Published in final edited form as:
Psychol Sci. 2013 December ; 24(12): 2369–2378. doi:10.1177/0956797613490743.

Shaping Attention with Reward: Effects of Reward on Space- and Object-Based Selection

Sarah Shomstein and **Jacoba Johnson**
Department of Psychology, George Washington University, Washington, DC 20015, USA

Abstract

The contribution of rewarded actions to automatic attentional selection remains obscure. We hypothesized that some forms of automatic orienting, such as object-based selection, can be completely abandoned in lieu of reward maximizing strategy. While presenting identical visual stimuli to the observer, in a set of two experiments, we manipulate *what* is being rewarded (different object targets or random object locations) and the *type* of reward received (money or points). It was observed that reward alone guides attentional selection, entirely predicting behavior. These results suggest that guidance of selective attention, while automatic, is flexible and can be adjusted in accordance with external non-sensory reward-based factors.

Keywords

Attention; Rewards

Voluntary behaviors are strongly influenced by the consequences that have ensued after similar behaviors in the past. Responses that are repeatedly followed by reward are more desirable than those followed by punishment (or absence of reward). Take for example an almost every day task of picking out fruit at your local supermarket. You will most likely stay away from purchasing a mango following last week's food poisoning after eating a mango salad, but will not hesitate to choose a fruit that has not led to any recent discomfort.

While the effects of reward on such voluntary behaviors as cognitive choices have been extensively researched and are now well understood, the effects of reward on involuntary behaviors, especially those that are considered to be automatic, or outside the range of the volitional control of the organism, remain ill specified (Della Libera & Chelazzi, 2006; Hickey, Chelazzi, & Theeuwes, 2010). Automatic behaviors vary along a spectrum, or hierarchy, ranging from reflexes on one end (i.e., hardwired) to certain types of automatic attentional allocation on the other. Here, we exclusively focus on two instances of automatic attentional allocation, that of spatial- and object-based attention, the two fundamental mechanisms by which an organism selects a subset of relevant information from the environment rich in sensory stimulation (Egeth & Yantis, 1997; Kanwisher & Driver, 1992;

Correspondence: Sarah Shomstein, Department of Psychology, George Washington University, 2125 G Street, NW, Washington, DC 20015, Phone: 202-994-5957; shom@gwu.edu.

Authorship: S.S. developed the study concept. All authors contributed to the study design, performed data analysis and interpretation, and drafted the paper. All authors approved the final version of the paper for submission.

Posner, 1980; Rock & Guttman, 1981; Shomstein & Yantis, 2002). Understanding whether reward modulates automatic attentional control is an important endeavor given that what we consciously perceive ultimately depends on where attention is directed in both voluntary and involuntary manner (Buschman & Miller, 2007; Egeth & Yantis, 1997; Shomstein, Lee, & Behrmann, 2010; Skinner, 1938; Yeari & Goldsmith, 2010).

Here, we present data from two experiments in which the influence of reward on automatic space- and object-based visual selective attention is investigated. To this end, we adopted a two-rectangle paradigm, one of the most robust and well-established experimental paradigms for demonstrating the influences of space- and object-based guidance to automatic attentional selection (Egly, Driver, & Rafal, 1994; Moore, Yantis, & Vaughan, 1998), and married it with a regimented schedule of reward and punishments. In a standard object-based paradigm, participants are presented with two parallel rectangles and are required to detect the presence of a target event. At the beginning of each trial, one end of one of the rectangles is cued. The critical target event then appears either in the cued location (*valid target*), or in a location equidistant from the cue but either within the cued rectangle (invalid *same-object target*) or within the uncued rectangle (invalid *different-object* target). Two markers of attentional allocation have been consistently obtained in studies adopting this paradigm: (1) automatic space-based facilitation, evidenced by faster and more accurate responses for valid than for invalid targets, suggesting that the distance between the cued location and the target affects perceptual efficiency; and (2) automatic object-based facilitation where invalid same-object targets are detected more rapidly than invalid different-object targets (though both are equidistant from the cue), suggesting that when part of an object is attended, the rest of the object benefits perceptually (Behrmann, Zemel, & Mozer, 1998; Moore, Yantis, & Vaughan, 1988; Shomstein & Yantis, 2004).

