



Hassall, C. D., Silver, A., Turk, D. J., & Krigolson, O. E. (2016). We are more selfish than we think: The endowment effect and reward processing within the human medial-frontal cortex. *Quarterly Journal of Experimental Psychology*, 69(9), 1676-1686. DOI: 10.1080/17470218.2015.1091849

Peer reviewed version

Link to published version (if available):
[10.1080/17470218.2015.1091849](https://doi.org/10.1080/17470218.2015.1091849)

[Link to publication record in Explore Bristol Research](#)
PDF-document

This is an Accepted Manuscript of an article published by Taylor & Francis in *Quarterly Journal of Experimental Psychology* on 23 November 2015, available online:
<http://http://www.tandfonline.com/doi/abs/10.1080/17470218.2015.1091849>.

University of Bristol - Explore Bristol Research

General rights

This document is made available in accordance with publisher policies. Please cite only the published version using the reference above. Full terms of use are available:
<http://www.bristol.ac.uk/pure/about/ebr-terms.html>

We are more selfish than we think: The endowment effect and reward processing
within the human medial-frontal cortex

Cameron D. Hassall^{a*}, Amy Silver^b, David J. Turk^c, and Olave E. Krigolson^a

^aSchool of Exercise Science, Physical and Health Education, University of Victoria,
Victoria, British Columbia, Canada, V8W 2Y2

^bDepartment of Neuroscience, Carleton University,
Ottawa, Ontario, Canada, K1S 5B6

^cSchool of Experimental Psychology, Bristol University,
Bristol, United Kingdom, BS8 1TU

*Corresponding author.

Cameron Hassall

School of Exercise Science, Physical and Health Education

University of Victoria, P.O. Box 17000 STN CSC, Victoria, British Columbia,
Canada, V8W 2Y2

Tel: 1-250-721-8373

Fax: 1-250-721-6601

E-mail address: chassall@uvic.ca

OWNERSHIP AND VALUE

Abstract

Perceived ownership has been shown to impact a variety of cognitive processes: attention, memory, and – more recently – reward processing. In the present experiment we examined whether or not perceived ownership would interact with the construct of value – the relative worth of an object. Participants completed a simple gambling game in which they either gambled for themselves or for another while electroencephalographic data were recorded. In a key manipulation, gambles for oneself or for another were for either small or large rewards. We tested the hypothesis that value affects the neural response to self-gamble outcomes, but not other-gamble outcomes. Our experimental data revealed that while participants learned the correct response option for both self and other gambles, the reward positivity evoked by wins was impacted by value only when gambling for oneself. Importantly, our findings provide additional evidence for a self-ownership bias in cognitive processing, and further demonstrate the insensitivity of the medial-frontal reward system to gambles for another.

Introduction

In spite of our best efforts to be “modest”, it is becoming increasingly apparent that the neural processes that underlie our behaviour have an inherent and immodest bias towards “self”. Given that self-preservation, and thus a desire to maximize utility, is the prime determinant behind almost all of our behaviours (Mill, 1863), it is reasonable to assume that our neural systems are biased towards self. In previous research, human memory has provided an excellent construct to consider this hypothesis. For example, items relevant to one’s own survival are more likely to be remembered than items relevant to someone else’s survival (see Cunningham, Brady-Van den Bos, & Turk, 2013). Items that are important to self survival are naturally associated with greater value than those that are not, with some items being more valuable than others (Nairne, Thompson, & Pandeirada, 2007). Such differential perceptions of value are crucial to decision-making (Sutton & Barto, 1997) and provide the basis for phenomena such as the endowment effect (Kahneman, Knetsch, & Thaler, 1990; Thaler, 1980).

Perceived ownership has been seen to influence memory, attention, perceptual processing, and most recently reward evaluation. More specifically, perceived ownership has been shown to result in enhanced memory, a greater attentional capacity, and a positively biased attitude (Beggan, 1992; Belk, 1988, 1991; Brebner, Krigolson, Handy, Quadflieg, & Turk, 2011; Cunningham, Turk, MacDonald, & Macrae, 2008; Gray, Ambady, Lowenthal, & Deldin, 2004; Huang, Wang, & Shi, 2009; Turk et al., 2011a; Turk, van Bussel, Waiter, & Macrae, 2011; van den Bos, Cunningham, Conway, & Turk, 2010). For example, in one recent study ownership cues were shown to modulate attentional processing as evidenced by changes in the human electroencephalogram (Turk et al., 2011a). Turk and colleagues found that

OWNERSHIP AND VALUE

cues indicating self ownership evoked a larger neural response associated with the focusing of visuospatial attention – enhancement of the P100 event-related brain potential (ERP) component – than those that indicated ownership by another. Strictly behavioural results parallel these ERP findings in studies of human memory.

Specifically, Cunningham, Brady-van den Bos, and Turk (2011) found that items that were identified as belonging to “self” exhibited a memory advantage during recall over those that were identified as belonging to another, even when the sense of ownership was artificial and illusory in nature.

As noted above, the examination of the self-ownership bias has also been extended to reward processing within the human medial-frontal cortex. In general, the human medial-frontal cortex is thought to contain a generic reinforcement-learning system (Holroyd & Coles, 2002). This system is differentially sensitive to wins and losses, and is especially active when feedback is unexpected. To explore the interaction between medial-frontal feedback processing and ownership, Krigolson, Hassall, Balcom, and Turk (2013) had participants complete a series of gambles within which they either won “prizes” for themselves or for another while electroencephalographic (EEG) data were recorded. Interestingly, the authors found that while there was a difference in the human ERP when wins and losses for oneself were contrasted, this difference was not present when participants were gambling for another. Krigolson and colleagues (2013) posited that the lack of a difference between the ERP waveforms for wins and losses when gambling for another meant that reward evaluation processes within the human medial-frontal cortex were only sensitive to wins or losses when they were directly relevant to oneself. The work of Krigolson and colleagues (2013) is supported by research using functional magnetic resonance imaging that demonstrated that perceived self ownership resulted in increased

OWNERSHIP AND VALUE

activations in neural regions associated with reward processing (i.e. the medial-frontal cortex: Turk et al., 2011b).

