was told to pull the joystick toward themselves for high-value items and push the joystick toward the item for low-value items. Likewise, the self-referenced group was now instructed to push the joystick toward the item for high-value items and pull it toward themselves for low-value items. The second block used the remaining half of the food items from the initial pricing task so that memory performance was independent of the first block. Again, participants were reminded that they would receive a treat at the end of the experiment if their responses were fast and accurate. At the end of the experiment, participants received a candy treat for their participation. The entire testing session was approximately 45 min in duration.

Results and Discussion

In the pricing task, we found that participants classified approximately half of the items as high-value (131/250 items = 52.4%) and half as low-value (119/250 = 47.6%; <\$0: 70/250 = 28%, \$0: 49/250 = 19.6%). Thus, the inclusion of \$0 items as "low-value" targets enabled roughly equivalent numbers of push/pull movements, allowing us to rule out directional response bias. However, because \$0 could be considered neutral in value (Plassmann et al., 2010), these trials were excluded when planned analyses were performed.

Proportion accuracy and mean correct response time (RT) values were calculated for each participant and condition. Based on the RT distributions of our data, we excluded RTs that were 3 standard deviations from each participant's mean, resulting in a loss of less than 1% of each participant's data.

Accuracy. A mixed-model analysis of variance (ANOVA) was conducted on accuracy data with a between-subject factor of Instruction Group (2: object-referenced, self-referenced) and within-subject factors of Direction Reversal (2: original, reverse), and Item Value (2: low, high). There was a significant main effect of Item Value, $F(1,47) = 5.75$, $p = 0.02$, $\eta_p^2 = 0.11$; although accuracy was high overall, accuracy was higher for low-value ($\mu = 0.95$, SE = 0.01) than high-value items ($\mu = 0.92$, SE = 0.01). However, this result was mediated by the significant interaction of Direction Reversal × Item Value, $F(1,47) = 4.12$, $p = 0.05$, $\eta_p^2 = 0.08$). Separate one-way ANOVAs on Item Value in the original versus reversal blocks found a significant effect only in the second, reversal block (original: $F(1,48) = 1.05$, $p = 0.30$, $\eta_p^2 = 0.02$; reversal: $F(1,48) = 10.90$, $p = 0.002$, $\eta_p^2 = 0.19$). This is consistent with the idea that the Direction Reversal manipulation had differential effects on accuracy for item value (Figure 2A): with the original direction instructions, accuracy for low-value ($\mu = 0.94$, SE = 0.01) and high-value items ($\mu = 0.92$, SE = 0.01) were comparable, but, when the direction instructions were reversed, low-value items ($\mu = 0.96$, SE = 0.01) were more accurate than high-value items ($\mu = 0.92$, SE = 0.01). One explanation for these Item Value effects is that some low-value items were particularly disgusting and thus, memorable (e.g., pig's feet, clam juice) and indeed this same effect was observed in all three experiments. No other main effects or interactions were significant (all *p*s > 0.10).

Correct RTs. A mixed-model ANOVA was conducted with a between-subject factor of Instruction Group (2: object-referenced, self-referenced) and within-subject factors of Direction Reversal (2: original, reverse), and Item Value (2: low, high) using correct RT data (Figure 2B). A significant Item Value effect ($F(1, 47) = 6.21$, $p = 0.02$, $\eta_p^2 = 0.12$) indicated faster responses to high ($\mu = 858.42$, SE = 15.57) than low-value items ($\mu = 903.19$, SE = 19.03). This effect is consistent with other studies showing faster RTs to stimuli associated with reward (e.g., van den Berg, Krebs, Lorist, & Woldorff, 2014). Given that accuracy for low-value items was higher, this might suggest a speed-accuracy trade-off; however, as discussed below, this pattern was not replicated in Experiments 2 and 3.