In order to investigate the impact of reward factors onto attentional allocation (space- and object-based) several important modifications were made to the traditional two-rectangle paradigm. First, the unlimited exposure paradigm was changed into a data limited design, such that targets appeared on the screen for only 60ms and were swiftly masked (Fig. 1A). This manipulation increased task difficulty thereby ensuring that participants employ maximal attentional resources for the purposes of the task (Lavie, 1995). The second, and most important modification, included an imposition of a performance- based reward schedule, contingent on point accumulation such that participants were rewarded for correct target identification, and punished for incorrect target identification. Importantly, the reward schedule was not uniform. Depending on the experiment, two different reward/punishment schemes were imposed. In the different-object (DO) biased experiment (Exp.1a), correctly identified targets presented in the validly cued *or* the same-object location were rewarded with 1 point, while targets presented in the different-object location were rewarded with 6 points (Fig.1B, middle), thereby biasing the DO location. In the random reward experiment (Exp.2), correctly identified targets presented in the validly cued location were rewarded with 1 point, while the correct identification of targets presented in the same- or different-object was rewarded with 1 or 6 points determined randomly, thereby eliminating reward-based biases for either the same- or different-object location while retaining reward.

Feedback was given after each trial, stating whether the trial was rewarded with points for correct responses, or punished with subtraction of points for incorrect responses (Fig.1A).

The logic of the experiments is straight forward. First, demonstrate that space- and object-based effects are elicited in a modified data limited paradigm (Exp. 1a). Second, adjust levels of reward in a manner counter to the standard space- and object-based effects (biasing invalidly cued and different-object locations; Exps. 1a&b) or distribute reward randomly thereby equating the bias (Exp.2). If reward exclusively affects attentional allocation, then RTs should be entirely predicted by the levels of reward alone, rather than interacting with space- and object-based attention. For example, object-based effects should be reversed when reward biases DO (Exp. 1a&b), and should be eliminated altogether when reward is distributed randomly (Exp.2). Alternatively, if reward influences attentional allocation, then reward will interact with space- and object-based effects to the same extent. Yet another alternative is that reward might differentially affect space- and object-based attentional allocation.

Methods

Observers

Three groups of 47 participants took part in two experiments (13 in Exp.1a, 24 in Exp.1b, and 10 in Exp.2). All participants provided informed consent, reported normal or corrected-to-normal visual acuity, and were naïve as to the purpose of the experiment.

Apparatus and Stimuli

Stimuli were displayed on a 19″ color monitor with viewing distance of about 62cm. A central 0.3° × 0.3° fixation cross and two white rectangle outlines appeared on a black background oriented vertically or horizontally (see Fig.1). Each rectangle subtended 1.3° × 4.5° with separation of 1.8° of visual angle between the rectangles. The cue was a red outline perfectly circumscribing one end of one of the rectangle.

One target (T/L) and three distractors (T/L hybrid) appeared on each trial. Each item was centered within the ends of the rectangles, 1° × 1°. Target and distractor characters were constructed with line segments each subtending 0.7° × 0.7°. Target and distractor letters were rendered in white and appeared in one of four possible orientations – upright, or rotated 90°, 180°, and 270° (Fig.1). Masks consisted of twelve line segments arranged into window-like configuration presented in the same location as the target and distractors and subtending 0.9° × 0.9°. Feedback displays consisted 14pt fonts in either white (for positive point accumulation) or red (for point loss).

Design and Procedure

For all experiments, the design was counterbalanced across subjects for rectangle orientation (vertical or horizontal). Validity was defined by whether the target appeared in the cued location (valid), at the opposite end of the cued object (invalid same-object), or at the end of the uncued rectangle nearest the cue (invalid different-object). The cue was valid on 58% of the trials. The target appeared in the two invalidly cued locations equally likely, 21% each.

Each trial began with a fixation cross and two rectangles presented for 1000ms followed by a 100ms cue. After a 200ms delay, target and distractors were presented for 60ms, followed by a 100ms rectangle display. Masks were then presented at each end of the rectangle and remained on the screen until response. The subjects' task was to identify the target as either T or L (selected randomly). Subjects were instructed to ignore the orientation and report only the identity of the target letter, and to respond as quickly and accurately as possible. Each trial ended with a feedback display. For Exp.1a, No-Reward manipulation, the display consisted of a red "incorrect" or white "correct" message depending on the accuracy of the response. For Exp.1a (DO-Reward manipulation), and Exp.1b and Exp.2, feedback display indicated the number of points earned (in white) or lost (in red) on any given trial along with the total number of points accrued since the beginning of the experiment. In Exp.1a total number of accrued points was matched to a subsequent monetary reward depending on performance: accuracy > 90% earned an extra $10; 80-90% earned $8; 70-80% earned $6; and performance below 70% earned $5. In Exp.1b and Exp.2 participants simply accrued points devoid of any value.

