Learning and Motivation 54 (2016) 12–21

Contents lists available at ScienceDirect

Learning and Motivation

journal homepage: www.elsevier.com/locate/l&m

Asymmetrical effects of posttraining outcome revaluation on outcome-selective Pavlovian-to-instrumental transfer of control in human adults

Andreas B. Eder[a,*], David Dignath[b]

[a] University of Würzburg, Germany
[b] University of Freiburg i.Br., Germany

ARTICLE INFO

Keywords:
Outcome-selective
Pavlovian-to-instrumental transfer
Posttraining outcome revaluation
Habit
Goal-directed action
Loss aversion

ABSTRACT

In outcome-selective Pavlovian-to-instrumental transfer (PIT), stimuli that are predictive of particular outcomes prime instrumental responses that are associated with these outcomes. Previous experiments with humans obtained evidence that a strong posttraining devaluation of the associated outcome abolishes outcome-selective PIT. The present study extends this research to an upvaluation of outcomes. Adults learned in a stock market paradigm to relate particular stimuli and responses with particular monetary outcomes. Participants preferred responses associated with the same outcome as that predicted by the Pavlovian cue in a first transfer test. Before a second test, one currency was devalued, while the value of another currency was increased. In two experiments, outcome devaluation reduced specific PIT, while the upvaluation had no effect. Thus, a downward shift in the reward value was more effective than an equidistant upward shift for a change of PIT.

1. Introduction

The motivation to work for a reward is altered by the presence of external stimuli and their particular reward history. Numerous studies showed that stimuli predictive of a specific outcome augment responses working for that outcome—a phenomenon that was termed *outcome-selective Pavlovian-to-instrumental transfer of control* (specific PIT). In a typical demonstration, relations between stimuli and differential outcomes (Pavlovian learning: S1-O1,S2-O2) and relations between responses and outcomes (instrumental learning: R1-O1, R2-O2) are first established in separate training sessions. In a transfer test, both responses are then made available in extinction and the preference for a specific response is measured in the presence of each Pavlovian cue (i.e., S1: R1 vs. R2; S2: R1 vs. R2). A typical result is a preference for the response whose outcome was signaled by the Pavlovian cue (for reviews see Holmes, Marchand, & Coutureau, 2010; Urcuioli, 2005).

Researchers have studied the underlying knowledge structures of specific PIT effects with a reinforcer devaluation treatment, for instance, by prefeeding rats with one of the rewards to satiety before a PIT test. Several rat experiments (e.g., Colwill & Rescorla, 1990; Holland, 2004; Rescorla, 1994) and studies with human adults (e.g., Hogarth, 2012; Hogarth & Chase, 2011; Watson, Wiers, Hommel, & de Wit, 2014) concluded that PIT is unaffected by a devaluation of the shared outcome after the training. In those experiments, working for a devalued reinforcer was still augmented by the presentation of an associated Pavlovian cue (relative to an unrelated cue), although the devaluation treatment decreased both baseline responding and

* Corresponding author at: Department of Psychology, University of Würzburg, Röntgenring 10, 97070 Würzburg, Germany.
E-mail address: andreas.eder@uni-wuerzburg.de (A.B. Eder).

http://dx.doi.org/10.1016/j.lmot.2016.05.002
0023-9690/

consumption of the devalued reinforcer. Furthermore, lesion studies with animals and human brain imaging studies suggest that the neural circuits underlying PIT tendencies and outcome devaluation on instrumental performance are mediated by anatomically and neurochemically distinct processes (Bray, Rangel, Shimojo, Balleine, & O'Doherty, 2008; Corbit & Balleine, 2005; Talmi, Seymour, Dayan, & Dolan, 2008). In combination, these studies argue that the cue-instigated response tendency is insensitive to the current incentive value of the associated outcome and therefore habitual.

A few studies however obtained positive evidence for an influence of posttraining reinforcer devaluation on outcome-selective transfer effects. In one study, human adults learned in a stock market paradigm to associate particular symbols and responses with particular money currencies (Allman et al., 2010Allman, DeLeon, Cataldo, Holland, & Johnson, 2010). In a first PIT test, participants preferred responses associated with the same outcome as that predicted by the presented Pavlovian cue (i.e., they exhibited specific PIT). Immediately before a second PIT test, participants were informed verbally that one of the currencies is now worthless. This devaluation treatment reduced responding to those stimuli associated with the devalued currency, eliminating the PIT effect for that particular currency. Responding for the nondevalued currency was still elevated by presentations of symbols associated with that currency. Eder and Dignath (2016) recently extended this line of research to a devaluation of primary reinforcers. After devaluation of a lemonade with bad-tasting Tween20, PIT was eliminated for the devalued lemonade. The Pavlovian cue paired with the devalued lemonade ceased to excite responses producing that outcome, indicating that posttraining devaluation does affect the strength of PIT tendencies in certain conditions. For an explanation of their findings, Eder and Dignath (2016) suggested that the strength of reinforcer devaluation critically determines whether cue-instigated responding after training is sensitive to devaluation or not. With a strong aversive outcome after the devaluation treatment, the instrumental response procuring that outcome is inhibited relative to other available responses (Frankel, 1975). Activation of the aversive outcome by an associated Pavlovian cue intensifies the inhibition of the devalued response (Bouton & Bolles, 1980; Dayan & Seymour, 2009), which explains why the response rate was reduced most in the presence of those cues.

While most revaluation studies studied effects of posttraining devaluation on PIT tendencies, much less research is available on effects of a posttraining upvaluation treatment. In fact, we found in our literature search not a single published study that used an upvaluation procedure in a PIT paradigm. A pronounced increase in the reward value after training may have a capacity to strengthen PIT, revealing symmetrical revaluation effects on outcome-selective transfer effects. Alternatively, it is also possible that value decrements and increments have asymmetrical effects on instrumental performance in a PIT paradigm. Many studies showed that losses loom larger than gains for motivational choice even with equidistant value changes (Tversky & Kahneman, 1991). Moreover, behavioral inhibition of a devalued response and behavioral activation of an upvalued response may be mediated by distinct motivational systems that affect PIT tendencies differently (Corr, 2013; Eder, Elliot, & Harmon-Jones, 2013; Gray & McNaughton, 2000). Accordingly, it is unclear whether and how PIT changes when a reward is increased after the training.