The main effect of Instruction Group was marginally significant, $F(1,47) = 3.44$, $p = 0.07$, $\eta_p^2 = 0.07$); the object-referenced group ($\mu = 852.86$, SE = 20.19) responded marginally faster than the self-referenced group ($\mu = 908.74$ ms, SE = 22.37). If participants can flexibly adapt to instructed action-value directions (i.e., instruction merely provide context), there should be no performance costs for changing the value-action mapping. However, if a value-action association exists, then performance should change depending on task instructions. An Instruction Group × Direction Reversal interaction ($F(1,47) = 6.54$, $p = 0.01$, $\eta_p^2 = 0.12$) revealed that value-action mapping is associated with item value and that there are potential costs or benefits associated with the specific value-action mapping. The object-referenced group, originally instructed to move the joystick toward the object to indicate high value, was faster with original directions ($\mu = 843.91$ ms, SE = 22.83) than with the reverse directions, when they indicated high value by moving the joystick toward themselves ($\mu = 861.81$ ms, SE = 18.58). In contrast, the self-referenced group was originally instructed to move the joystick toward themselves to indicate high value, and was slower using the original instructions ($\mu = 919.04$ ms, SE = 25.29) than when the instructions were reversed ($\mu = 898.45$ ms, SE = 20.58). Consistent with these observations, we found significant effects of Item Value in both original and reversal blocks when collapsing by group (original: $F(1,48) = 5.10$, $p = 0.03$, $\eta_p^2 = 0.10$; reversal: $F(1,48) = 4.77$, $p = 0.03$, $\eta_p^2 = 0.09$). No other main effects or interactions were significant (all *p*s > 0.50).

Together, the accuracy and RT data suggest that not only are value representations for real-world items linked to specific actions, but also there appears to be a performance benefit when moving toward high-value items and a cost when the value-action mapping is reversed (i.e., changing to move toward the self for high-value items). These associations are not simply dependent on the current instructional context, as object value and action associations did not appear to be flexibly assigned merely through instruction. Instead, the data suggest that there may be an underlying, automatic association between action direction and item value (e.g., extending the arm toward high-value items). These effects do not appear to be the result of motoric ease in one direction because participants responded more quickly while using the object-referenced mapping, rather than responding more quickly with either the push or pull movement alone.

Based on the mixed findings of previous studies, there was no *a priori* reason to believe that one value-action mapping—object referenced or self-referenced—would be preferential or easier than the other. However, the results of Experiment 1 suggest that object-referenced frameworks for high-value items improve performance. Nonetheless, an alternative explanation may account for interactions between value and action direction: Participants were instructed to move in specific directions to categorize high-value and low-value items, and some proportion of participants may not have moved in their preferred value-action mapping, potentially inhibiting their prepotent responses. For example, if some participants prefer pushing toward items of high value, using the reverse mapping requires the cognitive maintenance of counterintuitive instructions during the task. This maintenance could interfere with performance, providing an alternative explanation for the results found in this experiment. To address this alternative explanation, we allowed participants to select their own value-action mappings in Experiment 2.

Experiment 2

In Experiment 2, participants chose their initial value-action mapping so personal preference could be ruled out as an explanation for the performance differences revealed in Experiment 1. If an assigned mapping is counterintuitive to participants, they may have to inhibit their preferred value-action mapping during the task, which could impair performance. If most participants had a strong preference for a mapping, the performance benefits for the object-referenced group in Experiment 1 could be a reflection of general preferences rather than a value-action association.

Thus, in Experiment 2, we were able to 1) determine whether participants prefer one mapping when responding to items of value and 2) evaluate performance changes when switching to the non-preferred value-action mapping. If participants select a mapping and then exhibit improved performance on the task using the *reverse* mapping, this would support the hypothesis that there is a value-action association in memory, and that it is independent of *conscious* mapping preferences.

Methods

Participants. Fifty-nine (35 female; ages 18-22 years; 54 right-handed) participants volunteered for partial course credit in introductory psychology courses. Nine participants were excluded from subsequent analyses for the following reasons: did not follow the instructions (n=3) , exhibited below-chance accuracy (n=4),or abnormal distribution of prices across items (e.g., disliked a majority of the food items and were more than 2 standard deviations away from the participant mean for the number of high- and low-value items; n=2). Thus, a total of 50 participants were included in the statistical analyses.

Procedure. Participants were asked to fast for two hours prior to the experiment to motivate their attention to the food images. Experiment 2 used the same stimuli, apparatus, and procedure as Experiment 1, with one exception. Instead of instructing participants which direction to move for high-value items, participants were asked to choose which initial direction they wanted to move to indicate high-value items. Specifically, participants were told that, to maximize their performance, they needed to choose which direction to move the joystick for high-value items. Participants were then told to imagine a picture of their favorite food on the screen and to try out different movements on the joystick to see which movement was most intuitive as a response to the item. After participants chose a direction for the high-value item, they were told to use the opposite movement to respond to low-value items. Again, participants held the joystick with the palm of their dominant hand on the top of the joystick.

