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# The Influence of Motivational Salience on Attention Selection: An ERP Investigation

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The Influence of Motivational Salience on Attention Selection:

An ERP Investigation

by

Constanza de Dios

A thesis submitted in partial fulfillment  
of the requirements for the degree of  
Master of Arts  
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College of Arts and Sciences  
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### **Abstract**

The current study used event-related potentials (ERPs) to investigate how motivational salience in the form of expectation violation influences spatial attention. The medial frontal negativity (MFN) ERP indexes expected value, being negative to unexpected punishments and positive to unexpected rewards. The P1 and N1 ERPs index spatial attention, being larger to stimuli in attended locations. This design attached motivational value to locations by making one visual hemifield economically rewarding (greater probability of a rewarding outcome) and the other punishing (greater probability of a punishing outcome). Keypresses to a dot probe following a reward-signifying stimulus were awarded money if correct, and penalized following a punishment-signifying stimulus if incorrect. We predicted that salience would be attached to visual hemifield, thus the MFN would be most negative to punishing outcomes in the rewarding hemifield and most positive to rewarding outcomes in the punishing hemifield. We also predicted that attention would be allocated to a location where expectation was violated, thus the P1 and N1 ERPs would be larger and RTs (reaction times) faster to dot probes appearing in the same side as an outcome that violated expected value. In a sample of 36 participants, there were no significant effects on the MFN, although the means were in the predicted direction, suggesting a lack of power. Contrary to our hypothesis, keypresses were slower, P1 smaller, and N1 larger to probes opposite the location where an expectation violation occurred. This suggested that expectation violation did not direct attention to a particular location, but produced general interference.

## **The Influence of Motivational Salience on Attention Selection: An ERP Investigation**

The current study investigated the influence of motivational salience on spatial attention through event-related potentials (ERPs). Perceptual salience drives attention, but so does motivational salience (Berridge & Robinson, 1998; Posner & Dehaene, 1994; Posner & Petersen, 1990). Whereas perceptual salience is exogenously-driven by perceptual features of a stimulus, motivational salience is driven endogenously by imbuing value to an otherwise neutral stimulus (Berridge & Robinson, 1998). The current investigation used event-related potentials (ERPs) to measure salience and attention. Previously treated as separate components to error and attention selection, respectively, the MFN and P2a ERPs are suggested by more recent evidence to be manifestations of the same system responding to expectation violation and valence (Martin, Potts, Burton, & Montague, 2009; Potts, Martin, Burton, & Montague, 2006): specifically, the waveform is most negative to outcomes that are worse than expected (MFN), most positive to outcomes better than expected (P2a), and intermediate for as-expected outcomes (Potts et al., 2006). If motivationally salient objects can grab attention, then so should motivationally salient spatial locations. To measure spatial attention, the study employed the P1 and N1 ERPs that are larger and keypresses that are faster to attended locations.

The study addressed two specific aims:

*Aim 1.* Motivational salience can be imbued onto spatial location. The attention-elicited P2a and expectation violation MFN ERP components index activity in the same neural system representing the same cognitive operations, thus the two components will occur at the same latency and possess the same scalp topography. Therefore, the differentiation of the waveform

into the positive P2a elicited by infrequent attended visual stimuli and the negative MFN elicited by outcomes that are worse than expected will be similarly elicited to spatial locations.

*Aim 2.* Attention is allocated to motivationally salient spatial locations. The P1 and N1 ERP indices of spatial attention will be larger and keypresses faster to probes in locations where an expectation violation occurred previously.

## **Background and Significance**

### **Motivational Salience.**

The brain selects which information to prioritize over others for further processing through attention selection. Selection is a process of distinguishing relevant information from irrelevant information. One form of salience is perceptual salience, whereby an object possesses an extreme perceptual feature exogenous to the viewer, such as color, size, or shape, distinguishing it from its companions. Perceptual salience elicits a relatively fast orienting response from the viewer (Posner & Dehaene, 1994; Posner & Petersen, 1990). Another form of salience is motivational salience, whereby a stimulus is imbued with value through learning (Berridge & Robinson, 1998). Motivational salience elicits more controlled and effortful processing. Berridge and Robinson (1998) used the term *incentive salience* to describe the transformation of the brain's percept of a learned stimulus from a neutral representation to a wanted incentive that can drive attention.

Perceptual salience and motivational salience are related to distinct mechanisms of attention in the brain. Whereas the former involves the posterior attention system, the latter recruits an anterior attention system (Berridge, 2006; Petersen & Posner, 2012). Within the anterior system is a mesolimbic pathway mediated by dopamine, with projections from anterior



cingulate cortex (ACC) to both frontal and limbic areas; this suggests the ACC is well-poised to use information from midbrain and limbic areas to guide behavior through executive functions housed in the frontal area (Berridge & Robinson, 1998; Bush, Luu, & Posner, 2000).

Dopamine is suggested to be the primary agent in imbuing motivational salience in the anterior network. Schultz (Schultz, 1997) recorded the firing of dopaminergic neurons in monkeys' ventral tegmental area (VTA), a structure with projections to the limbic and frontal cortices. VTA neurons either increased firing when monkeys received fruit juice uncued (unexpected reward), suppressed firing when a paired light cue previously paired with juice was presented but followed by no juice (unexpected non-reward), or maintained baseline firing when juice followed the light (predicted reward). Dopamine, then, does not simply respond to the presence or absence of absolute reward, but responds in a valenced manner to actual outcomes relative to their expected values.

The monkey VTA firing behavior to outcomes in Schultz's study (1997) can be compared to a similar response in humans using event-related potentials (ERPs). Ongoing activity from neurons acting in concert closest to the surface of the cortex generates coherent electromagnetic fields, captured by electroencephalography (EEG). EEG to a specific time-locked event of interest such as a stimulus or motor response are then averaged to yield the ERP, which measures changes in electric fields related to an event. ERPs contain distinct voltage deflections reliably elicited by an event, termed *components*, characterized by their eliciting conditions, amplitude, polarity, and latency (Luck, 2014).