2. Experiment 1

A stock market paradigm similar to that used by Allman et al. (2010) was used. Participants were informed that they were to play the role of an investment banker who trades with three different African currencies at a simulated stock market. It was made clear to participants that the money earned in fictitious African currencies will be exchanged in real money (Euros) with identical exchange rates (50 Dollars = 1 Euro). Participants first learned in a "Pavlovian phase" to associated different companies (represented by specific symbols) with particular African currencies. In a subsequent "instrumental phase" they were able to earn their own money in an African currency with repeated key presses. In a first transfer test phase, the company symbols (Pavlovian cues) were presented again and participants were free to respond at will. Outcome-selective transfer was measured by the extent to which a company symbol increased the rate of the instrumental response working for the same currency (i.e., the number of key presses). After retraining of the Pavlovian and instrumental contingencies, a revaluation treatment followed that informed the participant about important changes in the exchange rates of currencies: Participants were told that one African currency had lost its value (to worthless), while another currency had doubled its value. The value of a third currency was not changed. Subsequently, a second transfer test was administered. PIT tendencies working for the different currencies could hence be compared before and after the revaluation treatment.

2.1. Method

2.1.1. Participants

Thirty-three volunteers (25 women, 1 left-hander, mostly students) with an age between 18 and 54 years ($M = 25.6$) participated in exchange for payment. Three participants did not pass the Pavlovian contingency tests (see Section 2.1.4 below). Additional data of three participants were lost due to computer failures. The experiment was approved by an ethics committee and all participants provided written consent.

2.1.2. Design

The experiment had a 2 (transfer test: before revaluation vs. after revaluation) × 4 (Pavlovian relation: Currency 1 vs Currency 2 vs Currency 3 vs. no currency) × 3 (instrumental relation: Currency 1 vs Currency 2 vs Currency 3) repeated-measures design. Each participant worked through two transfer tests, one before and one after the revaluation treatment.

Table 1
Summary of experimental procedure.

Stage 1 Exchange Rates	Stage 2 Pavlovian training	Stage 3 Instrumental training	Stage 4 Transfer Test 1	Stage 5 Pavlovian retraining	Stage 6 Instrumental retraining	Stage 7 Revaluation	Stage 8 Transfer Test 2
50	S1→ N$	R1→	S1: R1, R2, R3	S1→ N$	R1→	50	S1: R1, R2, R3
N$ → €1	S2→ B$	N$	S2: R1, R2, R3	S2→ B$	N$	N$ → €0	S2: R1, R2, R3
50	S3→ T$	R2→	S3: R1, R2, R3	S3→ T$	R2→	50	S3: R1, R2, R3
B$ → €1	S4→ –	B$	S4: R1, R2, R3	S4→ –	B$	B$ → €1	S4: R1, R2, R3
50 T$ → €1		R3→ T$			R3→ T$	50 T$ → €2	

Note: Pavlovian stimuli (S) were four sets of visually distinct geometrical shapes; responses (R) were presses of the keys "1", "2" and "3" of the number pad; outcomes were symbols indicating earnings in different African dollar currencies (Botsuana dollar, B$; Niger dollar, N$; Tansania dollar, T$) or no earning (–). Exchange rates in Euros were displayed at the start of the experiment (Stage 1) and during the revaluation phase (Stage 7). The assignment of the outcomes to the geometric figure sets and to the responses was counterbalanced across participants (see Section 2.1.2 for details).

Each transfer test had 48 trials. In a trial, a Pavlovian cue was presented and three response keys were made available that worked for money in a particular currency. Key 1 always worked for the devalued currency, Key 2 for the maintained currency, and Key 3 for the upvalued currency. The following factors were counterbalanced across participants: (1) The Pavlovian assignment of the geometric figure sets (2 stars, 2 squares, 2 triangles, and 2 circles) to the outcomes using a Latin square; (2) the assignment of the currencies to the response keys (keys 1, 2, and 3). This counterbalancing procedure resulted in $4 \times 6 = 24$ combinations.

2.1.3. Apparatus and material

Participants were seated at a distance of about 60 cm from a 17″ VGA color monitor. Stimulus presentation and measurement of response latencies were controlled by a software timer with video synchronization (E-Prime 2.0 Professional; Psychology Software Tools, Inc.). Participants pressed the keys "1", "2" and "3" of the number pad of the computer keyboard with the fingers of their dominant hand.

Pavlovian cues were 8 visually distinct geometric figures (2 stars, 2 squares, 2 triangles, 2 circles). Outcomes in the training phases were currency symbols: B$ for Botsuana Dollar; N$ for Niger Dollar; T$ for Tansania Dollar; – for no trade outcome.

2.1.4. Procedure

Table 1 gives an overview of the experimental procedure that was adapted from Allman et al. (2010). Participants read a vignette stating that they are working as a stockbroker. Companies in different African countries trade with particular currencies (B$, N$, T$). Their first task is to figure out what company trades with what African currency (Pavlovian phase). In a second task they should earn as many African dollars as possible (instrumental training). Instructions also emphasized that their profit in African dollars would be exchanged later for real money.

Stage 1: Exchange rates and currency rating

Exchange rates of the African currencies were displayed on the screen, with 50 Dollars of an African currency being worth 1 Euro. Participants were then asked to evaluate each currency on a scale ranging from 0 (very bad) to 9 (very good).

Stage 2: Pavlovian training

Participants were informed that geometric figures will appear on the screen that represent companies. The logo of one company was represented by a circle, a second company by a triangle, a third company by a square, and a fourth logo by a star. Each company was located in a different country and trades with a different currency. Participants were instructed to figure out the relationship between the companies and the currencies.

Participants observed 10 pairings of a company symbol with a particular trade outcome, distributed across 10 blocks with presentations of each company-outcome pair in a block. The company symbol was presented for 1 s and after 50 ms a currency symbol (1 African dollar) was presented as an outcome for 2 s. Participants were asked to press the spacebar during the presentation a trade outcome (currency symbol) and to refrain from a key press when no trade was indicated. This task procedure was implemented to direct the participants' attention to the events on the screen (cf. Allman et al., 2010). An error message appeared for 5 s if the spacebar was not pressed within 2 s following the presentation of a currency outcome or pressed following the symbol indicating no trade. The intertrial interval (ITI) ranged between 0.5 s and 1.5 s.

After the training, participants were asked to indicate the contingencies between the companies and the currencies. In each trial, a company symbol (circle, star, etc.) was presented and the four outcomes (3 currencies and no outcome) appeared on the screen below the company symbol. Participants were to indicate the paired outcome by pressing designated keys (different from those used for instrumental responding in the subsequent phase). Each company symbol was presented once and in randomized order. A message informed the participant after each key press whether the assignment was correct or incorrect. If one or more assignments were incorrect, the Pavlovian training was repeated but this time with half the number of training trials (5×8 trials). After retraining, a second Pavlovian contingency test was performed. If the participant failed again to provide the correct answers, the experiment ended and he or she was asked to work on another, unrelated experiment for the remaining time.