Of primary interest in the present study is the relationship between perceived ownership and value. Value, or the relative worth of a person, place, or item, is a key component of reinforcement learning and provides the basis for human decision-making (Rescorla & Wagner, 1972; Sutton & Barto, 1997). Specifically, reinforcement learning theory posits that decision-making is predicated upon an assessment of the expected value (Huygens, 1657) of the available choice options, and then in most instances choosing the option with the highest value (although occasionally it makes sense to choose a lower-value option to update an existing estimate: exploration, c.f. Hassall, Holland, & Krigolson, 2013; Sutton & Barto, 1997). Therefore, in order to make effective decisions it is important to learn appropriate estimates of the value of the choices available to us. Systems that use reinforcement learning accomplish this via prediction errors – the difference between an expected and actual outcome – that are used to adjust the value of a previously selected choice option. However, value is not ubiquitous in the sense that not all values are “equal”. Indeed, prospect theory is grounded in the notion that we treat values differently depending on whether or not what is being value is framed as a potential for gain or loss (Kahneman & Tversky, 1979).

So what of the perceptual nature of value? The endowment effect (Carmon & Ariely, 2000; Kahneman et al., 1990; Kanngiesser, Santos, Hood, & Call, 2011; Lakshminaryanan, Chen, & Santos, 2008; Morewedge, Shu, Gilbert, & Wilson, 2009; Thaler, 1980) is a well-reported psychological phenomenon in which people ascribe more value to things that they own simply because they own them. In seminal work, Kahneman and colleagues (1990) gave half of the participants in their experiment

OWNERSHIP AND VALUE

coffee cups and the other half nothing. They then conducted a market experiment in which the participants with coffee mugs determined a selling price and the participants without mugs a buying price. Kahneman et al. (1990) observed a reliable difference between the selling and buying prices – a result that supported the original observations of Thaler (1980) who first proposed the endowment effect. Further, the work of Kahneman et al. (1990), by demonstrating support for the endowment effect, also highlighted that value is perceptual in nature. In other words, the work of Kahneman et al. (1990) highlighted that value is not absolute and is sensitive to biases such as the endowment effect. With this in mind, here we sought to examine whether perceived ownership would impact perceived value.

In the present experiment we sought to assess the extent to which perceived ownership interacted with value to bias reward processing within the human medial-frontal cortex (Holroyd & Coles, 2002; Miltner et al., 1997). Participants played a gambling game in which they gambled for themselves or for another while EEG data were recorded. In a key manipulation, the gambles for self or for another were either for small or large amounts of points. First, we predicted that the amplitude of the reward positivity¹ – a positive deflection in the human ERP 200 to 300 ms after feedback onset that is sensitive to reward – would be affected by reward value for self gambles (c.f. Sambrook & Goslin, 2015) but not for other gambles. Specifically, we predicted that the reward positivity should be enhanced for high-value self rewards relative to low-value self rewards, but that there should be little or no difference between high- and low-value other rewards. Second, in previous work in our laboratory there was a potential confound in that due to the nature of the task used (Krigolson et al., 2013) we were unable to demonstrate that when gambling for another participants were actually performing in a manner similar to when they were

OWNERSHIP AND VALUE

gambling for themselves, as the game played was entirely based on chance (equiprobable gambles). In the present experiment the outcomes of the gambling game we used were not random, and thus we also hoped to demonstrate equivalent behavioural performance between self and other gambles concomitant with differences in the amplitude of the reward positivity.

Method

Participants

We tested 15 undergraduate participants (4 male) with normal or corrected-to-normal vision, ages 18-29. Participants were compensated for their time with extra credit in an undergraduate psychology course. All participants provided informed consent approved by the Health Sciences Research Ethics Board at Dalhousie University, and the study was conducted in accordance with the ethical standards described in the original (1964) and subsequent revisions of the Declaration of Helsinki.

Apparatus and Procedure

Participants completed a gambling task in which they won points by selecting one of four coloured squares. Participants were told that selecting one of the coloured squares was better than selecting the other three because it would result in more rewards, in the long run. Participants were also told that they would be playing several games (blocks) – in some games, they would be gambling for themselves, and in some games they would be gambling for someone else. Furthermore, participants were told that some games contained more available points compared to others. Participants were told that the other person they would be gambling for was the next participant to be tested, just as the previous participant had won points for them (i.e.

OWNERSHIP AND VALUE

for the current participant). The current participant was then told the point total won for them by the previous participant.