One class of ERP components, the medial frontal negativities (MFN), has been implicated in indexing motivational value, and responds in a similar fashion to the monkey VTA neurons in Schultz (1997). The MFN was originally found to be elicited to motor errors (error-

related negativity or ERN, (Gehring, Goss, Coles, Meyer, & Donchin, 1993) or feedback indicating an error has been committed (feedback-related negativity or FRN; for a review, see (Nieuwenhuis, Holroyd, Mol, & Coles, 2004), but recent evidence suggests that the MFN does not require explicit behavioral errors. Present over medial frontal scalp electrodes and occurring 80 milliseconds post-motor response or 250 milliseconds after feedback indicating a negative outcome, it has been source-localized to medial frontal cortex, elicited in passive viewing tasks (Martin & Potts, 2011), to monetary loss relative to gain, and to least optimal outcomes (Gehring & Willoughby, 2002), suggesting a sensitivity of the MFN to an endogenous appraisal to events.

Potts, Martin, Burton, and Montague (Potts et al., 2006) employed a passive S1-S2 viewing task resembling a slot machine where participants viewed stimuli (S1) that subsequently predicted rewarding or nonrewarding stimuli (S2) which served as outcomes. A valenced response to events similar to the monkey VTA neurons in Schultz (1997) was observed: the waveform was most negative to outcomes worse than expected, most positive to outcomes better than expected, and intermediate to as-expected outcomes. The neural generator of the waveform was estimated in the ACC, consistent with the model of the ACC as an intermediary between frontal and midbrain regions (Bush et al., 2000).

The negative deflection in Potts et al. (2006) was an MFN, but its accompanying positive deflection to better-than-expected outcomes resembled another family of ERPs, the P2a. The P2a (anterior P2, also termed the frontal selection positivity or FSP, frontal polar component or FP) is elicited to targets that are instructed to be relevant (Potts & Tucker, 2001; Potts, Patel, & Azzam, 2004). It is insensitive to stimulus frequency, distinguishing it from the frequency-sensitive P3 (Potts, Liotti, Tucker, & Posner, 1996). The P2a and MFN have similar frontal scalp

topographies, occur at the same latency, and localize to medial frontal cortex. Treated previously as separate components to error and attention selection, respectively, the MFN and P2a are suggested to be reflections of the same behavior monitoring system housed in the ACC, which as noted before, is well-positioned between limbic and frontal structures (Bush et al., 2000), with dopamine acting as a regulator in the informing of frontal executive about goal-relevant behavior (Berridge & Robinson, 1998; Braver & Cohen, 2000). Attention then might be guided at least in part by motivationally-relevant information.

Experimentally, we can induce motivational salience through reinforcement learning of value (Holroyd & Coles, 2002). Such value can differ in magnitude and probability. Both characteristics are components of the expected utility (EU) model, a formal theory of decision-making in economics, in which the utility of a decision is equal to its value (magnitude) multiplied by its probability (von Neumann & Morgenstern, 1947, as cited in Sanfey, Loewenstein, McClure, & Cohen, 2006). Outcome magnitude can be manipulated by varying dollar amounts; it can also be positive or negative, indicative of valence. Outcome probability can be manipulated using percentages, thereby producing high (congruent or as-expected outcomes) or low predictiveness (incongruent or unexpected outcomes, a prediction violation).

### **Influence on Attention.**

Motivational salience has been commonly imbued onto objects by pairing value in the manner described above with pictures (Potts et al., 2006; Yeung & Sanfey, 2004), gratings (Stolarova, 2005), faces (Pourtois, 2004), or words (Schacht, Adler, Chen, Guo, & Sommer, 2012). For learning to occur, perceptual features of an object must be processed to identify it and subsequently associate it with learned value. If the identifying feature is not a physical characteristic of the object (*what*) but its spatial location (*where*), then meaning should be

instilled similarly. That is, meaning should be imbued onto spatial location, just as it can onto objects. Further, motivationally salient locations should direct attention similarly as can salient objects. Selection of spatial location is necessary for prioritizing stimuli (Petersen & Posner, 2012), so locations that are salient, whether perceptually or motivationally, should be attended to.

To our knowledge, one study has directly tested the influence of motivational salience on spatial attention. In their study, (Chelazzi et al., 2014) observed better perceptual discrimination at spatial locations that were previously associated with greater probability of reward, especially when multiple targets were competing for attentional resources. Chelazzi et al. suggest that motivational salience can be attached to location, and that this attachment can affect subsequent attention to those locations. However, it is not known when in processing this influence occurs, a question that can be answered using ERPs.

Attention to location can be indexed by ERPs. The P1 (occurring over 80 to 100 milliseconds post-stimulus) and N1 (occurring 140 to 190 milliseconds post-stimulus) components, present over occipito-temporal electrodes, are larger for a stimulus occurring in an attended location relative to ignored locations (Hillyard, Vogel, & Luck, 1998). The P1 indexes the amplifying of early sensory gain that enhances processing at an already-attended location, prior to the delivery of a stimulus, while the N1 indexes orienting at a task-relevant location (Luck, Heinze, Mangun, & Hillyard, 1990; Mangun, 1995). Both components are invariant to stimulus content and are generated by extrastriate visual areas, indicating early perceptual selection (Luck et al., 1990; Luck, Woodman, & Vogel, 2000). If motivational salience drives the cognitive functions indexed by the P1 and N1, this finding might suggest that motivational salience operates on attention at a stage of early selection.

An often-used paradigm in studying spatial attention is the spatial cuing task (Posner, Cohen, & Rafal, 1982). In its fundamental version, two boxes stay on the screen, each flanking either side of a central fixation cross. One of the boxes brightens as a cue prior to a target (a dot) appearing in the same box (a valid trial), or the opposite box (an invalid trial). In some cases, the box does not brighten (uncued trial). The participant is instructed to press a button as soon as they see the dot. Participants' keypresses are typically fastest and P1 and N1 are largest on valid trials than on invalid trials, indicating a facilitation on the valid trials; reaction times and ERP amplitudes to uncued trials are intermediate (Mangun, 1995). These characteristic findings demonstrate attention to spatial location in a design using perceptual salience—a brightening box. The current study tests whether motivational salience would drive attention similarly.