Stage 3: Instrumental training

Instructions for this phase stated that the participant could now earn money with repeated key presses. An earning in an African currency was displayed after some keypresses and should be acknowledged with a press of the spacebar. Participants

were informed that they could switch between keys as often as they wished and that the computer may tell them to stop pressing one particular key. In this case, they should use the other keys to earn additional dollars.

A black fixation cross was presented on a white background while participants responded on three concurrent fixed ratio nine schedules (FR9). Response keys were the keys "1", "2"and "3" of the number pad with a green label attached to them. One response key worked for Botsuana Dollar (B$), one for Niger Dollar (N$), and the third for Tansania Dollar (T$). Participants were able to switch responding between keys, and if they did so before the FR9 criterion for a key had been reached they could complete the requirement for that key when they returned to it. Once a key had been pressed nine times, a dollar sign in an African currency (+1B$; +1N$; +1T$) was presented for 2 s, and participants were to press the spacebar to "bank" the dollar to their account. If the spacebar was not pressed, an error message appeared and the dollar was not added to the participant's account (see Allman et al., 2010; for the same procedure). The computer program prompted the participant to stop responding on a particular key after earnings of 20 dollars in a currency (i.e., 180 presses of a response key). Participants received information about their total earnings in African dollars only after instrumental training was completed.

After the instrumental training, participants were asked to indicate the instrumental contingency with a press of the response key that produced the African dollar presented on the screen. African currencies were presented in randomized order. If the assignment was incorrect, the instrumental training was repeated with half the number of outcome presentations (i.e., earning of 10 dollars of each currency). However, this never happened in this experiment.

Stages 4: Transfer Test 1

For the next phase, participants were instructed that they could now earn additional dollars with key presses but that this time their earnings would not be displayed during the task. Furthermore, they were informed that company symbols would appear regularly and that keypresses would be counted only during presentation of a symbol on the screen. Instructions also emphasized that the type of company symbol displayed on the screen did not influence the profit in African dollars earned with key presses.

Each of the eight company symbols that were presented during the Pavlovian phase were presented in randomized order in a block. A transfer test consisted of 6 blocks. A company symbol was displayed for 8 s; the next symbol appeared after a blank period of 2 s. Keypresses were recorded in every phase of a trial, but they counted for money only during the presentation of a company symbol. This task feature was implemented to minimize motor exhaustion and to direct the participants' attention to the stimuli presented on the screen (cf. Eder & Dignath, 2016). After nine presses of a response key, one dollar was added to the tally of that African currency. Currency symbols were however not presented as outcomes during this stage (corresponding with an extinction test). Participants were reminded to perform multiple keypresses. If no or only a single key press was registered during the presentation of a company symbol, the trial was repeated at the end of a block in randomized order. After the last block, a summary displayed their total dollar earnings in African currencies.

Stages 5–8: Pavlovian and instrumental retraining, outcome devaluation, and Transfer Test 2

Before devaluation, the Pavlovian training (Stage 4) and the instrumental training (Stage 5) were repeated with half the number of trials in each stage. This re-training served to reestablish the Pavlovian and instrumental contingencies following Transfer Test 1 (in extinction). Following retraining, and immediately prior to the revaluation treatment, the African dollars earned so far were exchanged for Euros, and the tally for each African currency was reset to zero. Then, two of the African currencies were revalued with the following instructions:

ALERT! – ALERT! – ALERT!

NEW EXCHANGE RATES!

The exchange rates of African dollars to Euros have changed due to an international financial crisis.

Exchange rates are now:

50 N$ = €0

50 T$ = €1

50 B$ = €2

The revaluation of African currencies was counterbalanced across participants. Participants worked through a second transfer test (Stage 7) that was identical with the first transfer test. Participants then rated again the African currencies as a manipulation check of the revaluation treatment (see Stage 1 for the rating procedure). Finally, participants were paid the earned money in Euros and were debriefed with respect to the nature of the study.

2.1.5. Data analysis

Keypresses during the presentation of the stimulus (8 s) and the subsequent ITI (2 s) were summed up for analyses of the response rate. This was done because participants often continued to press keys for a short period of time after the disappearance of a company symbol. Mean frequencies of key presses during Transfer Test 1 were analyzed with a two-way analysis of variance (ANOVA) with the factors *response* (B$ key, N$ key, T$ key) and *Pavlovian cue* (CS B$, CS N$, CS T$, CS–). For follow-up comparisons, conditions with Pavlovian cues associated with a matching outcome were compared with neutral cues and Pavlovian cues associated with a different outcome from the instrumental outcome (paired-samples *t*-tests). For

Table 2
Mean frequencies of instrumental responses for different outcomes in Experiment 1 as a function of Pavlovian stimulus and transfer test. Standard deviation is shown in parentheses.

		$RO1_{(dev)}$	$RO2_{(same)}$	$RO3_{(up)}$
Transfer Test 1 (before revaluation)	SO1	33.6 (12.3)	4.6 (8.6)	2.5 (4.9)
	SO2	4.9 (8.9)	32.6 (12.7)	3.8 (6.3)
	SO3	3.6 (6.4)	4.2 (5.9)	32.6 (11.1)
	$S_{neutral}$	8.5 (7.2)	11.2 (9.0)	10.2 (9.7)
Transfer Test 2 (after revaluation)	$SO1_{dev}$	13.4 (13.4)	8.0 (10.4)	14.7 (17.9)
	$SO2_{same}$	0.9 (3.7)	31.2 (14.1)	10.8 (15.4)
	$SO3_{up}$	0.9 (3.1)	4.8 (8.1)	39.4 (11.9)
	$S_{neutral}$	6.7 (9.0)	6.2 (8.8)	18.8 (19.3)

Note: SOx = stimulus paired with outcome x; ROx = response working for outcome x; $S_{neutral}$ = stimulus paired with no currency; dev = devalued outcome, same = maintained outcome, up = upvalued outcome. See text for further details.

the second transfer test, data were analogously analyzed with a two-way ANOVA with *response* (devalued, maintained, upvalued) and *Pavlovian cue* (CS devalued, CS maintained, CS upvalued, CS–) as variables.