Participants were seated 75 cm in front of a 22-inch LCD monitor (75 Hz, 2 ms response rate, 1680 by 1050 pixels, LG W2242TQ-GF, Seoul, South Korea). Visual stimuli were presented using the Psychophysics Toolbox Extension (Brainard, 1997; Pelli, 1997) for MATLAB (Version 8.2, Mathworks, Natick, USA). Participants were given both verbal and written instructions in which they were asked to minimize head and eye movements. In total, participants completed 76 blocks of 12 trials each. Each block began with a value cue indicating either upcoming high-value rewards (\$\$\$\$\$) or low-value rewards (\$) as well as who would receive the rewards (YOU or OTHER). The block cue was centered on the display and shown for 2000 ms. Each trial began with a central white fixation cross presented for 400 – 600 ms. Next, four coloured squares representing the four choices were displayed around the fixation cross in a two-by-two grid. The square colours for each block were chosen randomly at the beginning of the block, and the position of each square varied randomly from trial to trial. The coloured squares were displayed for 400 – 600 ms, at which time the fixation cross changed colour to grey to cue participants to make a selection by pressing a button on the USB gamepad. The squares were then removed from the screen, leaving the grey fixation cross for 400 – 600 ms. Finally, feedback in the form of a point total for that trial was displayed centrally for 1000 ms. The squares paid out rewards from normal reward distributions with different means (mean values from 1 – 100, selected randomly at the beginning of each block, standard deviation of 4). In high value blocks, rewards were scaled up by a factor of 10 so that they ranged from 1 – 1000. If participants responded too early (i.e. before the fixation cross changed colour) the words “TOO FAST” were displayed for 1000 ms, and no points

OWNERSHIP AND VALUE

were awarded. This was done in an attempt to separate the neural response to the choice stimuli from the neural activity and motor noise associated with the response. In order to ensure that the experiment was completed in a reasonable amount of time, if participants took longer than 2000 ms to respond, the words “TOO SLOW” were displayed for 1000 ms and no points were awarded. At the end of each block, participants were shown the total of number of points won for themselves (self block) or for the next participant (other block). Participants were given a self-paced rest period every 12 blocks. See Figure 1 for block and trial timing details.

Data collection

The experimental software recorded response time (elapsed time from fixation cross colour change to button press, in milliseconds) and square choice on each trial, including the choice ranking (rank 1 – 4, where 1 was the “best” choice and 4 was the “worst” choice). EEG data were recorded from 16 electrode locations (Fp1, F3, Fz, FCz, C3, P3, O1, O2, P4, Pz, Cz, C4, F4, Fp2, left mastoid, and right mastoid) in a fitted cap (standard 10-20 layout) using Brain Vision Recorder software (Version 1.20, Brain Products, GmbH, Munich, Germany) The vertical electrooculogram was recorded from an electrode placed above the right eye (electrode site Fp2). Electrode impedances were kept below 20 k Ω . The EEG data were sampled at 1000 Hz using active electrodes and amplified (V-Amp, Brainproducts, GmbH, Munich, Germany: 0 – 500 Hz bandwidth, 24-bit A/D conversion).

Data analysis

To determine whether performance differed based on ownership, value, or an interaction of the two, for each participant we computed the mean response time for each ownership (self, other) and value (low, high) combination (four means total). For each combination of conditions we also computed an accuracy score, defined as the

OWNERSHIP AND VALUE

proportion of trials in which the optimal square (rank 1) was chosen. One participant was removed from both the behavioural and EEG analysis because their accuracy scores indicated that they were guessing throughout the experiment (i.e. accuracy scores around .25 for all conditions). Both response time and accuracy were analyzed using a 2 (ownership: self, other) by 2 (value: low, high) repeated measures analysis of variance (ANOVA). In order to visually assess how participants' choices changed throughout a block, we computed the overall mean accuracy (across all 76 blocks) for each square (rank 1 – 4) for each trial. We then plotted the trial means for each square (Figure 2).

EEG data were downsampled from 1000 Hz to 250 Hz and rereferenced to the average of the mastoid channels. Following the application of a 0.1 – 40 Hz bandpass filter (60 Hz notch), we created epochs of EEG from 1000 ms before to 2000 ms after feedback onset (a -1000 to 2000 ms epoch). Independent component analysis (ICA) was then used to detect and correct ocular artifacts (Makeig & Onton, 2012), after which the existing epochs were reduced in size to -200 to 600 ms (Krigolson et al., 2013). Data were baseline corrected using a -200 to 0 ms window, and any epochs that contained artifacts were removed from subsequent analysis (Krigolson et al., 2013). Specifically, we removed any epoch that contained a sample-to-sample change in voltage of more than 10 $\mu\text{V}/\text{ms}$, or an epoch-wide change in voltage of more than 150 μV . On average, we removed $4 \pm 2\%$ of trials.

To analyze the reward positivity, we created average feedback-locked epochs for each combination of ownership (self, other) and value (high, low) for each participant. Since lower-ranked squares (i.e. rank 2 – 4) were rarely chosen, we only considered epochs defined around feedback following selection of the highest-ranked square (rank 1). Furthermore, we restricted our analysis to trials within the first half of

OWNERSHIP AND VALUE

each block (trials 1 – 6) since there is evidence to suggest that the reward positivity is reduced with learning (Krigolson et al., 2014) and our goal was to highlight an ownership- or value-based difference in the reward positivity, if any existed. After artifact rejection, the conditional waveform mean trial totals were: self, low: 110 ± 3 trials; self, high: 110 ± 3 trials; other, low: 109 ± 4 trials; other, high: 108 ± 5 trials. To select an electrode channel for analysis, we created two grand averages – one for all high-value wins, and one for all low-value wins. We then observed that the difference between these grand average waveforms was maximal at electrode site Cz from 290 – 340 ms post feedback, in line with previous work (Holroyd & Coles, 2002; Krigolson & Holroyd, 2006, 2007a, 2007b; Miltner et al., 1997). Thus, we defined the reward positivity for each condition as the mean voltage of the average waveform from 290 – 340 ms post feedback at electrode Cz. In summary, we computed four reward positivities – one for each condition (self-low, self-high, other-low, other-high). These reward positivities were then subjected to a 2 (ownership: self, other) by 2 (value: low, high) repeated-measures ANOVA. With all statistical tests presented here, an alpha level of .05 was assumed and error measures represent .95 within-subject confidence intervals (Masson & Loftus, 2003; Loftus & Masson, 1994).