### **The Current Study**

The current study adapted the spatial cuing task by making one hemifield punishing and the other rewarding with the use of fixed probabilities, i.e. The right side was rewarding 40% of the time and punishing 10% of the time, and the left side punishing 40% of the time and rewarding 10% of the time. Through these fixed probabilities assigned to either hemifield, salience in the form of valence (Rewarding or Punishing) and expectation violation (Congruent, 40%, or Incongruent with expectation, 10%) could be assigned to spatial location. To probe attention, a pair of dots appeared in the same (Valid) or the opposite (Invalid) hemifield as the outcome-signifying stimulus (angel for monetary reward, devil for monetary punishment). The participant's objective was to indicate which hemifield, the left or right, the dot probe appeared in.

The two primary questions in the current study are whether motivational salience can be imbued onto spatial location, and whether such salience can direct spatial attention. Addressing the first question, we used the MFN to measure motivational salience. We predicted that the MFN would be most negative to punishing outcomes in the rewarding hemifield (Incongruent Punish condition) and most positive to rewarding outcomes in the punishing hemifield (Incongruent Reward condition). Punishing outcomes in the punishing hemifield (Congruent Punish) and rewarding outcomes in the rewarding hemifield (Congruent Reward) were predicted to be intermediate.

As to the second question, we hypothesized that motivational salience in the form of expectation violation should, in turn, confer allocation of attention. Thus, we predicted that the dot probe occurring in the same hemifield where an unexpected outcome appeared (Incongruent Valid condition) would elicit shorter reaction times and larger P1 and N1 responses than probes replacing as-expected outcomes (Congruent Valid condition).

## Method

### Participants

63 participants were initially recruited from the SONA online participant pool at USF as dual-enrolled participants for a separate but related study. Both studies were approved by the Institutional Review Board. Of this set, 36 participants were included in the analysis for the current study.

Participants in the current sample were 36 undergraduates (7 males and 29 females), ages 18 through 31 ( $M = 19.8$ ,  $SD = 2.99$ ). All were right-handed, English-speaking, reported having no neurological abnormalities, and had normal or corrected-to-normal visual acuity. All gave consent prior to participating.

### Design

We utilized a modified spatial cuing dot-probe task. In this task, incentives were rewarded (Reward), taken away (Punish), or neither, depending on the visual hemifield (right or left) in which a stimulus appeared. A yellow square cue appearing in one location in either the right or left hemifield initiated a trial. A blue angel or red demon icon appeared in its place, serving as the outcome-signifying stimulus. Following this outcome, a dot probe appeared equiprobably in the right or left hemifield. The dot was in the Valid condition if it appeared on the same side as the outcome, and Invalid if on the opposite hemifield as the outcome.

The participant's objective was to indicate whether the dot probe appeared in the right or left visual field using a right or left button on a keypad, as a two-alternative forced choice task. Figure 1 displays a sequence of events in one trial.

If the participant indicated the correct dot visual field after an angel outcome, they gained \$0.25. If they were incorrect following a devil outcome, they lost \$0.25. The participant was neither rewarded nor punished if they encountered all other combinations (correct after devil outcome, incorrect after angel outcome). One visual hemifield was potentially rewarding (angels occurred 40% of the time, devils 10%) and the other potentially punishing (devils occurred 40% of the time, angels 10%), serving as a manipulation of expectation violation. Figure 2 depicts fixed probabilities for a participant whose right hemifield was rewarding and left hemifield was punishing.

Each participant encountered 448 trials total. The fixed probabilities were assigned across all 480 trials. The first 32 trials served as practice, during which EEG was not recorded and feedback about money gained or lost was given after each trial. EEG was recorded for the remaining 448 trials, which were divided into 7 blocks and did not include monetary feedback as in practice. The assignment of rewarded visual field was counterbalanced across participants. Each participant began each block with \$5 in their “bank”. At the end of the experiment, participants rolled a die to determine which block’s winnings they would earn in cash.

### **Incentives**

Participants were awarded SONA points for 2.5 total hours of participation in the study as they were dual-enrolled in a separate study (total of 5 SONA points). For the current study, participants were awarded money in an amount contingent on their performance in a particular block, serving as motivation to perform well and mirror the conditions of the game-like task in the experiment. The block from which they would earn their winnings was determined by rolling an 8-sided die; the amount from this block was multiplied by a fixed coefficient (0.098), and paid in cash. Although exact payment schedules were unknown, each participant could not earn a



final dollar amount greater than \$3. Payment was disbursed after the participant completed the experiment.

### **Procedure**

Participants volunteered to take part in the study through the SONA online research participant pool. After consent, participants were fitted with the appropriate EEG net then led to the testing room where they received instructions for the task. In between each block of trials, participants took a momentary break. After completing the task, the participant was asked about their performance on the task (e.g. “Which side do you think was more rewarding?”). The EEG net was removed from the participant’s head when they completed the entire session. Cash winnings according to the procedure described above (see *Incentives*) were disbursed.

### **EEG Recording and Preprocessing**

E-Prime 2.0 was used to present stimuli to the participant. The LCD monitor displaying the stimuli to the participant was set at 1920 x 1080 pixel resolution, 32-bit color, and 60.04 Hz refresh rate. Viewing distance between the participant and the monitor was kept at 50 cm.

Recording and preprocessing were performed on Net Station (Electrical Geodesics, Eugene, OR). EEG was acquired using a 128-channel geodesic sensor array net (HydroCel GSN 128 1.0) on Net Station 5.1.2 for participants 1 through 43, and on Net Station 5.2.0 for participants 44 through 63. Continuous EEG was recorded with a 250 Hz sampling rate and vertical reference. Impedances were kept below 10 kOhms. EEG was re-referenced offline to the vertex and digitally filtered at 0.1 Hz highpass and 100 Hz lowpass. The resulting EEG was segmented into 1000-ms epochs spanning 200ms pre- and 800ms post-stimulus; this segmentation process was done separately on the appearance of the outcome-signifying stimulus

(angel or devil) to generate the MFN component, and on the appearance of the dot probe to generate the P1 and N1 components.