Results and Discussion

More participants (n = 33, 66%) selected the object-referenced than the self-referenced mapping (n = 17, 34%), $\chi^2 (1) = 5.12$, $p = 0.02$. This indicates a general preference for the object-referenced mapping, suggesting that some of the participants in Experiment 1 may have inhibited their preferred value-action mapping during the original value categorization task.

As in Experiment 1, participants' valuations produced a relatively even split of push/pull movements with approximately 41% of items (102/250) priced as high-value items and 59% priced as low-value (<\$0: 93/250 = 37.2%; \$0: 55/250 = 22%). Only items that were priced as either above or below \$0 were included in the analyses below.

Proportion accuracy and mean correct RTs were calculated as in Experiment 1. Based on the RT distributions of our data, RTs that were 3 standard deviations from each participant's mean were excluded, resulting in a loss of less than 1% of each participant's data.

Accuracy. A mixed-model ANOVA was conducted with factors of Chosen Direction Group (2: object-referenced, self-referenced), Direction Reversal (2: chosen, reverse), and Item Value (2: low, high) for accuracy data. There was a significant main effect of Item Value, $F(1, 48) = 15.43$, $p < 0.001$, $\eta_p^2 = 0.24$, a significant Direction Reversal × Item Value interaction, $F(1, 48) = 4.27$, $p = 0 .04$, $\eta_p^2 = 0.08$, and a significant Chosen Direction Group × Direction Reversal interaction, $F(1, 48) = 13.17$, $p = 0.001$, $\eta_p^2 = 0.22$. These effects were all qualified by the significant Chosen Direction Group × Item Value × Direction Reversal interaction (Figure 3A), $F(1, 48) = 6.77$, $p = 0.01$, $\eta_p^2 = 0.12$. Across all participants, accuracy for low-value items was high (object-referenced: $\mu = 0.95$, SE = 0.01; self-referenced: $\mu = 0.96$, SE = 0.02) and unaffected by reversal (object-referenced reversal: $\mu = 0.95$, SE = 0.01; self-referenced reversal: $\mu = 0.96$, SE = 0.01). However, for participants who chose the object-referenced mapping, accuracy for high-value items decreased when they had to change to the self-referenced mapping (chosen: $\mu = 0.93$, SE = 0.01; reversal: $\mu = 0.88$, SE = 0.01). In contrast, for participants who chose the self-referenced mapping, accuracy for high-value items improved slightly when they switched to the object-referenced mapping (chosen: $\mu = 0.89$, SE = 0.02; reversal: $\mu = 0.90$, SE = 0.02). No other main effects or interactions were significant (all *p*s > 0.10).

Follow-up two-way ANOVAs by Chosen Direction Group found a significant main effect of Direction Reversal for the object-referenced group, but not the self-referenced group (object-referenced: $F(1,32) = 18.70$, $p = 0.0001$, $\eta_p^2 = 0.37$; self-referenced: $F(1,16) = 1.85$, $p = 0.19$, $\eta_p^2 = 0.10$), though the main effect of Item Value was significant for both (object-referenced: $F(1,32) = 7.41$, $p = 0.01$, $\eta_p^2 = 0.19$; self-referenced: $F(1,16) = 9.44$, $p = 0.01$, $\eta_p^2 = 0.37$). Likewise, the two-way interaction of Direction Reversal x Item Value was significant only for the object-referenced group (object-referenced: $F(1,32) = 15.80$, $p = .0004$, $\eta_p^2 = 0.33$; self-referenced: $F < 1$). An additional set of one-way ANOVAs looking at Item Value by block in the object-referenced group found a significant effect in the reversal block, but not the original block (original: $F(1,32) = 1.58$, $p = 0.22$, $\eta_p^2 = 0.05$; reversal: $F(1,32) = 13.29$, $p = 0.001$, $\eta_p^2 = 0.29$).

Correct RTs. A mixed-model ANOVA was conducted with factors of Choice Direction Group (2: object-referenced, self-referenced), Direction Reversal (2: chosen, reverse), and Item Value (2: low, high) for correct RT data. There was a significant Choice Direction Group × Item Value × Direction Reversal interaction ($F(1, 48) = 4.48$, $p = 0.04$, $\eta_p^2 = 0.85$). Overall, this interaction (Figure 3B) seems to be driven by the differences found in the self-referenced group, as the responses for the object-referenced group were quite similar across conditions. For participants who chose the self-referenced mapping, RTs to low-value items ($\mu = 858.38$ ms, SE = 31.15) were faster than to high-value items ($\mu = 901.26$ ms, SE = 28.07), but RTs to high-value items became faster when the direction was reversed (high-value: $\mu = 875.43$ ms, SE = 30.50; low-value: $\mu = 886.91$ ms, SE = 31.85). In other words, for the self-referenced group, RTs for high-value items became faster after direction reversal. However, RTs for low-value items were slightly slower after direction reversal. No other significant main effects or interactions were found (all $ps > 0.20$).