Experiment 1a

Exp. 1a was conducted over two one-hour sessions. The first session, No-reward manipulation, was performed in order to verify that the time-limited two-rectangle paradigm is capable of eliciting space- and object-based attentional effects and to acquire baseline measurements of space- and object-based effects without reward. Participants performed the time-limited two-rectangle paradigm task with feedback restricted to informing participants whether responses were correct or incorrect without any tractable reward (Fig.1B, left). The second session of Exp.1a, DO-reward manipulation, was performed in order to examine whether, and to what extent, automatic space- and object-based effects can be modulated or reversed by reward-based influences. For this purpose, the same group of participants performed the time-limited two-rectangle task with a superimposed feedback schedule that favored different-object locations (Fig.1B, middle). In this task, correct identification of targets appearing in the different-object (DO) location was reinforced with 6 points, whereas correct identification of targets in the valid or same-object (SO) location was reinforced with 1 point. Participants were informed that greater accrual of points will correspond to a greater monetary bonus to be received in a form of a payment upon the completion of the experiment: performance of 90% or above earned an extra $10; 80-90% correct response earned $8; 70-80% earned $6; and performance below 70% earned $5.

Experiment 1b

Exp.1a was repeated with two major differences: (1) employed a between-subject design with two different groups of subjects participating in the No-reward and DO-reward experimental sessions, and (2) participants were exposed to the same point reward-structure, only this time received no compensation, thus participants simply accumulated points that had no ultimate monetary value.

Experiment 2

Procedure was the same as in Exp.1b with one major difference, both SO and DO were rewarded randomly with SO targets rewarded with 1 or 6 points and DO targets rewarded with 1 or 6 points at random. Targets appearing in the valid location were consistently rewarded with 1 point (Fig.1B, right)

Statistical Analysis

Significance thresholds were $p<0.05$. Exp.1a was analyzed as a within subject analysis of variance model (ANOVA) with validity (valid, same-object, different-object) and reward-type(No-Reward, DO-Reward) as within subject variables. Exp. 1b was analyzed as a between subject ANOVA with validity (valid, same-object, different-object) as within subject factor and reward structure (No-reward vs. DO-reward) as a between-subject factor.

Results

Monetary-reward eliminates object-based orienting

Exp.1a No-reward session tested whether the modified paradigm is capable of eliciting automatic space- and object-based effects. Fig.2A (top left) shows the pattern of performance observed with feedback restricted to indicating whether a target was identified correctly or incorrectly with no other reward information. The space-based effect was assessed by comparing invalidly cued trials (SO and DO combined) with the validly cued targets, showing a 109ms effect [$F(1,12)=34.28$, $p<.001$]. In addition, we observed a significant 17ms object-based effect by comparing invalidly cued targets appearing in SO and DO [$F(1,12)=5.52$, $p<.04$] indicating that targets in the DO location were identified slower than those appearing in the SO location. The presence of these automatic space- and object-based effects, as well as their magnitudes, is consistent with those reported in a plethora of object-based paradigms (Drummond & Shomstein, 2010; Egly et al., 1994; Shomstein & Behrmann, 2008).

Taking advantage of the within-subject design of this experiment, we directly examined whether imposing a reward-based schedule alters the automatic distribution of space- and object-based attentional orientation. To do so, we first compared the magnitude of space-based effect across the No-reward and DO-reward manipulation. An ANOVA was conducted with reward schedule (No-reward vs. DO-reward) and validity (valid vs. invalid) as within subject factors. The presence of an automatic space-based attentional allocation was confirmed by faster identification times (113ms) for the validly cued targets [$F(1,12)=45.1$, $p<.001$] as compared to the invalidly cued targets. Additionally, it was observed that targets in the No-reward manipulation were identified slower than those in the DO-reward manipulation [$F(1,12)=6.2$, $p<.03$] a finding that could reflect (a) a practice effect, since participants always performed the No-reward schedule before the DO-reward condition, and improved with more exposure to the task; or (b) a consequence of reward with the reward schedule motivating participants to perform faster. Regardless of the slight overall decrease in RTs in the DO-reward manipulation, the most important observation is that the magnitude of the validity effect did not differ between the No-reward and DO-reward manipulations (109 and 117m respectively), as is evidenced by the absence of a two-way interaction ($F<1$). This finding strongly suggests that reward based manipulation did not affect the automatic distribution of spatial attention.