Outcome-selective PIT was assessed with a comparison of the instrumental response rate in the presence of Pavlovian cues associated with the same outcome relative to the response rate in the baseline condition with presentations of neutral Pavlovian cues (CS-). Comparisons were also made with the conditions in which the Pavlovian cue was associated with another currency. Such comparison does however not only involve a Pavlovian priming of the response associated with the same outcome but also a Pavlovian priming of the response associated with the other outcome that produces response interference. Furthermore, outcomes (currencies) were grouped into different motivational classes after revaluation (Flaherty, 1996), which complicates comparisons of outcome-selective transfer effects before and after revaluation (Rescorla & Solomon, 1967). Accordingly, a comparison with a baseline condition involving neutral cues is better suited for the present research purpose.

Magnitudes of PIT effects in the two transfer tests were directly compared to examine whether they were changed by the revaluation treatment. For this comparison, we transformed the raw values into z scores to adjust for differences in the base rates of key presses after the revaluation treatment (Bush, Hess, & Wolford, 1993). A low base rate in responding will also decreases the absolute differences between the PIT conditions relative to a high overall response rate, which qualifies the interpretation of interaction effects with PIT conditions (Faust, Balota, Spieler, & Richard, 1999; Salthouse & Hedden, 2002). Transformation into a common metric hence reduces false positives in the detection of magnitude changes. It should be noted that analyses of untransformed values produced basically the same results (see the Supplement for a full report in the online version at http://dx.doi.org/10.1016/j.lmot.2016.05.002).

The significance criterion was set to $p < 0.05$ for all analyses. Greenhouse-Geisser corrected p values are reported with the original degrees of freedom (if applicable). Standardized effect sizes (Cohen's *d,* partial eta-square) are reported when appropriate.

2.2. Results

2.2.1. Outcome rating

Ratings of the African currencies were nearly identical before the revaluation treatment ($3.9 < Ms < 4.2$) but differed after the revaluation treatment, $F(2, 52) = 17.97$, $p < 0.001$, $\eta_p^2 = 0.409$. Ratings of the devalued currency were lowest ($M = 2.1$, $SD = 2.4$) and ratings of the upvalued currency were highest ($M = 6.2$, $SD = 2.8$), with intermediate ratings for the maintained currency ($M = 5.2$, $SD = 2.2$). This pattern confirms that the participants understood the change in the exchange rates and that the revaluation treatment was effective.

2.2.2. Transfer Test 1 (before revaluation)

In the ANOVA, the main effect of response was not significant ($F < 1$). The main effect of Pavlovian cue was significant, $F(3, 78) = 14.61$, $p < 0.001$, $\eta_p^2 = 0.360$, and, more important, the interaction between both factors reached significance, $F(6, 156) = 63.60$, $p < 0.001$, $\eta_p^2 = 0.710$. As can be seen in Table 2, Pavlovian cues selectively enhanced the frequency of the response that worked for the same currency relative to neutral cues, $t(26) = 9.70$, $p < 0.001$ ($d_z = 1.87$), and relative to Pavlovian cues associated with a different currency, $t(26) = 9.80$, $p < 0.001$ ($d_z = 1.89$). Furthermore, Pavlovian cues associated with a different outcome reduced the response rate relative to the baseline condition, showing a suppression of cue-incongruent responses, $t(26) = -5.10$, $p < 0.001$ ($d_z = 0.98$). This finding confirms that the response elevation was specific to the response associated with a matching outcome.

2.2.3. Transfer Test 2 (after revaluation)

In the ANOVA, the main effect of response was significant, $F(2, 52) = 17.09$, $p < 0.001$, $\eta_p^2 = 0.397$. Response rates were reduced for the devalued currency ($M = 5.5$) and increased for the upvalued currency ($M = 20.9$) relative to working for the maintained currency ($M = 12.5$). Thus, the revaluation treatment was effective. The main effect of Pavlovian cue was signif-

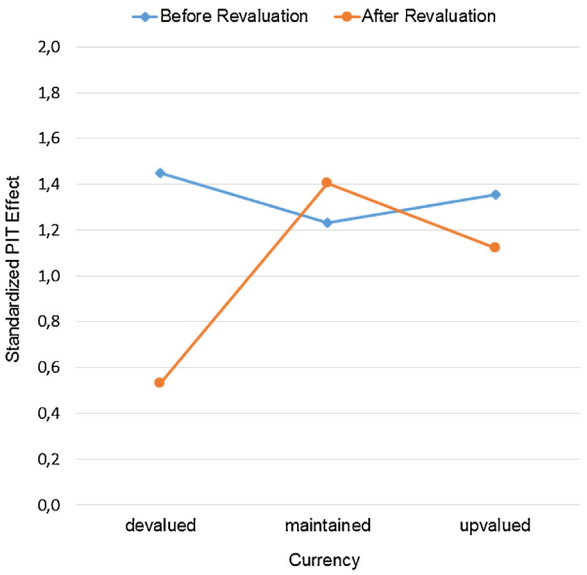

Fig. 1. Standardized PIT effects (z-scores) in Experiment 1.

icant, $F(3, 78) = 9.62$, $p < 0.001$, $\eta_p^2 = 0.270$, and the interaction between both factors was also significant, $F(6, 156) = 36.39$, $p < 0.001$, $\eta_p^2 = 0.583$, indexing an outcome-selective PIT effect (see Table 2 for the means).

Simple ANOVAs of the mean response rates with Pavlovian cue (devalued, maintained, upvalued, neutral) as factor revealed significant effects for the devalued currency, $F(3, 78) = 16.81$, $p < 0.001$, $\eta_p^2 = 0.393$, the maintained currency, $F(3, 78) = 44.39$, $p < 0.001$, $\eta_p^2 = 0.631$, and the upvalued currency, $F(3, 78) = 31.84$, $p < 0.001$, $\eta_p^2 = 0.551$. Follow-up comparisons showed that working for the devalued currency was still augmented by a matching Pavlovian cue relative to neutral cues, $t(26) = 2.98$, $p < 0.01$ ($d_z = 0.57$), and relative to cues associated with the maintained currency, $t(26) = 4.66$, $p < 0.01$ ($d_z = 0.90$), or an upvalued currency, $t(26) = 4.74$, $p < 0.01$ ($d_z = 0.91$). Analogous effects were observed in the response rates for the maintained currency (in comparison with neutral cues: $t[26] = 7.26$, $p < 0.001$, $d_z = 1.40$; devalued cues: $t[26] = 6.90$, $p < 0.001$, $d_z = 1.33$; upvalued cues: $t[26] = 7.76$, $p < 0.001$, $d_z = 1.49$) and for the upvalued currency (compared to neutral cues: $t[26] = 5.57$, $p < 0.001$, $d_z = 1.07$; devalued Pavlovian cues: $t[26] = 6.49$, $p < 0.001$, $d_z = 1.25$; maintained cues: $t[26] = 7.98$, $p < 0.001$, $d_z = 1.54$). Thus, outcome-selective PIT-effects were observed with all three currencies.