The above group differences may be explained by the greater variability and smaller sample size of the self-referenced group compared to the object-referenced group. A follow-up two-way ANOVAs examining Item Value x Direction Reversal failed to find significant effects (all $ps > 0.10$), although the interaction of Direction Reversal x Item Value approached marginal significance for the self-referenced group ($F(1,16) = 2.77$, $p = 0.12$, $\eta_p^2 = 0.15$). Our finding of a significant three-way interaction in the original ANOVA, despite unequal sample sizes, supports the idea that object- and self-referenced action mappings are associated with differences in performance, but our interpretation of these group differences must be moderated by the relatively low power of this analysis.

In summary, when participants were allowed to choose their preferred action direction to indicate high-value items, the majority of participants chose the object-referenced mapping, suggesting that reaching for high value items is the more natural value-action association. Moreover, the object-referenced mapping group committed more errors on high-value items when they switched to the self-referenced mapping. This group displayed little to no change in RT on high-value items when they switched to the self-referenced mapping, thereby ruling out a speed-accuracy tradeoff. In contrast, the self-referenced mapping group committed slightly fewer errors on high-value items when they switched to the object-referenced mapping. The self-referenced group also responded more quickly to high-value items when they switched to the object-referenced mapping, also ruling out a speed-accuracy tradeoff. It appears that even for participants who *consciously* preferred the self-referenced mapping, performance for high-value items may be better when participants switched to the object-referenced mapping. These patterns were not observed for low-value items.

Experiment 2's results suggest that directional movement towards the object is associated with the cognitive representation of high item value. It is also possible that this effect may occur when participants consciously opt for a different value-action mapping. However, to disambiguate the axis of movements to high/low value from that of self- versus object-referenced actions we conducted a third experiment.

Experiment 3

To what extent does the advantage for high-value categorization towards the object reflect a meaningful object-referenced framework versus some confounding aspect of reaching and pulling actions? In Experiment 3 participants performed the same value categorization task as in Experiments 1 and 2, but now used a left/right action mapping. Critically, left/right actions are not associated in daily experience with object acquisition, so if we find a similar advantage to value categorization in one of these mappings, it would constitute a strong argument against embodied valuation.

Specifically, participants were assigned into one of two instruction groups: a group instructed to move left for high value items and right for low value items ("left high group") and a group instructed to use the opposite mapping ("right high group"). If performance differences exist for value-action mappings using horizontal left and right arm movements, then the results from the previous experiments may be explained by factors other than value-action associations. However, if there are no differences found for horizontal actions related to value, this lends support to the idea that value-action associations exist from a lifetime of reaching and pulling items of value.

Methods

Participants. Fifty-nine (34 female; ages 18-23 years; 55 right-handed) participants volunteered for partial course credit in introductory psychology courses. Participants were randomly assigned to one of two instructed value-action mapping groups: a "left high" group in which participants were asked to initially move a joystick to the left for high-value items on the computer screen, or a "right high" group in which participants were asked to initially move a joystick to the right when they viewed high-value items on the computer screen. Four participants were excluded from subsequent analyses for below-chance accuracy or abnormal distribution of prices across items, following the same criteria as the previous experiments. Thus, a total of 55 participants were included in the statistical analyses (left high n = 27, right high n = 28).

Procedure. As in the previous experiments, participants were asked to fast for two hours prior to the experiment to motivate their attention to the food images. The same stimuli, apparatus, and procedure were used as in Experiment 1, with three exceptions. First, during the pricing task, the pricing number line was presented vertically on the left side of the computer screen rather than horizontally at the bottom of the screen (as in Experiment 1 and 2) so that it was perpendicular to the axis of movement in the categorization task. This orientation change prevented participants from associating left and right directions with a particular value. Second, participants were assigned a value-action mapping that involved right and left arm movements rather than push/pull arm movements. Third, the joystick used in the previous experiments was rotated 90° counterclockwise to ensure the same amount of tension and range of motion for the directional movements as in Experiments 1 and 2.