Results

Behavioural results

Our analysis of response time revealed no effect of either ownership or value, nor was there an ownership by value interaction (self, low: 344 ± 50 ms; self, high 349 ± 54 ms; other, low: 350 ± 48 ms; other, high: 342 ± 56 ms; all p values $> .05$). Similarly, the proportion of times the optimal square was chosen did not depend on either ownership, value, or an interaction between ownership and value (self, low: 64

OWNERSHIP AND VALUE

$\pm 3\%$; self, high: $66 \pm 4\%$; other, low: $63 \pm 4\%$; other, high: $66 \pm 4\%$; all p values $> .05$). In other words, no behavioural differences were observed for response time or proportional choice of the optimal square.

In spite of the lack of differences related to perceived ownership or value, we did however observe robust effects indicating that participants learned to select the correct response for both self (24 +/- 5% to 89 +/- 6%) and other (24 +/- 9% to 88 +/- 8%) gambles. When we compared mean performance on the first trial with the last trial (averaged across all 76 blocks), we observed a significant effect of trial in a 2 (trial: first, last) by 2 (ownership: self, other) ANOVA, $F(1, 13) = 1465$, $p < .001$.

Electroencephalographic Results

An analysis of the reward positivity (see Figure 3) revealed that component amplitude was larger for high-value as opposed to low-value gambles, $F(1,13) = 11.44$, $p = .0049$. We also observed an ownership (self, other) by value (low, high) interaction, $F(1,13) = 5.89$, $p = .03$. Post hoc decomposition of the interaction revealed that the amplitude of the reward positivity was impacted by value for self gambles but not for other gambles. Specifically, the interaction revealed that for self gambles the reward positivity was smaller in amplitude for low-value gambles ($0.87 \pm 2.09 \mu\text{V}$) relative to the amplitude of the reward positivity for high-value gambles ($2.79 \pm 2.51 \mu\text{V}$), $t(13) = 3.61$, $p = .003$. However, the amplitude of the reward positivity did not differ for low-value ($1.83 \pm 2.11 \mu\text{V}$) and high-value gambles ($2.87 \pm 2.43 \mu\text{V}$) for other gambles, $t(13) = 1.16$, $p = .27$. Finally, the reward positivity for both self and other gambles had a timing (250 – 350 ms) and location (maximal at channel Cz) consistent with previous accounts of the reward positivity/FRN (see Footnote 1; also see Holroyd & Coles, 2002; Krigolson & Holroyd, 2006, 2007a, 2007b; Miltner et al., 1997).

Discussion

In the present study we examined the interaction between perceived ownership and reward value during performance of a simple gambling task. Gains from gamble outcomes contributed either to a participant's own total, or to another's. Our behavioural data demonstrated that when gambling for oneself or for another participants learned the value of the presented squares and subsequently were able to maximize their wins by selecting the highest-value gamble most of the time (see Figure 2). Our examination of the reward positivity revealed that the magnitude of this ERP component was sensitive to value when gambling for oneself but not when gambling for another (see Figure 3). Importantly, this result demonstrates that perceived ownership impacts reward processing. Specifically, when gambling for another the medial-frontal system underlying the reward positivity (Holroyd & Coles, 2002; Miltner et al., 1997) does not differentiate between low- and high-value gamble outcomes although it does make this differentiation when gambling for oneself.

Why would reward processing be insensitive to value when gambling for another? Our previous work (Krigolson et al., 2013) demonstrated that the medial-frontal reward system was not sensitive to gambles for another – a result in line with a large body of work demonstrating differences in cognitive processing due to differences in perceived ownership (Beggan, 1992; Belk, 1988, 1991; Cunningham et al., 2008; Gray et al., 2004; Huang et al., 2009; Turk et al., 2011a, 2011b; van den Bos et al., 2010). Recall that work on the endowment effect (e.g. Kahneman et al., 1990) found that value was relative and dependent on gain or loss (in that instance). Here, we propose that perceived ownership also biases value, and specifically in this instance does not differentiate value when gambling for another. In other words, we propose that perception of value is sensitive to perceived ownership – when gambling

OWNERSHIP AND VALUE

for another, differences in value are not processed by the medial-frontal system (Holroyd & Coles, 2002; Krigolson et al., 2013; Miltner et al., 1997) and are ignored, or are at least affected less relative to when one gambles for oneself.

Our observation that for self gambles the reward positivity was affected by value is in line with recent previous findings. It is worth noting, however, that for a long time the amplitude of the FRN (the precursor to the reward positivity) was thought to be binary in nature. Indeed, Holroyd and Krigolson (2007; amongst others: Haczak et al., 2006, 2007; Holroyd & Coles, 2002; Nieuwenhuis et al., 2004) proposed that the reward positivity/FRN was a binary evaluation of outcome within which a solitary better-than-expected or worse-than-expected outcome was compared against the other conditions as a whole. But, more recently this finding has been reversed in a key meta-analysis of the reward positivity/FRN (see Sambrook & Goslin, 2015) that is supported by a growing number of findings suggesting that the reward positivity/FRN is impacted by reward value. Indeed, in previous work we demonstrated that the reward positivity was affected by reward value in a simple gambling task (Krigolson et al., 2014) – a result in line with the aforementioned meta-analysis. Thus, the differentiation of value observed in the self-gamble condition in the present study is in line with the majority of previous experimental findings.