## **Statistical Analyses**

### **Behavior.**

Trials where keypresses to the dot probe (in milliseconds) were erroneous, missing, or outliers (greater than the mean plus 3 SD of the individual's own reaction times or RTs) were excluded from analyses to normalize the RT distribution, as RTs are notoriously skewed (Koster, Crombez, Verschuere, & De Houwer, 2004). RTs were averaged for each condition and each participant, and then cast into a 2 x 2 repeated measures ANOVA with Outcome Expectation (Congruent, Incongruent) and Dot Validity (Valid, Invalid) as factors. This yielded four conditions: Congruent Valid, Congruent Invalid, Incongruent Valid, and Incongruent Invalid. Paired *t*-tests identified contrasts within interactions. Table 1 lists the proportions of trials from each condition to the total number of trials.

### **ERPs.**

Segmented EEG epochs were digitally screened for ocular and excess motor artifacts before getting sorted and averaged by condition. Average ERPs were then baseline-corrected to the prestimulus period of 200ms for each participant. Waveforms for each component—MFN, P1, N1—were averaged across all participants to create grand average ERPs.

Mean amplitudes from each of the conditions extracted over electrode sites and time windows specific to the ERP component were cast into a repeated-measures ANOVA with paired *t*-tests identifying contrasts within interactions.

***MFN.***

To produce the MFN component, the mean amplitude of the waveform 225-275ms post-stimulus (after the appearance of the angel or devil outcome) was extracted over medial frontal leads. Mean amplitudes for all participants were cast into a 2 x 2 repeated-measures ANOVA with Outcome Expectation (Congruent, Incongruent) and Outcome Valence (Reward, Punish) as factors, producing four conditions: Congruent Reward, Congruent Punish, Incongruent Reward, Incongruent Punish. Due to the ordered predictions about the conditions (Incongruent Reward > Congruent Reward = Congruent Punish > Incongruent Punish), a Friedman test was performed. The Friedman test is the nonparametric equivalent of the one-way repeated-measures ANOVA and tests for variance in ranks between conditions that are believed to be ordinal. Paired Wilcoxon signed-rank tests were performed on pairs of conditions to determine the directions in which each condition compared to another.

***P1 and N1.***

The spatial attention ERP indices were extracted as the mean amplitude occurring 100-135ms (P1) and 165-200ms (N1) post-stimulus (after the appearance of the dot probe) over occipitotemporal electrode leads. Mean amplitudes for each participant were cast into a 2 x 2 repeated-measures ANOVA with Outcome Expectation (Congruent, Incongruent) and Dot Validity (Valid, Invalid) as factors. Paired *t*-tests identified contrasts within interactions.

## Results

### Behavior

Erroneous trials (range across participants: 3 to 66,  $M = 19.2$ ,  $SD = 13.66$ ) and trials without a keypress (range: 1 to 76,  $M = 11.33$ ,  $SD = 13.88$ ) were first excluded. Outlier trials for each participant were then removed (range: 1 to 9,  $M = 4.72$ ,  $SD = 2.05$ ). Table 2 gives the mean proportion of trials per condition to the original trial count included in the behavioral analyses. Tables 3, 4, and 5 depict the mean proportion of trials per condition excluded from the behavioral analyses due to error, nonresponse, and outlier analyses, respectively.

Figure 3 illustrates the mean reaction times in each of the conditions. They are numerically depicted in Table 6.

The ANOVA revealed a significant main effect of Dot Validity,  $F(1, 35) = 88.79$ ,  $p < 0.001$ , with Invalid RTs faster than Valid RTs. There was also a significant main effect of Expectation,  $F(1, 35) = 20.02$ ,  $p < 0.001$ , with Congruent RTs faster than Incongruent RTs. There was a marginally significant interaction,  $F(1, 35) = 2.80$ ,  $p = 0.10$  (Table 7).

Paired  $t$ -tests (Table 8) revealed that Incongruent Valid dots elicited the slowest RTs, being longer than RTs to each of the three other conditions (vs. Congruent Valid:  $t(35) = 4.23$ ,  $p < 0.0001$ ; vs. Incongruent Invalid:  $t(35) = 9.36$ ,  $p < 0.0001$ ; vs. Congruent Invalid:  $t(35) = 10.65$ ,  $p < 0.0001$ ). Congruent Invalid dots elicited the fastest RTs (vs. Congruent Valid:  $t(35) = 7.96$ ,  $p < 0.0001$ ). Responses to Invalid dots were slowed when the preceding outcome was incongruent; this effect approached significance (Congruent Invalid vs. Incongruent Invalid,  $t(35) = 1.82$ ,  $p = 0.08$ ).

## ERPs

### MFN.

There were no main effects of Expectation,  $F(1, 35) = 0.04, p = 0.85$ , or of Valence,  $F(1, 35) = 1.01, p = 0.32$ . There was no significant interaction ( $F(1, 35) = 1.25, p = 0.27$ ). Figure 4 depicts a plot of the waveform across time of the MFN over medial frontal electrodes. Figure 5 illustrates the mean amplitude of the MFN in each of the conditions. See Table 9 for ANOVA results and Table 10 for paired  $t$ -test results.

The Friedman test indicated a non-significant difference in MFN amplitude depending on condition,  $\chi^2(3) = 6.23, p = 0.10$ . Wilcoxon signed-rank tests indicated that the Incongruent Reward and Incongruent Punish conditions did not elicit a statistically significant change in MFN amplitude; this difference was marginal ( $Z = -1.68, p = 0.093$ ). Differences between other combinations of conditions were not statistically significant ( $p$ 's  $> 0.2$ ).

In sum, although the means of MFN amplitude were in the predicted directions, the differences did not reach statistical significance.

### P1.

Figure 6 shows the P1 and N1 waveforms across time over occipitotemporal electrodes.