Results and Discussion

As in Experiments 1 and 2, participants' valuations produced a relatively even split of movement directions in the value categorization tasks, with 39.6% (99/250) of items priced as high-value and 60.4% priced as low-value (<\$0: 89/250 = 35.6%; \$0: 62/250 = 24.8%). As in the previous experiments, only items that were priced as either above or below \$0 were included in the analyses below. Proportion accuracy and mean correct RTs were calculated as in Experiment 1. Less than 1% of trials were excluded as outliers.

Accuracy. A mixed-model ANOVA was conducted on accuracy data with a between-subject factor of Instruction Group (2: left high, right high) and within-subject factors of Direction Reversal (2: original, reverse), and Item Value (2: low, high). As in Experiments 1 and 2, there was a significant main effect of Item Value, $F(1,53) = 31.90$, $p < 0.01$, $\eta_p^2 = 0.38$; although accuracy was high overall, accuracy was higher for low-value ($\mu = 0.96$, SE = 0.01) than high-value items ($\mu = 0.89$, SE = 0.01). No other main effects or interactions were significant (all ps > 0.40).

Correct RTs. A mixed-model ANOVA was conducted with a between-subject factor of Instruction Group (2: left high, right high) and within-subject factors of Direction Reversal (2: original, reverse), and Item Value (2: low, high) for correct RT data (Figure 4B). A significant Item Value effect ($F(1, 53) = 4.80$, $p = 0.03$, $\eta_p^2 = 0.08$) indicated faster responses to low (μ =876.49 ms, SE = 15.56) than high-value items (μ = 911.34 ms, SE = 15.57). As in Experiment 2, there did not appear to be any accuracy-response trade-offs. No other main effects or interactions were significant (all ps > 0.10).

Together, the accuracy and RT data suggest that the performance benefit found in Experiments 1 and 2 for the object-referenced mapping cannot be explained by factors specific to the stimuli, apparatus, or procedure in this study. None of the performance differences were found when participants used horizontal arm movements to categorize items.

General Discussion

In our daily lives, valuation and decision making are often accompanied by specific actions. We reach out and grab things we want, or pull them toward us. However, little work has examined the association between actions and valuation in conceptual representations. Whereas economic good-based models of choice represent value as independent of action (e.g., Padoa-Schioppa, 2011), embodied cognition frameworks suggest that the actions used to interact with objects may be tied to our conceptual representations of those objects (e.g., Barsalou, 1999; Kiefer & Pulvermüller, 2012). To address this question, we used a novel manipulation to test the association of specific actions with items of different values. By mapping a movement to a concept of value (high or low) and then instructing participants to reverse the mapping, we tested whether there were performance benefits for specific value-action mappings.

In our first two experiments, we found mapping-specific performance benefits for the recollection of item value, with object-referenced actions producing faster and more accurate responses. However, when participants mapped value to left and right arm movements in Experiment 3, we found no significant performance differences. These results suggest that value and specific actions are linked in conceptual representations of objects, and our history of using specific actions while interacting with objects can affect memory for value. Of note, although accuracy was high overall, the presence of errors in high-value categorization is particularly striking. When participants erroneously categorized a high-value item as low-value, the participants effectively indicated that they would need to be *given* money to consume an item that they claimed they would *pay for* just a short time before. The mapping-based performance differences found in this study suggest that the actions we use can have a substantial impact on our memory for the valuation of items and, therefore, subsequent choices. Further, as suggested in Experiment 2, it is possible that this effect may be dissociated from participants' own conscious preferences for value-action mapping: regardless of whether individuals chose to pull high-value items towards themselves or reach towards high-value items, the latter was associated with performance benefits.

These findings extend the results of previous work on approach-avoidance behavior linking emotional valence and actions. For example, Seibt et al. (2008) found that emotional valence-action mappings could be changed by changing instructional context, regardless of the direction of the joystick movement response. Similarly, van Dantzig et al. (2008) found that the specific movement cue associated with a stimulus affected RTs, independent of the direction of the joystick movement response. Our results suggest that certain value-action mappings can persist despite instructional context.