Our behavioural data are important here because in our previous work (Krigolson et al., 2013) a key confound was that we were not able to demonstrate that participants were “trying” on other-ownership trials. In other words, our finding that the amplitude of the reward positivity was reduced for other gambles (Krigolson et al., 2013) could have been attributed to a lack of effort when gambling for another. Here, we demonstrated that this was not the case. Specifically, we found that behavioural performance was almost identical for self and other gambles – in both

OWNERSHIP AND VALUE

conditions (independent of value) participants learned to choose the highest-value option, thus demonstrating effort on other gambles. This result is also important because it helps clarify the case we made in our previous work. In particular, the results of the present study suggest that although the outcomes of other gambles are still processed (and thus learning may occur), they are processed differently compared to self gambles, as evidenced by the ownership by value interaction effect on the reward positivity.

Conclusions

In sum, the results of present study demonstrate that the impact of perceived ownership on reward processing extends to perceived value. More specifically, our results demonstrate that while the medial-frontal reward system is sensitive to value when gambling for oneself, this sensitivity to value is not observed when gambling for another. Importantly, this result supports our previous work (Krigolson et al., 2013) and suggests that the medial-frontal system is biased towards self.

References

- Beggan, J. K. (1992). On the social nature of nonsocial perception: The mere ownership effect. *Journal of Personality and Social Psychology*, 62(2), 229–237. <http://doi.org/10.1037/0022-3514.62.2.229>
- Belk, R. W. (1988). Possessions and the Extended Self. *Journal of Consumer Research*, 15(2), 139–168.
- Belk, R. W. (1991). The ineluctable mysteries of possessions. *Journal of Social Behavior & Personality*, 6(6), 17–55.
- Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision*, 10(4), 433–436. <http://doi.org/10.1163/156856897X00357>
- Brebner, J. L., Krigolson, O., Handy, T. C., Quadflieg, S., & Turk, D. J. (2011). The importance of skin color and facial structure in perceiving and remembering others: An electrophysiological study. *Brain Research*, 1388, 123–133. <http://doi.org/10.1016/j.brainres.2011.02.090>
- Carmon, Z., & Ariely, D. (2000). Focusing on the Forgone: How Value Can Appear So Different to Buyers and Sellers. *Journal of Consumer Research*, 27(3), 360–370. <http://doi.org/10.1086/317590>
- Cunningham, S. J., Brady-Van den Bos, M., & Turk, D. J. (2011). Exploring the effects of ownership and choice on self-memory biases. *Memory*, 19(5), 449–461. <http://doi.org/10.1080/09658211.2011.584388>
- Cunningham, S.J., Brady-Van den Bos, M., Gill, L., & Turk, D.J. (2013). Survival of the selfish: Contrasting self-referential and survival-based encoding. *Consciousness & Cognition*, 22(1), 237-244.

OWNERSHIP AND VALUE

Cunningham, S. J., Turk, D. J., Macdonald, L. M., & Macrae, C. N. (2008). Yours or mine? Ownership and memory. *Consciousness and Cognition*, *17*(1), 312–318.

<http://doi.org/10.1016/j.concog.2007.04.003>

Gray, H. M., Ambady, N., Lowenthal, W. T., & Deldin, P. (2004). P300 as an index of attention to self-relevant stimuli. *Journal of Experimental Social Psychology*,

40(2), 216–224. [http://doi.org/10.1016/S0022-1031\(03\)00092-1](http://doi.org/10.1016/S0022-1031(03)00092-1)

Hajcak, G., Moser, J. S., Holroyd, C. B., & Simons, R. F. (2006). The feedback-related negativity reflects the binary evaluation of good versus bad outcomes.

Biological Psychology, *71*(2), 148–154.

<http://doi.org/10.1016/j.biopsycho.2005.04.001>

Hajcak, G., Moser, J. S., Holroyd, C. B., & Simons, R. F. (2007). It's worse than you thought: The feedback negativity and violations of reward prediction in

gambling tasks. *Psychophysiology*, *44*(6), 905–912.

<http://doi.org/10.1111/j.1469-8986.2007.00567.x>

Hassall, C. D., Holland, K., & Krigolson, O. E. (2013). What do I do now? An electroencephalographic investigation of the explore/exploit dilemma.

Neuroscience, *228*, 361–370. <http://doi.org/10.1016/j.neuroscience.2012.10.040>

Holroyd, C. B., & Coles, M. G. . (2002). The neural basis of human error processing: reinforcement learning, dopamine, and the error-related negativity.

Psychological Review, *109*(4), 679.

Holroyd, C. B., & Krigolson, O. E. (2007). Reward prediction error signals associated with a modified time estimation task. *Psychophysiology*, *44*(6), 913–917.

<http://doi.org/10.1111/j.1469-8986.2007.00561.x>

Holroyd, C. B., Pakzad-Vaezi, K. L., & Krigolson, O. E. (2008). The feedback correct-related positivity: Sensitivity of the event-related brain potential to

OWNERSHIP AND VALUE

unexpected positive feedback. *Psychophysiology*, 45(5), 688–697.

<http://doi.org/10.1111/j.1469-8986.2008.00668.x>

Huang, Y., Wang, L., & Shi, J. (2009). When do objects become more attractive? The individual and interactive effects of choice and ownership on object evaluation. *Personality and Social Psychology Bulletin*, 35(6), 713–722.

<http://doi.org/10.1177/0146167209333046>

Huygens, C. (1657). *De ratiociniis in ludo aleae (On reckoning in games of chance)*. London: T. Woodward.