2.2.4. Comparison of PIT effects before and after revaluation

The magnitudes of PIT effects in the two transfer tests were compared after z-transformation of the raw values (see Section 2.1.5). PIT effects were computed by subtraction of responses to neutral cues from responding to cues with a matching outcome (with higher values indicating a stronger PIT effect). The standardized effect sizes were then entered into a repeated-measures ANOVA with transfer test (first, second) and response (devalued, maintained, upvalued) as factors. The main effect of transfer test was significant, $F(1, 26) = 8.51$, $p < 0.01$, $\eta_p^2 = 0.247$, indexing stronger PIT effects in the first transfer test. The main effect of response was significant, $F(2, 52) = 3.89$, $p < 0.05$, $\eta_p^2 = 0.130$, and the interaction between transfer test and response was also significant, $F(2, 52) = 4.11$, $p < 0.001$, $\eta_p^2 = 0.356$. Planned comparisons revealed that PIT tendencies for responses working for the maintained currency had similar strength before and after the revaluation treatment, $t(26) = -1.10$, $p = 0.28$ (see Fig. 1). PIT tendencies were however weakened by a devaluation of the associated currency, $t(26) = 4.98$, $p < 0.001$, $d_z = 0.96$. Upvaluation of a currency had no significant effect on the strength of PIT tendencies, $t(26) = 1.60$, $p = 0.12$.

2.3. Discussion

The results reveal asymmetrical effects of the revaluation treatment on outcome-selective PIT effects: While PIT was reduced after devaluation of the associated outcome, PIT effects were not changed by an increase in the outcome value. This result pattern is remarkable given that the value increment and decrement was equidistant and hence of comparable magnitude. Thus, these results suggest that PIT is sensitive to value decrements but not to value increases of the associated outcome.

Although the PIT effect was weakened by the outcome devaluation, working for the devalued outcome was still augmented by matching cues. This is different from the findings of Allman et al. (2010), who observed a complete elimination of the PIT effect after an identical devaluation treatment (now-worthless currency). A possible explanation of this difference between experiments is increased demand characteristics of our task procedure. While participants in Allman et al.'s study were allowed to press keys anytime during a transfer test, instructions for our experiment stated that keypresses were counted

only during the presentation of Pavlovian cues. Furthermore, participants in our experiment were explicitly instructed to perform multiple key presses (and an error message was given if not), which may have artificially inflated the response rates. This response requirement prevented participants from not responding during a stimulus period. It cannot be ruled that the explicit response demand cue-instigated response tendencies. This issue was addressed in a second experiment.

3. Experiment 2

Experiment 2 used a task procedure similar to Experiment 1 but this time without an explicit response demand. Participants were informed that a sign was going to indicate whether the stock market was open or closed. Keypresses for profits in particular African currencies were registered during the opening period. Importantly, a company symbol was displayed only for one half of the opening period. Trading (responding) was hence possible in the absence and presence of company symbols, which reduced explicit demand characteristics by the Pavlovian signals. Furthermore, there was no minimum number of key presses anymore. Response rates in the absence of company symbols were analyzed as baseline measures of instrumental performance.

3.1. Method

3.1.1. Participants

Fifty-three adults (39 women, mostly students) aged between 18 and 56 years ($M = 27.7$, $SD = 9.4$) participated for monetary compensation. Three participants did not pass the Pavlovian contingency tests and an additional three participants could not report the instrumental contingencies. Data of two participants were lost due to a computer crash, leaving 45 data sets for analysis.

3.1.2. Procedure

Apparatus, stimuli, and procedure were the same as in Experiment 1 with the following exceptions: The time period for responding in the transfer tests was now marked by the color of a dollar sign that was displayed at the center of the screen. Instructions stated that the stock market is open when the dollar sign is green and closed when red. Keypresses working for money were registered only during the opening period. The dollar sign was green for 8 s and red for 2 s (defining the ITI). During the opening period, a company symbol (geometric figure) appeared for 4 s superimposed on the dollar sign. In half of the trials, the company symbol appeared immediately at the onset of the opening period, and, in the other half of the trials, it appeared at the onset of the second half of the opening period. Participants were not required to press a response key during these periods (i.e., there was no minimum number of keypresses). The number of trials in a transfer test was doubled (96 trials). Data were analyzed in the same way with the change that the factor Pavlovian cue now had five levels and that responses during the ITI were not included in the analyses. The rate of responding was slightly lower when the Pavlovian cue was presented during the second half ($M = 7.1$) compared to the first half of the opening period ($M = 7.3$). The period of stimulus presentation did however not influence transfer effects in either test phase. Therefore, data were collapsed across this factor for subsequent analyses.

3.2. Results and discussion

3.2.1. Outcome rating

The currencies were given equal ratings before the revaluation treatment ($4.5 < Ms < 4.7$), but ratings differed after the revaluation treatment, $F(2, 88) = 49.56$, $p < 0.001$, $\eta_p^2 = 0.530$. In line with the revaluation treatment, the devalued currency was rated lowest ($M = 2.2$, $SD = 2.2$), the upvalued currency was rated highest ($M = 7.2$, $SD = 1.7$), and the maintained currency received intermediate ratings ($M = 5.5$, $SD = 2.4$).

3.2.2. Transfer test 1 (before revaluation)

Table 3 shows the mean response frequencies as a function of the stimulus period. In the ANOVA, the main effect of response was significant, $F(2, 88) = 6.76$, $p < 0.01$, $\eta_p^2 = 0.133$, the main effect of Pavlovian cue was significant, $F(4, 176) = 6.42$, $p < 0.05$, $\eta_p^2 = 0.127$, and the interaction between both factors was significant, $F(8, 352) = 27.75$, $p < 0.001$, $\eta_p^2 = 0.387$. Pavlovian cues selectively augmented responding for the same currency relative to the baseline period, $t(44) = 5.65$, $p < 0.001$ ($d_z = 0.84$), neutral cues, $t(44) = 5.33$, $p < 0.001$ ($d_z = 0.79$), and Pavlovian cues associated with a different currency, $t(44) = 5.63$, $p < 0.001$ ($d_z = 0.84$). Furthermore, Pavlovian cues associated with a different currency reduced the response rate relative to the baseline period, $t(44) = -5.47$, $p < 0.001$ ($d_z = 0.82$), and neutral cues, $t(44) = 3.97$, $p < 0.001$ ($d_z = 0.59$). Thus, responding was again suppressed in the presence of cues associated with a different currency, showing that the response elevation was specific for the response with a matching outcome.