One key difference from previous studies was the inclusion of a reversal manipulation, in which all participants were asked to switch value-action mappings. Without this feature, it would be impossible to distinguish whether value-action mappings can be flexibly reassigned depending on instructions, or whether they reflect long-term experiential effects from object interactions. Here the reversal manipulation revealed that the object-referenced mapping was not only the preferred mapping, but also the faster, more accurate mapping. The performance differences with the mapping reversals suggest that both value and action are part of an item's conceptual representation. In addition, this within-subject manipulation allowed us to rule out alternative explanations that particular value-action mappings reflect short-term stimulus-response associations (as opposed to long-term associations), unidirectional motoric ease (e.g., it is generally easier to push than pull), or specific joystick function (e.g., our joystick moved more easily in one direction). Moreover, the results of Experiment 3 demonstrated that push/pull movements are uniquely linked to conceptual representations of value.

These results join recent findings from Schonberg and colleagues (Schonberg et al., 2014) in identifying a role for sensorimotor context in cognitive representations of value. Whereas Schonberg et al. (2014) showed that a simple motor response (button press) paired with an approach cue increased the value of the irrelevant food stimulus, our data further suggest that some action mappings are more strongly associated with valuation than others. Interestingly, in both Schonberg et al. (2014) and our study, effects were asymmetric for high- and low-value items, with the latter showing less perturbation by cue-approach training (Schonberg et al., 2014) and greater memorability here. Although our stimulus set included highly distinctive aversive foods such as pigs' feet and canned meat, potentially explaining the higher accuracy we observed, it is worth noting that only appetitive snack foods were used by Schonberg and colleagues (2014). Thus, representations of low-value items may be less mutable and/or more elaborated, in keeping with observations of negativity bias across numerous psychological domains (e.g., Rozin & Royzman, 2001).

This study provides evidence that actions can become associated with mental concepts like value through long-term associations. Although cognitive representations of value are often treated as entirely independent of action selection (Padoa-Schioppa, 2011), these data suggest that action mapping should be included as a factor even before the motor output stage. Building on previous findings that alternative actions are represented by sensorimotor networks from early in the choice process (Cisek & Kalaska, 2010; Cisek, 2012), the current results suggest a route by which the potentially broad space of available actions may be constrained to a more restricted set of high-probability responses. Just as affordances themselves reflect statistical regularities in the environment (Gibson, 1979; Humphreys, 2001), repeated experience interacting with real-world objects may bias motor response selection towards specific value-action mappings.

Of course, in real-world interactions these representations must ultimately be translated into egocentric coordinates for reaching and grasping. For example, the full action cycle could consist of reaching out for an item, and then pulling back the arm with the item in hand. The latter type of self-referenced representations was not observed here. This could arise from our task's focus on cognitive components of value judgment (e.g., memory), rather than physical object interactions. Further experiments integrating physical object interactions with conceptual value representations are warranted to study this transformation. Examining the kinematics of movement associated with obtaining high-value items might provide greater insight into how object- and self-referenced frameworks are ultimately combined.

Another parameter to explore in future experiments is that of movement vigor. Greater rewards are commonly associated with increased movement vigor (Niv, Daw, Joel, & Dayan, 2006). Given the putative role of the basal ganglia in both valuation and motor gain control (Rigoux & Guigon, 2012), it would be interesting to examine whether object-referenced value-action mappings also vary in response vigor as a function of the reward strength of the item (e.g., foods priced at $1 versus $2).

Finally, it remains an open question how long these value-action mappings take to develop, and for how long they last. One hint comes from Schonberg and colleagues (2014), who found effects of cue-approach training persisting more than two months after training with 16 repetitions. No such effect was observed for smaller training sets (e.g., 12 repetitions). Because the actions tested here more accurately reflect affordances encountered in daily life, we might expect acquisition of these value-action mappings to occur even more rapidly. Additionally, it remains unclear how these value-action mappings might be influenced by fine-grained motor and action-timing-related variables, as have been shown to modulate various aspects of manual responses in verbal tasks (Garcia & Ibáñez, 2016).

In conclusion, the results of this study are important for the development of accurate models of choice. The data support the hypothesis that value and action are inextricably linked in memory, and suggest that action should be depicted as a determinant as well as output in models of choice. In addition, the results of this study have important implications for understanding consumer behavior, especially for online purchasing decisions in computerized shopping environments. If specific actions are related to concepts of value, this has consequences for how purchasing decisions are implemented in terms of how customers interact with items on websites, especially for different types of digital devices that require specific actions to make purchasing decisions. For example, if the findings from this study generalize, an online shopper who has to flex their arm by dragging a mouse to browse items could experience a decrease in valuation for high-value items. Future research is needed to assess how actions can affect valuation of items in online shopping environments.