Kahneman, D., Knetsch, J. L., & Thaler, R. H. (1990). Experimental tests of the endowment effect and the coase theorem. *Journal of Political Economy*, 98(6), 1325–1348.

Kahneman, D., & Tversky, A. (1979). Prospect theory: An analysis of decision under risk. *Econometrica*, 47(2), 263–291. <http://doi.org/10.2307/1914185>

Kanngiesser, P., Santos, L. R., Hood, B. M., & Call, J. (2011). The limits of endowment effects in great apes (*Pan paniscus*, *Pan troglodytes*, *Gorilla gorilla*, *Pongo pygmaeus*). *Journal of Comparative Psychology*, 125(4), 436–445.

<http://doi.org/10.1037/a0024516>

Krigolson, O. E., Hassall, C. D., & Handy, T. C. (2014). How we learn to make decisions: Rapid propagation of reinforcement learning prediction errors in humans. *Journal of Cognitive Neuroscience*, 26(3), 635–644.

http://doi.org/10.1162/jocn_a_00509

Krigolson, O. E., Hassall, C. D., Balcom, L., & Turk, D. (2013). Perceived ownership impacts reward evaluation within medial-frontal cortex. *Cognitive, Affective, & Behavioral Neuroscience*, 13(2), 262–269. <http://doi.org/10.3758/s13415-012-0144-4>

OWNERSHIP AND VALUE

Krigolson, O. E., & Holroyd, C. B. (2006). Evidence for hierarchical error processing in the human brain. *Neuroscience*, 137, 13–17.

doi:10.1016/j.neuroscience.2005.10.064

Krigolson, O. E., & Holroyd, C. B. (2007a). Predictive information and error processing: The role of medial-frontal cortex during motor control.

Psychophysiology, 44, 586–595. doi:10.1111/j.1469-8986.2007.00523.x

Krigolson, O. E., & Holroyd, C. B. (2007b). Hierarchical error processing: Different errors, different systems. *Brain Research*, 1155, 70–80.

doi:10.1016/j.brainres.2007.04.024

Lakshminaryanan, V., Chen, M. K., & Santos, L. R. (2008). Endowment effect in capuchin monkeys. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, 363(1511), 3837–3844.

<http://doi.org/10.1098/rstb.2008.0149>

Loftus, G. R., & Masson, M. E. J. (1994). Using confidence intervals in within-subject designs. *Psychonomic Bulletin & Review*, 1(4), 476–490.

Makeig, S., & Onton, J. (2012). *ERP Features and EEG Dynamics: An ICA*

Perspective. In S.J. Luck & E.S. Kappenman (Eds.), *The Oxford Handbook of ERP Components* (pp 51–86). New York: Oxford University Press.

Masson, M. E., & Loftus, G. R. (2003). Using confidence intervals for graphically based data interpretation. *Canadian Journal of Experimental Psychology*, 57(3), 203.

Miltner, W. H. R., Braun C. H., & Coles M. G. H. (1997) Event-related brain potentials following incorrect feedback in a time-estimation task: Evidence for a “generic” neural system for error detection. *Journal of Cognitive Neuroscience*, 9 (6), 788-798. <http://doi.org/10.1162/jocn.1997.9.6.788>

OWNERSHIP AND VALUE

- Morewedge, C. K., Shu, L. L., Gilbert, D. T., & Wilson, T. D. (2009). Bad riddance or good rubbish? Ownership and not loss aversion causes the endowment effect. *Journal of Experimental Social Psychology, 45*(4), 947–951.
<http://doi.org/10.1016/j.jesp.2009.05.014>
- Nairne, J. S., Thompson, S. R., & Pandeirada, J. N. S. (2007). Adaptive memory: Survival processing enhances retention. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*(2), 263–273. <http://doi.org/10.1037/0278-7393.33.2.263>
- Nieuwenhuis, S., Holroyd, C. B., Mol, N., & Coles, M. G. H. (2004). Reinforcement-related brain potentials from medial frontal cortex: origins and functional significance. *Neuroscience & Biobehavioral Reviews, 28*(4), 441–448.
- Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: transforming numbers into movies. *Spatial Vision, 10*(4), 437–442.
<http://doi.org/10.1163/156856897X00366>
- Proudfit, G. H. (2015). The reward positivity: From basic research on reward to a biomarker for depression. *Psychophysiology, 52*(4), 449–459.
<http://doi.org/10.1111/psyp.12370>
- Rescorla, R. A., & Wagner, A. R. (1972). *A Theory of Pavlovian Conditioning: Variations in the Effectiveness of Reinforcement and Nonreinforcement*. New York: Appleton Century Crofts.
- Sambrook, T. D., & Goslin, J. (2015). A neural reward prediction error revealed by a meta-analysis of ERPs using great grand averages. *Psychological Bulletin, 141*(1), 213–235. <http://doi.org/10.1037/bul0000006>
- Sutton, R. S., & Barto, A. G. (1998). *Reinforcement Learning: An Introduction*. Cambridge, MA: MIT Press.

OWNERSHIP AND VALUE

Thaler, R. (1980). Toward a positive theory of consumer choice. *Journal of Economic Behavior & Organization*, *1*(1), 39–60. [http://doi.org/10.1016/0167-](http://doi.org/10.1016/0167-2681(80)90051-7)

[2681\(80\)90051-7](http://doi.org/10.1016/0167-2681(80)90051-7)

Turk, D. J., van Bussel, K., Brebner, J. L., Toma, A. S., Krigolson, O., & Handy, T. C. (2011). When “it” becomes “mine”: Attentional biases triggered by object ownership. *Journal of Cognitive Neuroscience*, *23*(12), 3725–3733.