There was a significant main effect of Dot Validity,  $F(1, 35) = 8.82, p = 0.005$  so that the P1 to dots occurring on the opposite side as an outcome (Invalid) was larger than to dots appearing on the same side (Valid). There was also a marginally significant main effect of Expectation,  $F(1, 35) = 2.77, p = 0.11$  such that the P1 to dots occurring after outcomes Congruent with expectation was larger than to dots following Incongruent outcomes. The interaction was not significant,  $F(1, 35) = 0.14, p = 0.71$  (Table 11). Figure 7 illustrates the mean amplitude of the P1 in each of the conditions.

According to the paired *t*-tests (Table 12), the P1 was smaller to dots in the Incongruent Valid condition when compared to Congruent Invalid,  $t(35) = -3.87, p < 0.0001$ . Incongruent Valid was not significantly different from Incongruent Invalid,  $t(35) = -1.72, p = 0.09$ , or from Congruent Valid,  $t(35) = -0.95, p = 0.35$ . Congruent Invalid dots elicited a significantly larger P1 when compared to Congruent Valid,  $t(35) = -3.80, p = 0.001$ . When compared to Incongruent Invalid, this difference was non-significant,  $t(35) = -1.48, p = 0.15$ .

### **N1.**

There was a significant main effect of Dot Validity,  $F(1, 35) = 4.87, p = 0.03$ , so that the N1 to dots occurring on the opposite side as an outcome (Invalid) was larger than to dots appearing on the same side (Valid). There was also a significant main effect of Expectation,  $F(1, 35) = 5.91, p = 0.02$ , such that the N1 to dots occurring after Incongruent outcomes was larger than to dots occurring Congruent outcomes. There was a significant Dot Validity x Expectation interaction,  $F(1, 35) = 5.28, p = 0.03$  (Table 13). Figure 8 depicts the mean amplitude of the N1 in each of the conditions.

Planned *t*-tests (Table 14) indicated a larger N1 to dots in the Incongruent Invalid condition when compared to each of the other three conditions (vs. Incongruent Valid,  $t(35) = 2.69, p = 0.01$ ; vs. Congruent Valid,  $t(35) = 3.11, p = 0.004$ ; vs. Congruent Invalid,  $t(35) = 3.66, p = 0.001$ ). All other pairs did not reveal significant differences.

## Discussion

The current study investigated the impact of motivational salience on spatial attention. We predicted that salience in the form of economic expectation violation and valence could be attached to visual hemifield, and that this could direct subsequent attention. We used the MFN to measure motivational salience, predicting that it would be most negative to unexpected punishment-signifying stimuli in the rewarding hemifield and most positive to unexpected reward-signifying stimuli in the punishing hemifield. To measure attention, we used keypress speeds, and the P1 and N1 ERP responses to a probe occurring in the same or opposite hemifield as the outcome-signifying stimuli, hypothesizing that keypresses would be faster and P1 and N1 responses larger to the probe when it appeared on the same side as an expectation-violating outcome.

The MFN findings were in the predicted direction: most negative to unexpected punishments in the rewarding hemifield and most positive to unexpected rewards in the punishing hemifield, consistent with Potts et al. (2006) and Chelazzi et al. (2014). This effect, however, did not reach statistical significance potentially due to low power. Another possible reason for the small effect was the low perceived relevance of the outcome-signifying stimuli. The primary task for the participant was to pay attention to the visual field of the dots, not the outcome-signifying angels or devils. Instructed relevance has been shown to produce stronger MFN and P2a effects (Hajcak, Moser, Yeung, & Simons, 2005; Potts et al., 2004). Thus, the lessened instructed relevance of the ERP-eliciting stimuli may have weakened the potential effects in the MFN/P2a.

The behavioral results did not support our hypothesis that salience would direct spatial attention. Keypresses were slower, not faster, to the dot probes when they occurred in the same hemifield as an unexpected outcome. RTs were also faster to dots occurring on the opposite side as an outcome, regardless of that outcome's predictiveness. This result indicates a potential inhibition of orienting towards locations that were previously attended, or an inhibition of return (IOR). This effect may have been due to the temporal interval between the outcome and dot probe falling within the time range where an IOR is observed, typically between 300 and 800ms (Posner, Rafal, Choate, & Vaughan, 1985).

Interestingly, RTs to probes in the opposite (invalid) hemifield were slowed when the preceding outcome was incongruent. Attention was not drawn to the same (valid) hemifield in which something incongruent occurred. This suggests that violated economic expectation did not necessarily draw spatial attention, but slowed down general processing.

The P1 results were not consistent with our hypothesis of attention allocation to a location where an expectation violation occurred. Although not significant, the P1 was smaller, not larger, to dots appearing in the same hemifield as an unexpected outcome, mirroring the behavioral finding. The P1 was also larger to dots in the opposite hemifield as an outcome, again reflecting the IOR effect in the behavior. When examining the P1 only to the dots opposite an outcome, we noted that the P1 was smaller when the preceding outcome was unexpected compared to when it was expected. Although this result was not statistically significant, it reflected the reduction of RTs. This suggests that violated expected value slowed processing, but did not limit this slowness to a specific location. This result could be interpreted to be consistent with the model of attention as a zoom-lens, in which attention causes the greatest enhanced processing of stimuli at focal locations, but may still exert a weaker enhancement on processing



stimuli that are adjacent to the focal location (Heinze et al., 1994). It is possible that the data showed an effect of expectation violation in the opposite (non-focal invalid) hemifield, not the focal (valid) hemifield, due to the overwhelming strength of the IOR effect (Taylor, Chan, Bennett, & Pratt, 2015).

The N1 results showed an opposite effect of the P1 and behavioral results. Although the N1 displayed the IOR effect as previously seen in the behavior and P1 (larger amplitude to dots in opposite hemifield as any outcome), it was larger to dots appearing in the opposite hemifield as an unexpected outcome. The discrepancy in the attention indices might be explained by functional differences between the P1 and N1. Although both P1 and N1 are larger to attended locations, these components are dissociable. The P1 reflects a suppression of processing at ignored locations, amplifying sensory gain prior to a delivery of a stimulus, whereas the N1 reflects enhanced processing at the attended location, enhancing discriminability at a location that has been processed as task-relevant (Hillyard et al., 1998; Luck et al., 1990). Considering this functional dissociation, we speculate that our N1 finding reflects attention to a location that has been deemed even more relevant following a violation of expected value.