Of additional interest to online marketers, the results from Experiment 2 suggest that users may not be aware of how their actions are related to item value and mismatching the value and the action can lead to reduced memory for the item. Although further research is needed to explore the way common actions—such as swiping, tapping, and using a mouse—can affect online shopping decisions, this study provides critical first steps to show that physical movement is an important consideration when designing online shopping websites.

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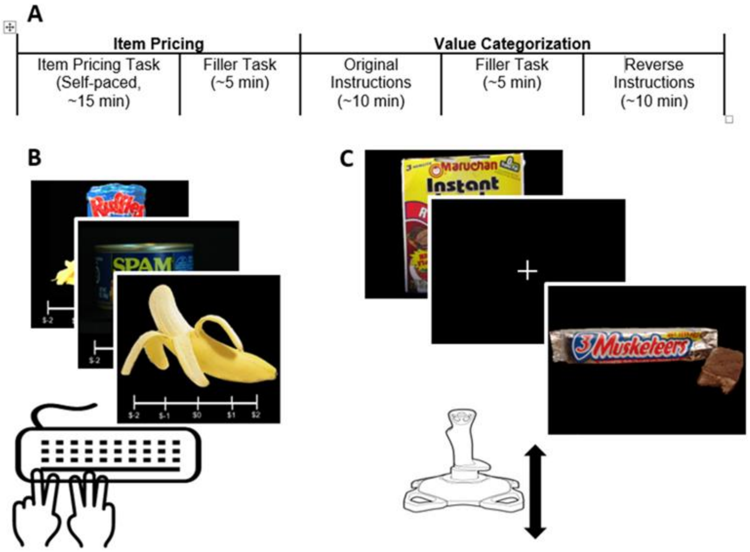
Figure Captions

Figure 1. Experimental procedure. (A): The experiment consisted of three parts, an item pricing task followed by two blocks of a value categorization task. (B) Item Pricing Task: participants priced items in values from -\$2.00 to +\$2.00 in increments of \$1.00 using a key press response. (C) Value Categorization Task: participants either pushed or pulled a joystick indicate whether an item was previously priced above \$0 (High value) or \$0 or less (Low value).

Figure 2. Experiment 1 Results: Assigned Value-action Mappings. (A) Proportion accuracy. (B) Mean correct RTs. Error bars represent standard errors.

Figure 3. Experiment 2 Results: Self-selected Value-action Mappings. (A) Proportion accuracy. (B) Mean correct RTs. Error bars represent standard errors.

Figure 4. Experiment 3 Results: Left versus Right Value-action Mappings. (A) Proportion accuracy. (B) Mean correct RTs. Error bars represent standard errors.


A
Item Pricing
Item Pricing Task (Self-paced, ~15 min)
Filler Task (~5 min)
Value Categorization
Original Instructions (~10 min)
Filler Task (~5 min)
Reverse Instructions (~10 min)
B
Ruffles
SPAM
$-2
$-1
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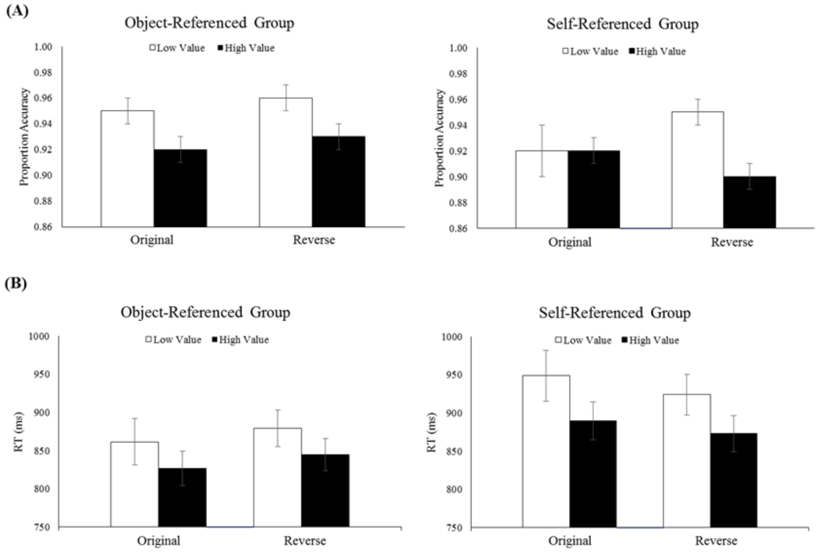
$1
$2
C
Maruchan
Instant
3 Musketeers