Turk, D. J., van Bussel, K., Waiter, G. D., & Macrae, C. N. (2011). Mine and Me: Exploring the Neural Basis of Object Ownership. *Journal of Cognitive Neuroscience*, *23*(11), 3657–3668. http://doi.org/10.1162/jocn_a_00042

van den Bos, M., Cunningham, S. J., Conway, M. A., & Turk, D. J. (2010). Mine to remember: The impact of ownership on recollective experience. *The Quarterly Journal of Experimental Psychology*, *63*(6), 1065–1071.

<http://doi.org/10.1080/17470211003770938>

OWNERSHIP AND VALUE

Footnotes

¹In the past few years there has been a shift from the term feedback related negativity (FRN) to reward positivity when discussing the feedback/outcome evoked ERP component first reported by Miltner, Braun, & Coles (1997). In short, the new, emerging view is that feedback-locked waveforms are modulated by rewards as opposed to losses – see Holroyd, Pakzad-Vaezi, & Krigolson (2008); see also Proudfit (2014) for a review.

OWNERSHIP AND VALUE

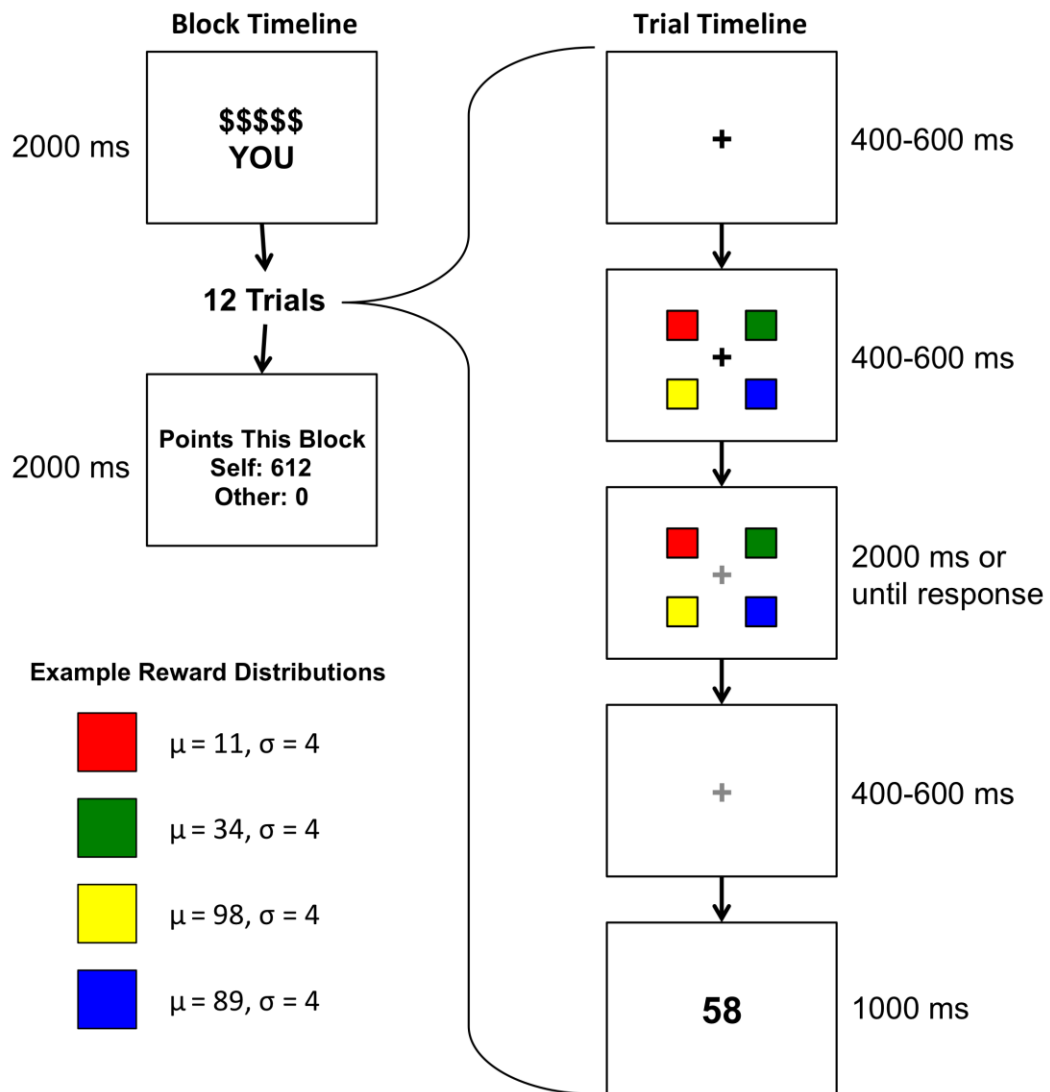


Figure 1. Experiment design, with timing details. Each block began with an ownership and value cue and concluded with a point total. Selecting coloured squares resulted in point totals drawn from reward distributions with four different mean payouts.