In sum, the data showed modest support for the predicted assignment of motivational salience to visual hemifield through the MFN. The data, however, was not consistent with the hypothesized attention allocation to locations where an expectation violation occurred, as indicated by the behavioral, P1, and N1 measures. The behavioral and P1 results indicated a potential general interference following a violation of economic expectation, by slowing down processing of the target stimuli after an unexpected outcome occurred. The slowed keypresses and reduced P1 to probes in the opposite hemifields were more pronounced following an expectation violation than when following an expectation confirmation, suggesting that the

interference due to value violation was not directed at a specific spatial location. While the P1 and RT results were consistent with general interference, the N1 result suggested orienting to a location that has been valuated as more relevant due to a violation of expected value.

The findings on the attentional indices must be tempered due to limitations in the design. The behavioral, P1, and N1 results showed evidence of IOR, potentially due to timing issues between the delivery of the outcome and the probe. The experimental design could be improved to lessen the inter-stimulus interval and reduce IOR effects, or alternatively, statistically control for or use the IOR effect itself as a direct measure of attention in an alternative design. Future studies might investigate reaction times further through modeling, due to issues of skewedness in traditional RT analyses. This gives rise to problematic or incomplete interpretations about the cognitive phenomena being measured by response times (Balota & Yap, 2011).

In conclusion, the data in the current study indicated that motivational salience in the form of expectation violation and valence was weakly attached to spatial location. Such salience, however, did not direct attention to locations where expectation was violated, but might have produced general interference in processing.

Table 1

*Proportion and Number of Trials per Condition*

	Valid		Invalid	
	A	B	A	B
Congruent	38% [172]	41% [183]	41% [183]	38% [172]
Incongruent	11% [48]	10% [45]	10% [45]	11% [48]

*Note.* Since laterality of outcome was counterbalanced across participants, numbers of trials per condition differed; values are given for both versions of the task (A = right side rewarding, B = left side rewarding). Proportions are percentages out of 448 total trials. Frequencies are given in brackets. Conditions are from the Expectation x Dot Validity ANOVA.

Table 2

*Proportion of Trials Included in the Final Behavioral Analyses to Total Trials*

	Valid	Invalid
Congruent	36.0 (2.2)	37.2 (2.0)
Incongruent	9.5 (0.8)	9.6 (0.7)

*Note.* Proportion is given in percent (%) of 448 trials. Conditions are from the Expectation x Dot Validity ANOVA. Standard deviations in parentheses.

Table 3

*Proportion of Error Trials to Total Trials*

	Valid	Invalid
Congruent	1.9 (1.5)	1.7 (1.2)
Incongruent	0.6 (0.5)	0.5 (0.3)

*Note.* Proportion is given in percent (%) of 448 trials. Conditions are from the Expectation x Dot Validity ANOVA. Standard deviations in parentheses.

Table 4

*Proportion of Trials without a Response to Total Trials*

	Valid	Invalid
Congruent	1.2 (1.3)	1.1 (1.5)
Incongruent	0.6 (0.4)	0.5 (0.4)

*Note.* Proportion is given in percent (%) of 448 trials. Conditions are from the Expectation x Dot Validity ANOVA. Standard deviations in parentheses.

Table 5

*Proportion of Individual Subject Outlier Trials to Total Trials*

	Valid	Invalid
Congruent	0.6 (0.4)	0.4 (0.2)
Incongruent	0.3 (0.2)	0.2 (0.0)

*Note.* Proportion is given in percent (%) of 448 trials. Conditions are from the Expectation x Dot Validity ANOVA. Standard deviations in parentheses.

Table 6

*Mean RTs*

	Valid	Invalid
Congruent	263.5 (26.5)	241.8 (33.8)
Incongruent	269.7 (24.6)	244.4 (33.6)

*Note.* RTs are in milliseconds (ms). Conditions are from the Expectation x Dot Validity ANOVA. Standard deviations in parentheses.

Table 7

*Repeated-Measures ANOVA Results for RTs*

Source	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p</i>
Expectation	705.59	1	705.59	20.02	< 0.0001
Error(Expectation)	1233.63	35	35.25		
Dot Validity	19806.32	1	19806.32	88.79	< 0.0001
Error(Dot Validity)	7807.67	35	223.08		
Expectation x Dot Validity	116.22	1	116.22	2.80	0.10
Error(Expectation x Dot Validity)	1453.76	35	41.54		

*Note.* *SS* = sum of squares; *df* = degrees of freedom; *MS* = mean square.

Table 8

*Paired t-test Results for RTs*

Pair	<i>Mean difference</i>	<i>SD</i>	<i>SEM</i>	<i>t</i> (35)	<i>p</i>
Incongruent Valid - Congruent Valid	6.22	8.83	1.47	4.23	< 0.0001
Incongruent Valid - Incongruent Invalid	25.25	16.20	2.70	9.36	< 0.0001
Incongruent Valid - Congruent Invalid	27.88	15.71	2.62	10.65	< 0.0001
Congruent Valid - Incongruent Invalid	19.03	16.43	2.74	6.95	< 0.0001
Congruent Valid - Congruent Invalid	21.66	16.34	2.72	7.96	< 0.0001
Incongruent Invalid - Congruent Invalid	2.63	8.70	1.45	1.82	0.08

*Note.* *SD* = standard deviation; *SEM* = standard error of the mean.

Table 9

*Repeated-Measures ANOVA Results for Mean MFN Amplitudes*

Source	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p</i>
Expectation	0.02	1	0.02	0.04	0.85
Error(Expectation)	15.97	35	0.46		
Valence	0.41	1	0.41	1.01	0.32
Error(Valence)	14.07	35	0.40		
Expectation x Valence	0.56	1	0.56	1.25	0.27
Error(Expectation x Valence)	15.60	35	0.45		

*Note.* *SS* = sum of squares; *df* = degrees of freedom; *MS* = mean square.