Having established that space-based orienting is robust to the effects of reward we turn to examining whether object-based attentional allocation is modulated by reward based influences. An ANOVA was conducted with reward schedule (No-reward vs. DO-reward) and object (SO vs. DO) as within subject factors (Fig. 2A, top right). Just as with the previous analysis, we observed a main effect of reward type, such that participants were faster in the DO-reward condition as compared to the No-reward condition [$F(1,12)=5.2$, $p<.05$], suggesting that participants speed up either as the time on task increased or as a result of a monetary motivational factors. Important however, is the finding that the imposed DO-reward schedule completely reversed the observed object-based effect as evidenced by the presence of a reward type by object interaction [$F(1,12)=11.2$, $p<.01$]. Whereas in the No-reward experiment, targets appearing in the same-object location were detected faster than the different-object location (17ms [$F(1,12)=5.5$, $p<.04$]), in the DO-reward experiment, targets appearing in the different-object location were detected faster than in the same-object location (26ms [$F(1,12)=10.1$, $p<.01$]). This finding strongly suggests that the automatic object-based allocation was replaced by the reward-based factors, and attentional allocation was determined exclusively by the reward schedule. Similar effects were observed in accuracy (Fig.SF1A).

As a next step, afforded by the fact that the same participants took part in No-reward and DO-reward manipulations, we assessed the relationship between the magnitude of the automatic space-based and object-based effects depending on the imposed reward structure for each individual participant. This analysis allows one to look beyond the overall mean differences, and specifically examine whether the magnitude of each individual's effect remains the same (e.g., space-based) or reverses to the same extent (e.g., object-based) across reward manipulation. First, we correlated the size of the space-based effect (i.e., invalid-valid) for No-reward and DO-reward manipulations. The logic is as follows: if space-based effect is robust to reward structure, then the magnitude of the space-based effect should be similar across reward schedules. A significant positive correlation was observed between the two variables, $r=0.77$, $n=13$, $p<.001$ (Fig. 3). We next correlated the size of the object-based effect for No-reward (SO-DO) with that for DO-reward (SO-DO). If automatic object-based effect is completely reversed when DO reward is introduced, then the magnitude of the object based effect should reverse. A significant negative correlation was observed between the two variables [$r=-0.39$, $n=13$, $p<.09$, with a single outlier point removed $r=-0.64$, $n=12$, $p=.01$] suggesting object-based effects were of the same magnitude but reversed according to the reward schedule (i.e., participants who showed large object-based effects showed large reward-based effects).

Same effects were replicated with using the measure of inverse efficiency (Kennett, Eimer, Spence, & Driver, 2001; Townsend & Ashby, 1983), verifying that faster responses to highly rewarded targets were not attributed to reward related speed accuracy tradeoffs (Fig2B; supplemental materials 1).

Thus far, we demonstrated that the time-limited paradigm is capable of eliciting traditional automatic space- and object-based effects when the only feedback given to participants is whether their performance on a trial-by-trial basis is correct or incorrect. However, once a reward schedule, disproportionately favoring targets appearing in the different-object is introduced, space-based effect remained unchanged but the object-based effect became aligned with the reward schedule (i.e., reversed). These results support two important conclusions: (1) automatic space-based effects are robust to influences of reward, evidenced by the fact that even when validly cued targets were only reinforced with 1 point reward, targets detected in the validly cued locations were detected faster than at the highly rewarded different object location; and (2) automatic object-based effects are reversed with the presence of an alternative reward based schedule, evidenced by the fact that reward alone determined attentional allocation within and between objects in the DO rewarded manipulation.

Non monetary-reward eliminates object-based orienting

We next asked the question: is automatic object-based attentional guidance abandoned in favor of a reward structure only in the presence of monetary reward, or might any reward, even non-monetary, provides sufficient signal to elicit reward-based guidance? Demonstrating the influence of non-monetary reward on automatic attentional guidance will serve two important purposes: (1) demonstrate that reward-based effects are generalizable to other reward settings, and (2) provide evidence for robustness of the observed effect via a replication.

In order to assess whether automatic space-based attention changed as a function of the imposed reward structure, an ANOVA was conducted with validity (valid vs. invalid) as within subject factors and reward structure (No-reward vs. DO-reward) as a between-subject factor (Fig.2C). Results revealed a main effect of validity, or space-based effect [$F(1,23)=59.91$, $p<.01$], with valid targets detected faster than invalid targets (M=506ms vs. M=616ms, respectively). Importantly, absence of a significant interaction with reward structure ($F<1$) suggests that space-based effect remained stable across different reward schedules (replicating Exp. 1a results).