3.2.3. Transfer test 2 (after revaluation)

In the ANOVA the main effect of response was significant, $F(2, 88) = 55.76$, $p < 0.001$, $\eta_p^2 = 0.559$, indexing a strong effect of the revaluation treatment. Response rates were reduced for the devalued currency ($M = 1.9$) and increased for the upvalued currency ($M = 13.9$) relative to the maintained currency ($M = 7.0$). The main effect of Pavlovian cue, $F(4, 176) = 4.76$, $p < 0.05$,

Table 3
Mean frequencies of instrumental responses for different outcomes in Experiment 2 as a function of Pavlovian stimulus and transfer test. Standard deviation is shown in parentheses.

		$RO1_{(dev)}$	$RO2_{(same)}$	$RO3_{(up)}$
Transfer Test 1 (before revaluation)	SO1	11.7 (6.6)	4.9 (4.7)	4.5 (4.5)
	SO2	4.8 (4.7)	11.8 (5.9)	4.3 (4.3)
	SO3	4.5 (4.2)	5.4 (4.8)	10.8 (6.1)
	$S_{neutral}$	6.4 (4.4)	6.9 (4.7)	5.2 (3.9)
	Blank	7.0 (3.8)	7.6 (3.5)	6.3 (3.3)
Transfer Test 2 (after revaluation)	$SO1_{dev}$	3.3 (5.9)	6.0 (6.4)	12.9 (8.4)
	$SO2_{same}$	1.5 (3.4)	10.5 (8.2)	12.0 (8.6)
	$SO3_{up}$	1.4 (3.4)	5.5 (6.1)	16.9 (6.3)
	$S_{neutral}$	1.6 (3.5)	6.1 (6.2)	13.2 (8.4)
	Blank	1.7 (3.5)	7.0 (5.7)	14.6 (6.6)

Note: SOx = stimulus paired with outcome x; ROx = response working for outcome x; $S_{neutral}$ = stimulus paired with no outcome; blank = no stimulus; dev = devalued outcome, same = maintained outcome, up = upvalued outcome. See text for further details.

$\eta_p^2 = 0.098$, and the interaction effect were also significant, $F(8, 352) = 10.53$, $p < 0.001$, $\eta_p^2 = 0.193$, indexing cue-instigated response tendencies (see Table 3 for the means).

One-way ANOVAs of the response rates with Pavlovian cue (devalued, maintained, upvalued, neutral, no cue/baseline) as within-factor showed significant effects for the devalued currency, $F(4, 176) = 5.16$, $p < 0.05$, $\eta_p^2 = 0.105$, the maintained currency, $F(4, 176) = 11.41$, $p < 0.001$, $\eta_p^2 = 0.206$, and the upvalued currency, $F(4, 176) = 9.55$, $p < 0.001$, $\eta_p^2 = 0.178$. Follow-up comparisons showed that responding for the devalued currency was augmented by a matching Pavlovian cue relative to the baseline period, $t(44) = 2.32$, $p < 0.05$ ($d_z = 0.35$), neutral cues, $t(44) = 2.25$, $p < 0.05$ ($d_z = 0.34$), and relative to Pavlovian cues associated with the maintained currency, $t(44) = 2.31$, $p < 0.05$ ($d_z = 0.34$), or the upvalued currency, $t(44) = 2.40$, $p < 0.05$ ($d_z = 0.36$). Analogous effects were observed in the response rates for the maintained currency (in comparison with baseline period: $t[44] = 3.68$, $p < 0.01$, $d_z = 0.55$; neutral cues: $t[44] = 3.47$, $p < 0.01$, $d_z = 0.52$; devalued cues: $t[44] = 3.40$, $p < 0.01$, $d_z = 0.51$; upvalued cues: $t[44] = 3.78$, $p < 0.001$, $d_z = 0.56$) and for the upvalued currency (compared to baseline period: $t[44] = 3.14$, $p < 0.01$, $d_z = 0.47$; neutral cues: $t[44] = 3.19$, $p < 0.01$, $d_z = 0.48$; devalued Pavlovian cues: $t[44] = 3.32$, $p < 0.01$, $d_z = 0.49$; maintained cues: $t[44] = 3.74$, $p < 0.01$, $d_z = 0.56$). Again, outcome-selective PIT-effects were observed with all three currencies.

3.2.4. Comparison of PIT effects before and after revaluation

After z-transformation, PIT effects were again computed by subtraction of responses to neutral cues from responding to cues with a matching outcome (with higher values indicating a stronger PIT effect). The standardized effect sizes were then entered into a repeated-measures ANOVA with transfer test (first, second) and response (devalued, maintained, upvalued) as factors. The main effect of transfer test was significant, $F(1, 44) = 7.92$, $p < 0.01$, $\eta_p^2 = 0.152$, with stronger PIT effects in the first transfer test. The main effect of response was not significant, $F(2, 88) = 1.86$, $p = 0.16$. The interaction between both factors approached significance, $F(2, 88) = 2.56$, $p = 0.083$, $\eta_p^2 = 0.055$. As expected, the revaluation treatment did not affect PIT tendencies for the maintained currency, $t(44) = 0.73$, $p = 0.47$ (see Fig. 2). In contrast, PIT tendencies were substantially weakened by a devaluation of the associated currency, $t(44) = 3.55$, $p < 0.01$, $d_z = 0.53$. Notably, upvaluation of a currency had a tendency to decrease the strength of PIT tendencies as well, $t(44) = 1.99$, $p = 0.053$, although this effect did not meet our significance criterion ($p < 0.05$).

4. General discussion

Two experiments examined effects of a posttraining revaluation treatment on PIT. The results were clear-cut. While a decrease of the reward value significantly reduced PIT, it was not affected by a reward increase. It should be noted that the value changes were equidistant (decrease/increase by 1 Euro) and thus of comparable magnitude. Furthermore, upvaluation of a currency increased and downvaluation decreased the instrumental response rates, respectively. Thus, there was clear evidence that the revaluation treatments were effective. Nevertheless, only devaluation changed PIT, suggesting that posttraining decreases and increases in the reward value have asymmetrical effects on cue-instigated response tendencies.