Table 10

*Paired t-test Results for Mean MFN Amplitudes*

Pair	<i>Mean difference</i>	<i>SD</i>	<i>SEM</i>	<i>t</i> (35)	<i>p</i>
Incongruent Reward - Congruent Reward	0.10	0.83	0.14	0.74	0.46
Incongruent Reward - Congruent Punish	0.08	0.92	0.15	0.55	0.59
Incongruent Reward - Incongruent Punish	0.23	1.06	0.18	1.31	0.20
Congruent Reward - Congruent Punish	-0.02	0.76	0.13	-0.14	0.89
Congruent Reward - Incongruent Punish	0.13	0.93	0.15	0.83	0.41
Congruent Punish - Incongruent Punish	0.15	1.06	0.18	0.83	0.41

*Note.* *SD* = standard deviation; *SEM* = standard error of the mean.

Table 11

*Repeated-Measures ANOVA Results for Mean P1 Amplitudes*

Source	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p</i>
Expectation	0.68	1	0.68	2.77	0.11
Error(Expectation)	8.58	35	0.25		
Dot Validity	3.25	1	3.25	8.82	0.005
Error(Dot Validity)	12.89	35	0.37		
Expectation x Dot Validity	0.03	1	0.03	0.14	0.71
Error(Expectation x Dot Validity)	7.53	35	0.22		

*Note.* *SS* = sum of squares; *df* = degrees of freedom; *MS* = mean square.

Table 12

*Paired t-test Results for Mean P1 Amplitudes*

Pair	<i>Mean difference</i>	<i>SD</i>	<i>SEM</i>	<i>t</i> (35)	<i>p</i>
Incongruent Valid - Congruent Valid	-0.11	0.68	0.11	-0.95	0.35
Incongruent Valid - Incongruent Invalid	-0.27	0.95	0.16	-1.72	0.09
Incongruent Valid - Congruent Invalid	-0.44	0.68	0.11	-3.87	< 0.001
Congruent Valid - Incongruent Invalid	-0.16	0.88	0.15	-1.12	0.27
Congruent Valid - Congruent Invalid	-0.33	0.52	0.09	-3.80	0.001
Incongruent Invalid - Congruent Invalid	-0.17	0.67	0.11	-1.48	0.15

*Note.* *SD* = standard deviation; *SEM* = standard error of the mean.

Table 13



*Repeated-Measures ANOVA Results for Mean NI Amplitudes*

Source	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p</i>
Expectation	1.05	1	1.05	5.91	0.02
Error(Expectation)	6.20	35	0.18		
Dot Validity	4.88	1	4.88	4.87	0.03
Error(Dot Validity)	35.03	35	1.00		
Expectation x Dot Validity	0.82	1	0.82	5.28	0.03
Error(Expectation x Dot Validity)	5.42	35	0.16		

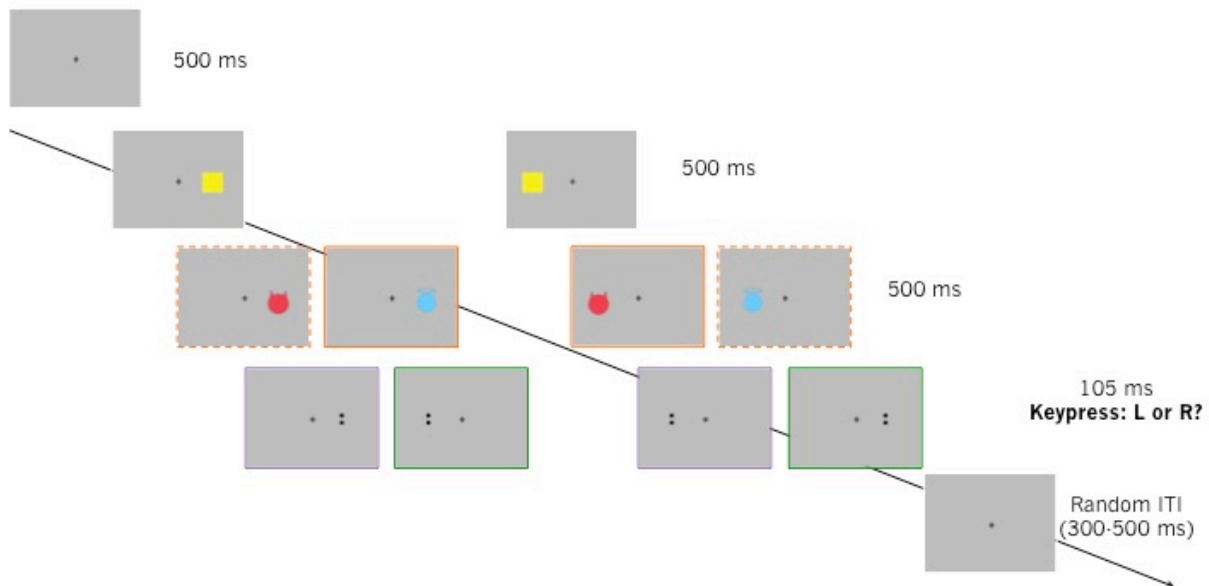
*Note.* *SS* = sum of squares; *df* = degrees of freedom; *MS* = mean square.

Table 14

*Paired t-test Results for Mean NI Amplitudes*

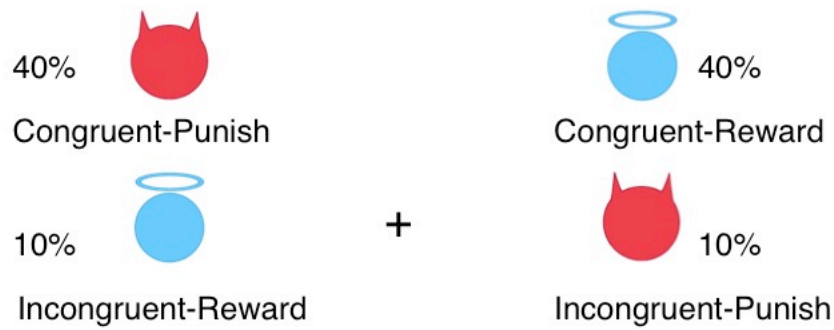
Pair	<i>Mean difference</i>	<i>SD</i>	<i>SEM</i>	<i>t</i> (35)	<i>p</i>
Incongruent Valid - Congruent Valid	0.02	0.62	0.10	0.19	0.85
Incongruent Valid - Incongruent Invalid	0.52	1.16	0.19	2.69	0.01
Incongruent Valid - Congruent Invalid	0.20	1.13	0.19	1.05	0.30
Congruent Valid - Incongruent Invalid	0.54	1.04	0.17	3.11	0.004
Congruent Valid - Congruent Invalid	0.22	0.99	0.16	1.32	0.20
Incongruent Invalid - Congruent Invalid	-0.32	0.53	0.09	3.66	0.001

*Note.* *SD* = standard deviation; *SEM* = standard error of the mean.