To assess whether automatic object-based attentional allocation was affected by reward structure, an ANOVA was conducted with object (SO vs. DO) as a within-subject factor and reward (No-reward vs. DO-reward) as a between-subjects factor. Results revealed a significant interaction of object and reward structure [$F(1,23)=9.13$, $p<.01$] in the absence of a significant main effect of object ($F=2$), suggesting that the magnitude of the object-based effect was completely reversed under the two reward procedures. In other words, when no reward structure was imposed, the standard object-based effect was observed with SO targets detected faster than DO targets (M=591 vs. M=607ms; $F(1,10)=4.36$, $p<.05$). However, when a DO-reward schedule was introduced, the object-based effect was reversed with DO targets detected faster than SO targets (M=606 vs. M=661ms; $F(1,13)=7.65$, $p<.02$). Inverse efficiency and accuracy data largely mirrored that of RTs (Fig. 2D and Fig. S1B, respectively). These results strongly suggest that while automatic space-based attention is robust to influences of reward, the automatic object-based attention is entirely abandoned in favor of the reward-based strategy. Interestingly, these results also suggest that reward-based strategy is not dependent on concrete monetary reward and that the reward-based attentional allocation can be driven by non-material reward.

In order to rule out that the two groups (No-reward and DO-reward) might have had inherent differences leading to the differential object-based effects, we repeated the DO-reward experiment with another group of 14 participants. We perfectly replicated our original findings (Supplemental Materials 2). Additionally, in order to provide evidence for strong internal validity, we directly compared effect sizes in DO-reward condition across Experiments 1a and 1b, showing exactly the same results across the two experiments (Supplementary Materials 3).

Random reward eliminates object-based orienting

To provide the strongest test of the emerging conclusion that automatic object-based attention is abandoned entirely in the presence of a reward structure we conducted a second experiment in which reward structure was entirely random. The logic is as follows: if reward alone determines object-based allocation then when reward is being administered randomly, DO and SO locations should be attended to the same extent (i.e., no difference between DO and SO). However, if automatic object-based attention is insensitive to reward, or is somehow overridden by reward in previous experiments, then we should still observe an SO advantage over DO.

An ANOVA conducted with validity (valid vs. invalid) as a within-subject factor revealed a main effect [$F(1,9)=30.84$, $p<.001$], evidencing strong 125ms effect of automatic space-based allocation (M=647ms for invalid and M=522ms for valid targets). Interestingly, however, we observed no main effect of object ($F<1$) when SO targets were compared to DO targets with object as a within subject factor (M=647ms for DO and M=646 for SO targets). These results strongly support the hypothesis that reward alone determines object allocation, and that spatial allocation remains immune (Fig. 4A). We conducted the same analysis on inverse efficiency (Fig. 4B) and observed similar results with a significant main effect of validity [$F(1,9)=29.51$, $p<.001$] and no effect of object ($F=3$). Similar results were observed with accuracy (SF2).

In order to provide greater internal validity, we replicated this experiment with another group of 14 participants. Same results were observed (Supplemental Material 4).

Discussion

In a set of two experiments reported here, we provide strong evidence that reward-based orienting serves as a signal for attentional selection, such that some forms of automatic attentional guidance are abandoned in lieu of a reward-based contingency. First, across two experiments, we demonstrated that space-based attentional guidance following an informative sensory cue is robust to reward-based influences. This result, while novel, is not necessarily surprising as decades of research investigating space-based orienting have demonstrated the robustness and inflexibility of spatial orienting. In other words, as long as there is a sensory cue, attention will be automatically deployed to that location (Millken, Tipper, Houghton, & Lupianez, 2000; Posner, 1980). The novel, and surprising, finding reported here is that automatic contribution of objects to attentional guidance, or object-based attention, is completely abandoned in the presence of a reward-based strategy. We clearly, and for the first time, demonstrate that object-based effects are reversed when reward-based structure biases different-object, with targets appearing in a different-object from the cue identified faster and more accurately than those appearing within the same-object. More importantly, we show that even when reward-based structure biases SO and DO locations equally, object-based attention is completely abandoned and reward predicts orienting with SO and DO targets identified with the same speed and accuracy. The latter finding strongly suggests that the reward-based contingency provides an informative signal that constrains attentional allocation (Anderson, Laurent, & Yantis, 2011; Della Libera, Perlato, & Chelazzi, 2011; Hickey et al., 2010).

Interestingly, our results suggest that while space- and object-based effects appear similarly automatic and mandatory (when all things being equal, i.e., no reward or other biasing signals), introducing a simple reward-based strategy reveals that the two mechanisms are in fact different. It was observed, over the course of 3 experiments (and 2 replications) that the magnitude of space-based effect did not change with varying degrees of reward, suggesting that space-based attentional allocation is in fact automatic and mandatory. On the other hand, our results clearly indicate that object-based attentional allocation is a default setting, emerging in the absence of an alternative strategy, and is not automatic or mandatory. With two objects and no other biases, object-based effects emerge, however in the presence of another strategy, reward in this case, reward replaces object-based effects (DO location is favored when DO is rewarded; or neither DO or SO is favored when reward is distributed randomly) (see also Yeari & Goldsmith, 2010) and Shomstein (2012) for discussions on automaticity of object-based effects).