The reduction of outcome-selective PIT after devaluation was expected based on a previous study that used a similar revaluation treatment (Allman et al., 2010). However, while PIT was reduced after outcome devaluation in the present experiment, Allman et al. found it completely eliminated. Differences in the effectiveness of the devaluation treatment may explain the different study results. Specifically, participants in Allman et al.'s study lost all earnings in a currency after devaluation of that currency (i.e., even the money earned before the devaluation treatment), whereas in our study the profit earned in African dollars was paid out to the participant before devaluation for ethical reasons. With the devaluation of all earning in that currency, the devaluation treatment was arguably stronger in the study of Allman et al., which may explain why PIT was completely abolished in this study. It should be noted, however, that even a reduction of PIT effects after devaluation is at odds with strong claims that outcome-selective transfer does not depend on the current value of the associated outcome (Balleine & Ostlund, 2007; Hogarth, 2012; Rescorla, 1994).

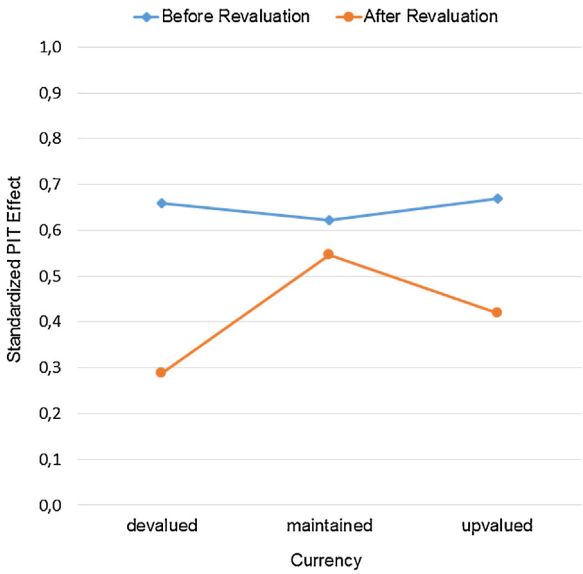

Fig. 2. Standardized PIT effects (z-scores) in Experiment 2.

Interestingly, specific PIT effects were numerically decreased even after an upvaluation of the associated currency. It is possible that the capacity for a response elevation was exhausted by the high baseline response rate after the revaluation treatment, leaving little room for additional response excitation (cf. Colagiuri & Lovibond, 2015). As a consequence, PIT effects may have decreased due to a shrinking difference in the elevated response rate in the baseline condition. It should be noted, however, that the reduction of the PIT effect after upvaluation was not significant in both experiments and must therefore be interpreted with caution. Furthermore, instrumental response rates in the test trials varied substantially after the upvaluation treatment in Study 1 (grand mean of the *SD*s = 17.2) and Study 2 (grand mean of the *SD*s = 6.1), which is at odds with the theoretical argument that an increment in the response rate (induced by a matching Pavlovian cue) was not possible beyond the observed level. Notwithstanding this discussion, one can conclude from our results that PIT was maximal at moderate motivation levels relative to more extreme motivation levels.

What processes can explain asymmetrical effects of outcome revaluation treatments on PIT? One possibility is that a value decrease loomed larger than a value increase in the present research (Tversky & Kahneman, 1991). When working for multiple rewards in a PIT task, a transition to a non-reward is likely more salient than an equidistant increase to a larger reward (Flaherty, 1996). As a consequence, behavioral inhibition instigated by conditioned stimuli predictive of a non-reward is more supported than behavioral activation instigated by conditioned stimuli predictive of an increased reward (Dayan & Seymour, 2009; Gray & McNaughton, 2000). It should be noted that this explanation predicts augmented PIT for conditions with a salient value increase. This prediction could be tested with experiments that study effects of a posttraining reward increase on PIT separately from effects of a posttraining devaluation treatment.

Furthermore, the abrupt devaluation of a previously earned reward may have elicited a qualitatively different reaction than the increase in the reward magnitude. There is much evidence that the unexpected omission or reduction of a reward can elicit strong emotional reactions that can be collectively described as “frustration” (Papini & Dudley, 1997). Although our participants were verbally informed about the changes in the reward magnitudes, and hence aware of a reward loss contingent upon their responding, a non-reward was presented in the context of Pavlovian signals of an intact reinforcer, which may have induced surprise to some degree. Frustration may hence have contributed to the asymmetrical effect of the revaluation procedures despite the verbal instruction of a reward loss.

Another possibility is that participants adopted an explicit response strategy after the revaluation treatment that selectively disrupted PIT for the devalued outcome. Evidence is accumulating that PIT effects in human studies depend on propositional instrumental expectancies encoding the relations between conditioned stimuli, instrumental responses, and associated outcomes (Cartoni, Moretta, Puglisi-Allegra, Cabib, & Baldassarre, 2015; Hogarth et al., 2014). For instance, one study found cue-evoked reward seeking was reversed after verbal instruction that the cue no longer indicated which response would be rewarded (Seabrooke, Hogarth, & Mitchell, 2015). It is possible that our verbal instruction of a currency devaluation analogously impaired hierarchical cue-outcome beliefs. For this explanation, it is unclear, however, why the verbal information about an increase in the reward value had no comparable disruptive effect on explicit instrumental beliefs. Clearly, more research is needed on this issue.

5. Conclusions

To summarize, the present study reveals asymmetrical effects of a posttraining revaluation treatment on cue-instigated responding in an outcome-selective PIT task: While a decrease of the reward value after training significantly reduced outcome-selective PIT, an equidistant increase of the reward had no comparable effect. This finding suggests that cue-instigated responding is changed more effectively by a devaluation of the associated reward, which may be useful knowledge for behavior treatments.

Acknowledgement

This research was supported by grant ED 201/2-2 of the German Research Foundation (DFG) to Andreas Eder.

References

Allman, M. J., DeLeon, I. G., Cataldo, M. F., Holland, P. C., & Johnson, A. W. (2010). Learning processes affecting human decision making: an assessment of reinforcer-selective Pavlovian-to-instrumental transfer following reinforcer devaluation. *Journal of Experimental Psychology: Animal Behavior Processes*, *36*, 402–408.

Balleine, B. W., Ostlund, S. B., & O'Doherty, J. P. (2007). Still at the choice-point: action selection and initiation in instrumental conditioning. In B. W. Balleine, K. Doya, & M. Sakagami (Eds.), *Reward and decision making in corticobasal ganglia networks* (pp. 147–171). Malden: Blackwell Publishing.