(A)
Object-Referenced Group
Self-Referenced Group
□ Low Value ■ High Value
Proportion Accuracy
1.00
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Original
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(B)
Object-Referenced Group
Self-Referenced Group
□ Low Value ■ High Value
RT (ms)
1000
950
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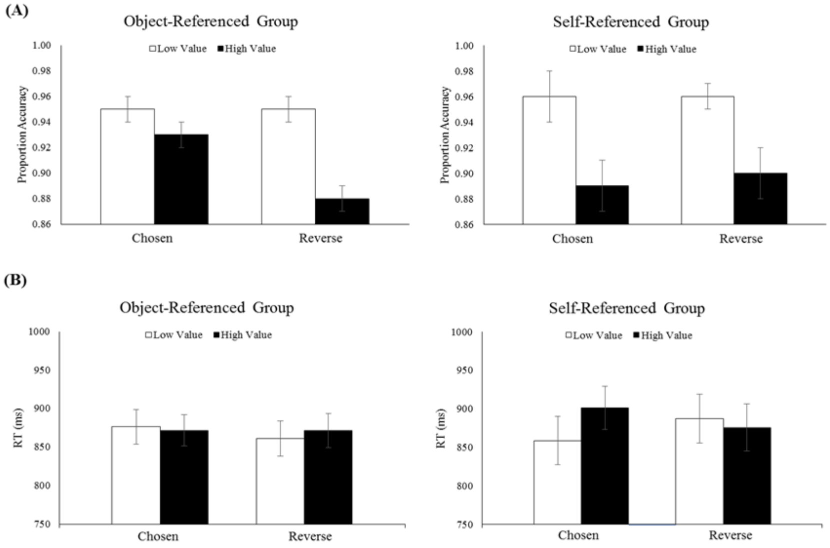
850
800
750
Original
Reverse


(A)
Object-Referenced Group
☐Low Value ■High Value
Proportion Accuracy
1.00
0.98
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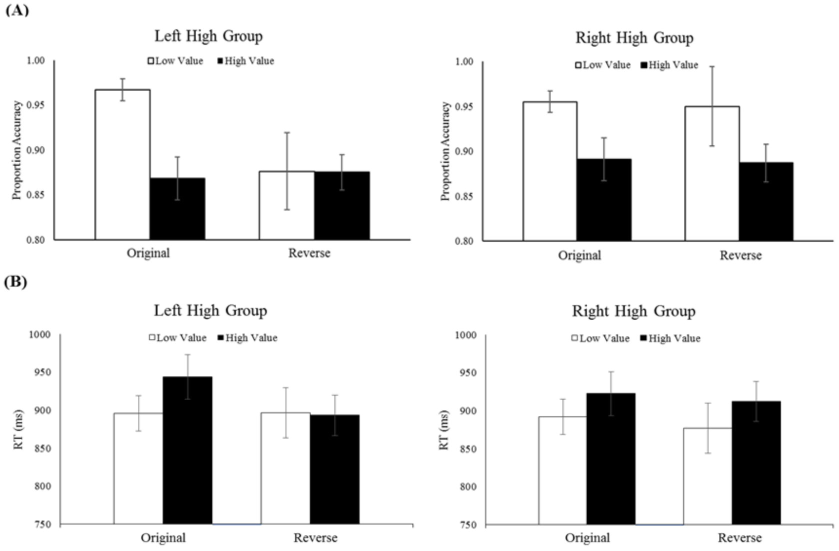
Chosen
Reverse
Self-Referenced Group
☐Low Value ■High Value
Proportion Accuracy
1.00
0.98
0.96
0.94
0.92
0.90
0.88
0.86
Chosen
Reverse
(B)
Object-Referenced Group
☐Low Value ■High Value
RT (ms)
1000
950
900
850
800
750
Chosen
Reverse
Self-Referenced Group
☐Low Value ■High Value
RT (ms)
1000
950
900
850
800
750
Chosen
Reverse


(A)
Left High Group
□Low Value ■High Value
Proportion Accuracy
1.00
0.95
0.90
0.85
0.80
Original
Reverse
Right High Group
□Low Value ■High Value
Proportion Accuracy
1.00
0.95
0.90
0.85
0.80
Original
Reverse
(B)
Left High Group
□Low Value ■High Value
RT (ms)
1000
950
900
850
800
750
Original
Reverse
Right High Group
□Low Value ■High Value
RT (ms)
1000
950
900
850
800
750
Original
Reverse