These results also suggest that reward-based contributions to selection should not be viewed separately from attention. Several studies suggest that attentional and reward modulating effects are independent, resulting in separate salience maps based on reward or attention alone. For example, studies using decision-making paradigms showed that the saccade-related activity of the lateral intraparietal (LIP) area increased as a function of the difference in the amount or probability of reward, but did not differentiate behaviorally relevant and irrelevant distractors, and maintained that LIP area contains a salience map that only takes reward and decision information into account (Dorris & Glimcher, 2004; Platt & Glimcher, 1999). This line of research assumes that visual attention can be treated as conceptually separable from reward-related process, and hypothesizes that there are separate salience maps constructed either by reward or attention alone. On the other hand, several studies proposed that there exists a single integrated saliency map that incorporates both reward and attentional information. This line of research hypothesizes that the multiple feature maps, consisting of different units of attention (location, color, orientation, size, movement, etc.) are combined into a single salience map that encodes visual scenes in a featureless manner, predicting attentional allocation. Reward, we argue, is treated as one of units contributing to attentional guidance (Balan & Gottlieb, 2006; Della Libera & Chelazzi, 2006, 2009; Della Libera et al., 2011; Kiss, Driver, & Eimer, 2009; Small et al., 2005). The observation that automatic object-based attentional selection is discarded, rather than overridden or suppressed, in lieu of the reward-based schedule, provides strong evidence for a unified saliency map, with reward as one of the contributing signals guiding and restricting attentional selection.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

We thank M. Behrmann, J. Philbeck, and D.J. Kravitz for comments and suggestions. We thank Michelle Rattinger for assistance with data collection. This work was supported by National Science Foundation Grant BCS-1059523 to S.S.

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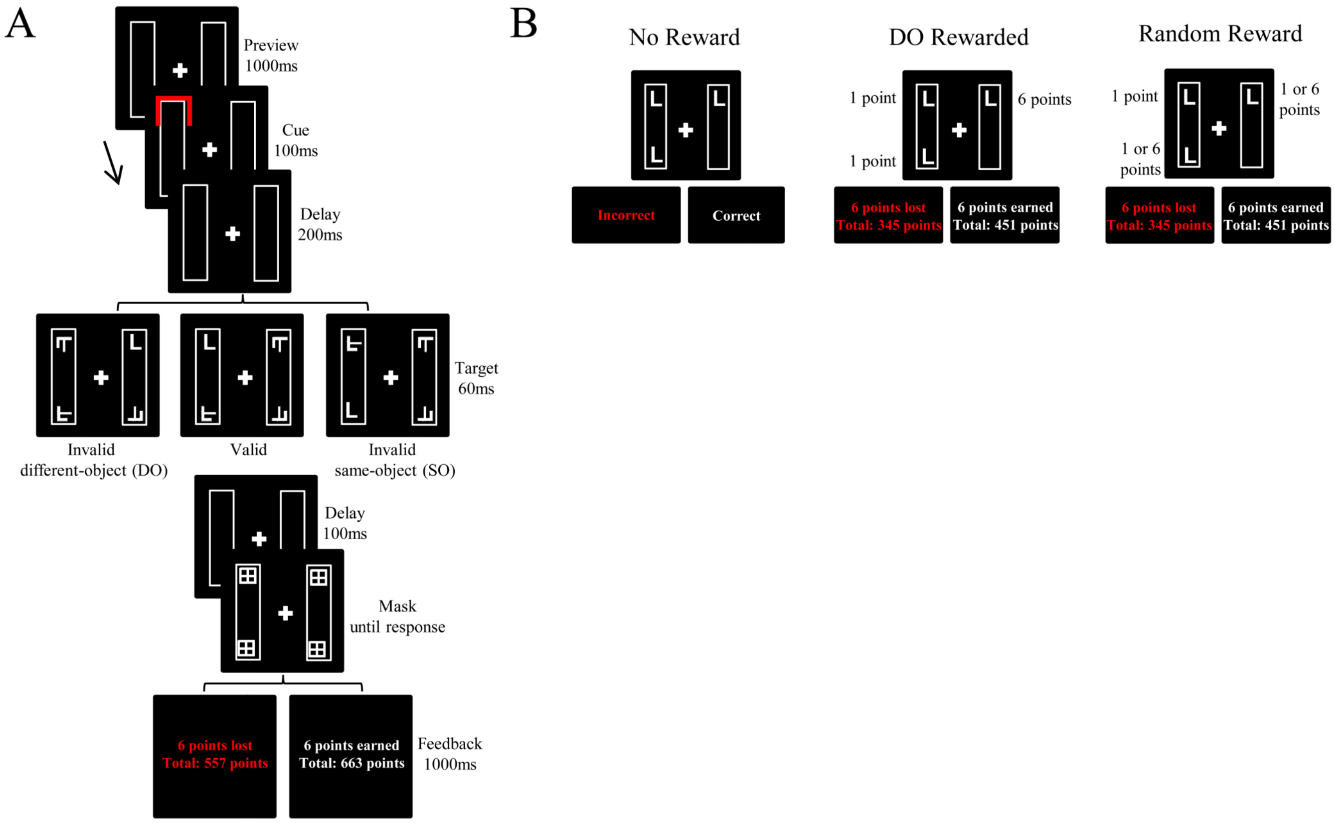