OWNERSHIP AND VALUE

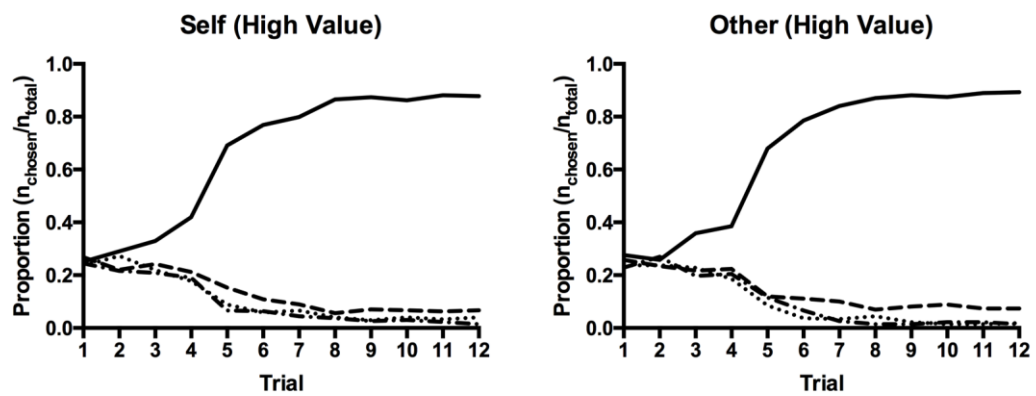
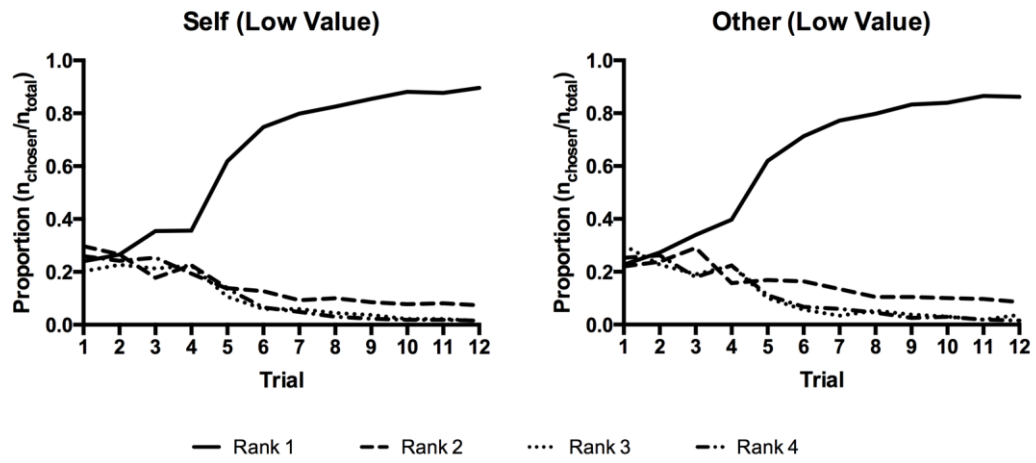


Figure 2. Mean proportion across each block type (low-valued self and other blocks, and high-valued self and other blocks) that each coloured square was chosen.

Coloured squares were ranked based on their mean payout (1 = highest, 4 = lowest).

OWNERSHIP AND VALUE

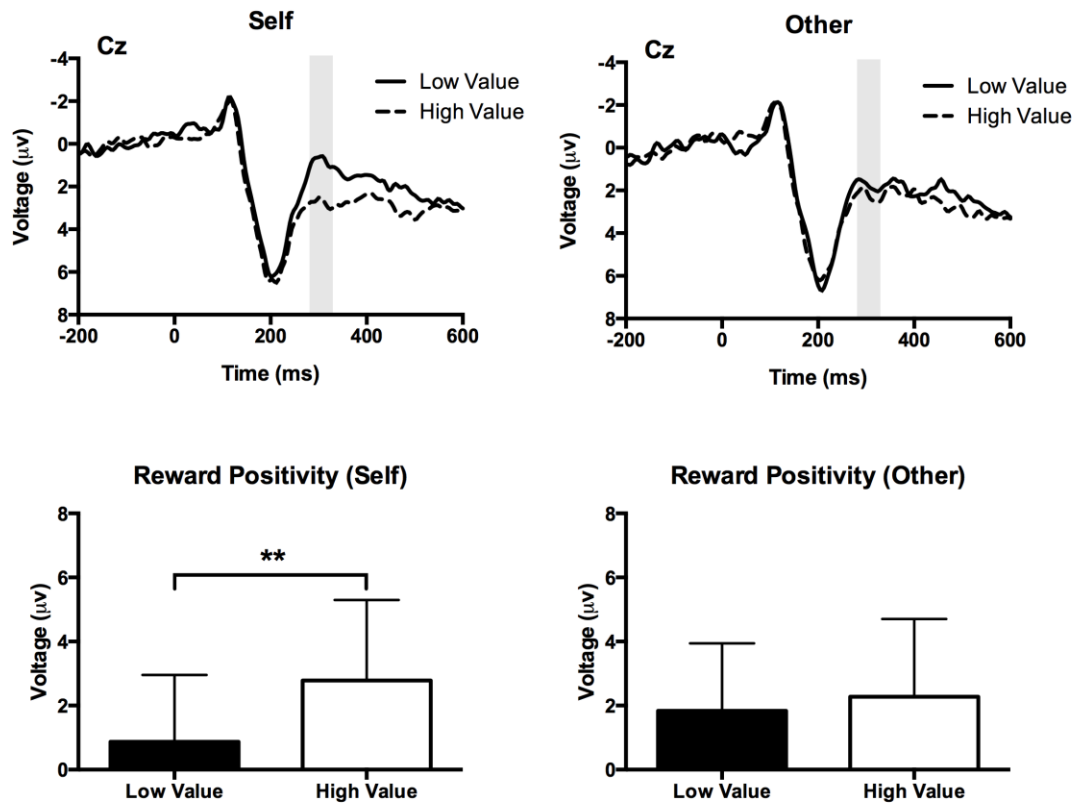


Figure 3. Average ERP waveforms in response to feedback (top). Shaded regions indicate the reward positivity analysis windows (290 - 340 ms after feedback), the results of which are shown on the bottom.