Bouton, M. E., & Bolles, R. C. (1980). Conditioned fear assessed by freezing and by the suppression of three different baselines. *Animal Learning & Behavior*, *8*, 429–434. http://dx.doi.org/10.3758/BF03199629

Bray, S., Rangel, A., Shimojo, S., Balleine, B., & O'Doherty, J. P. (2008). The neural mechanisms underlying the influence of Pavlovian cues on human decision making. *The Journal of Neuroscience*, *28*, 5861–5866.

Bush, L. K., Hess, U., & Wolford, G. (1993). Transformations for within-subject designs: a Monte Carlo investigation. *Psychological Bulletin*, *113*, 566–579. http://dx.doi.org/10.1037/0033-2909.113.3.566

Cartoni, E., Moretta, T., Puglisi-Allegra, S., Cabib, S., & Baldassarre, G. (2015). The relationship between specific Pavlovian instrumental transfer and instrumental reward probability. *Frontiers in Psychology*, *6* http://dx.doi.org/10.3389/fpsyg.2015.01697

Colagiuri, B., & Lovibond, P. F. (2015). How food cues can enhance and inhibit motivation to obtain and consume food. *Appetite*, *84*, 79–87. http://dx.doi.org/10.1016/j.appet.2014.09.023

Colwill, R. M., & Rescorla, R. A. (1990). Effect of reinforcer devaluation on discriminative control of instrumental behavior. *Journal of Experimental Psychology: Animal Behavior Processes*, *16*, 40–47.

Corbit, L. H., & Balleine, B. W. (2005). Double dissociation of basolateral and central amygdala lesions on the general and outcome-specific forms of Pavlovian-instrumental transfer. *The Journal of Neuroscience*, *25*, 962–970.

Corr, P. J. (2013). Approach and avoidance behaviour: multiple systems and their interactions. *Emotion Review*, *5*(3), 285–290. http://dx.doi.org/10.1177/1754073913477507

Dayan, P., & Seymour, B. (2009). Values and actions in aversion. In P. W. Glimcher, C. F. Camerer, E. Fehr, & R. A. Poldrack (Eds.), *Neuroeconomics* (pp. 175–191). London: Academic Press.

Eder, A. B., & Dignath, D. (2016). Cue-elicited food seeking is eliminated with aversive outcomes following outcome devaluation. *The Quarterly Journal of Experimental Psychology*, *69*, 574–588. http://dx.doi.org/10.1080/17470218.2015.1062527

Eder, A. B., Elliot, A. J., & Harmon-Jones, E. (2013). Approach and avoidance motivation: issues and advances. *Emotion Review*, *5*, 227–229.

Faust, M. E., Balota, D. A., Spieler, D. H., & Richard, F. (1999). Individual differences in information-processing rate and amount: implications for group differences in response latency. *Psychological Bulletin*, *125*, 777–799. http://dx.doi.org/10.1037/0033-2909.125.6.777

Flaherty, C. F. (1996). *Incentive relativity*. New York: Cambridge University Press.

Frankel, F. D. (1975). The role of the response-punishment contingency in the suppression of a positively-reinforced operant. *Learning and Motivation*, *6*, 385–403. http://dx.doi.org/10.1016/0023-9690(75)90017-X

Gray, J. A., & McNaughton, N. (2000). *The neuropsychology of anxiety: an enquiry into the function of the septo-hippocampal system*. Oxford, England: Oxford University Press.

Hogarth, L., & Chase, H. W. (2011). Parallel goal-directed and habitual control of human drug-seeking: implications for dependence vulnerability. *Journal of Experimental Psychology: Animal Behavior Processes*, *37*, 261–276.

Hogarth, L., Retzler, C., Munafò, M. R., Tran, D. M. D., Troisi, J. R., Rose, A. K., et al. (2014). Extinction of cue-evoked drug-seeking relies on degrading hierarchical instrumental expectancies. *Behaviour Research and Therapy*, *59*, 61–70. http://dx.doi.org/10.1016/j.brat.2014.06.001

Hogarth, L. (2012). Goal-directed and transfer-cue-elicited drug-seeking are dissociated by pharmacotherapy: evidence for independent additive controllers. *Journal of Experimental Psychology: Animal Behavior Processes*, *38*, 266–278.

Holland, P. C. (2004). Relations between Pavlovian-instrumental transfer and reinforcer devaluation. *Journal of Experimental Psychology: Animal Behavior Processes*, *30*, 104–117.

Holmes, N. M., Marchand, A. R., & Coutureau, E. (2010). Pavlovian to instrumental transfer: a neurobehavioural perspective. *Neuroscience & Biobehavioral Reviews*, *34*, 1277–1295. http://dx.doi.org/10.1016/j.neubiorev.2010.03.007

Papini, M. R., & Dudley, R. T. (1997). Consequences of surprising reward omissions. *Review of General Psychology*, *1*, 175–197.

Rescorla, R. A., & Solomon, R. L. (1967). Two-process learning theory: relationships between Pavlovian conditioning and instrumental learning. *Psychological Review*, *74*, 151–182.

Rescorla, R. A. (1994). Transfer of instrumental control mediated by a devalued outcome. *Animal Learning & Behavior*, *22*, 27–33.

Salthouse, T. A., & Hedden, T. (2002). Interpreting reaction time measures in between-group comparisons. *Journal of Clinical and Experimental Neuropsychology*, *24*, 858–872. http://dx.doi.org/10.1076/jcen.24.7.858.8392

Seabrooke, T., Hogarth, L., & Mitchell, C. (2015). The propositional basis of cue-controlled reward seeking. *The Quarterly Journal of Experimental Psychology*, http://dx.doi.org/10.1080/17470218.2015.1115885 [online advance publication]

Talmi, D., Seymour, B., Dayan, P., & Dolan, R. J. (2008). Human Pavlovian-instrumental transfer. *The Journal of Neuroscience*, *28*, 360–368.

Tversky, A., & Kahneman, D. (1991). Loss aversion in riskless choice: a reference-dependent model. *The Quarterly Journal of Economics*, *106*, 1039–1061. http://dx.doi.org/10.2307/2937956

Urcuioli, P. J. (2005). Behavioral and associative effects of differential outcomes in discrimination learning. *Learning & Behavior*, *33*, 1–21.

Watson, P., Wiers, R. W., Hommel, B., & de Wit, S. (2014). Working for food you don't desire: cues interfere with goal-directed food-seeking. *Appetite*, *79*, 139–148. http://dx.doi.org/10.1016/j.appet.2014.04.005