Fig. 1.

The experimental paradigm. (A) Each trial began with a display consisting of two rectangles presented either horizontally or vertically, along with a fixation cross. Each end of the rectangle was equidistant from the cue and from each other. After a 1000ms delay, a red cue appeared for 100ms indicating the likely location of the target. After a short delay of 200ms, target (either letter T or a letter L) along with three distractors (T/L hybrids) were presented for a brief duration of 60ms. Target display was followed by a short delay of 100ms and was then replaced by a mask display that remained on the screen until response. Participants' task was to indicate, with an appropriate button press, whether the target letter T or L was present during the target display.

Targets appeared in three locations relative to the cue – same location as the cue, valid target; in the opposite end of the cued rectangle, same-object (SO) target, and opposite end of a different rectangle, different-object (DO) target. Targets appeared in the cued location on 58% of the trials, while remaining 42% of the trials were equally split between the DO and SO target conditions. Each trial ended with a feedback display indicating the number of points earned or lost on any given trial along with the total number of points accrued since the beginning of the experiment. In addition, the running total of accrued points was presented in order to keep participants informed and motivated.

(B) A schematic representation of possible target locations and the corresponding structure of reward/punishments along with subsequent feedback for the three reward schedules. Left panel, Exp. 1a with no reward; Middle panel, Exp. 1b with DO rewarded more than SO or Valid; Right panel, Exp. 1c with random rewarded distributed over DO and SO. Each example is given for a preceding cue appearing in top left location (cues appeared in one of four possible locations).

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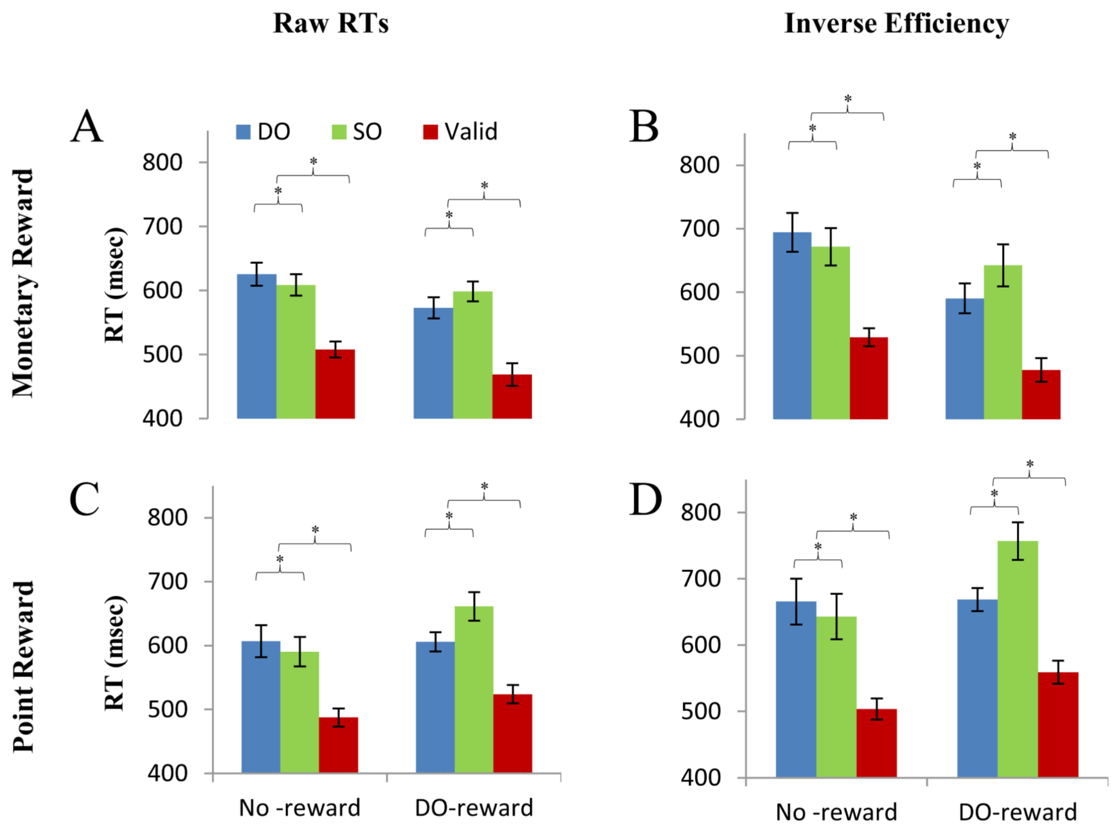

Fig. 2.

(A) Monetary reward RT data for No-reward and DO-reward schedules (Exp.1). Reward schedule was a within subject factor thereby allowing for a direct comparison of the magnitudes of space- and object-based effects under the influence of two different reward schedules. (B) Monetary reward inverse efficiency measure for Exp. 1 (C) Point reward RT data for No-reward and DO-reward schedules (Exp.2). Two different groups of subjects in no-reward and DO-reward conditions (D) Inverse efficiency for non-monetary reward. ANOVA on space-based effect (valid vs. invalid) revealed a main effect of validity [$F(1,23)=49.82$, $p<0.01$] with no significant interaction ($F<1$). While an ANOVA conducted with object (SO vs. DO) as within subject factor and reward (No-reward, DO-reward) as between subject factor revealed a significant interaction [$F(1,23)=11.15$, $p<.01$].

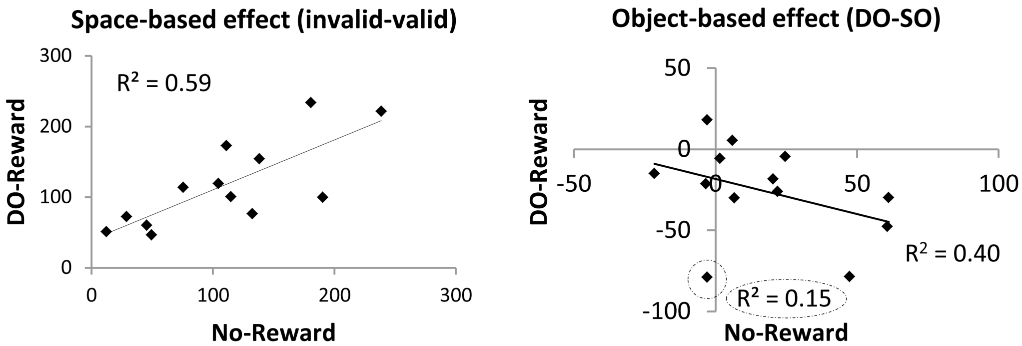

Fig. 3.

Within-subject correlations between No-reward and DO-Reward for the magnitude of the validity effect (invalid-valid RTs) and the magnitude of the object-based effect (DO-SO RTs). For the object-based correlation plot the outlier is marked by a dashed circle along with the R^2 with the outlier.

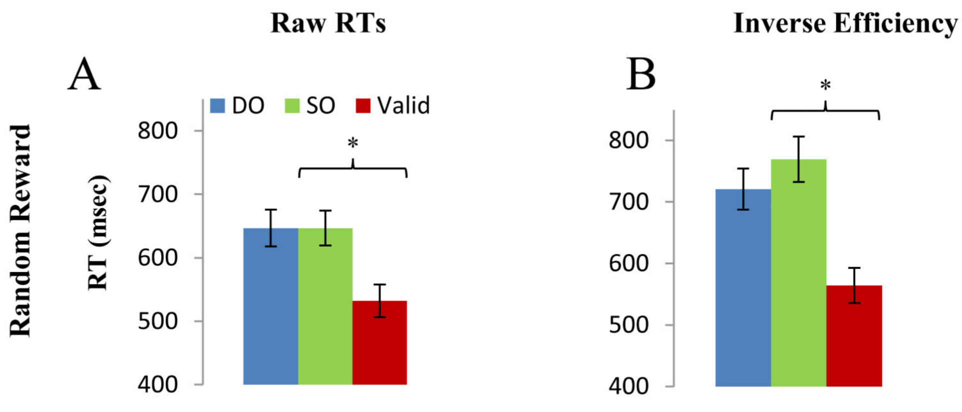

Fig. 4.

(A) Random point reward RT and (B) inverse efficiency data for Exp.2.