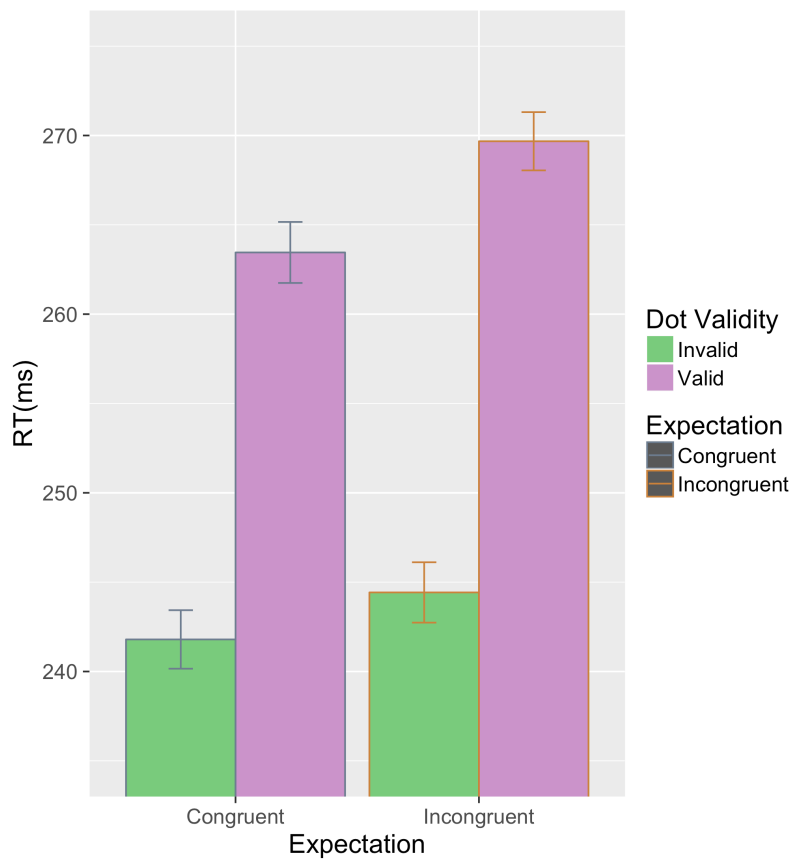
*Figure 1.* Trial Sequence Showing All Possible Scenarios.

Slides not enclosed in a box stayed constant across participants. (The colored box enclosures themselves were not visible to the participant and are only used here for demonstration purposes.) A trial began with fixation, followed by a warning cue (yellow square) appearing to the left or right of fixation. This cue was then replaced by the outcome-signifying stimulus (angel or devil) in the same hemifield. For a participant whose right hemifield was potentially rewarding and the left side potentially punishing, trials enclosed in solid yellow were Congruent outcomes, while trials enclosed in dotted yellow boxes were Incongruent outcomes (for fixed probabilities of outcomes, see *Figure 2.*) Following the outcomes were the dot probes, which could either appear in the same hemifield as the previous outcome (Valid, violet boxes), or in the opposite hemifield as the previous outcome (Invalid, green boxes).



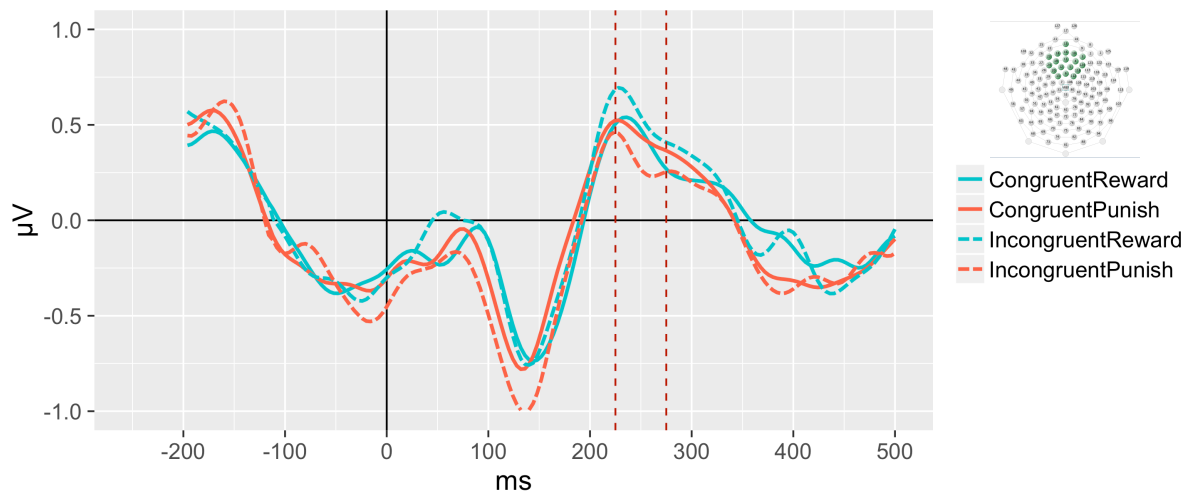
*Figure 2.* Distribution of Fixed Probabilities of Outcomes.

Conditions arise from an Outcome Expectation x Valence interaction. The above example depicts probabilities for a participant whose right hemifield was potentially rewarding and left hemifield was punishing. The laterality of probabilities of conditions was reversed for a participant whose right hemifield was punishing and left hemifield was rewarding. Laterality of probabilities was counterbalanced across participants.



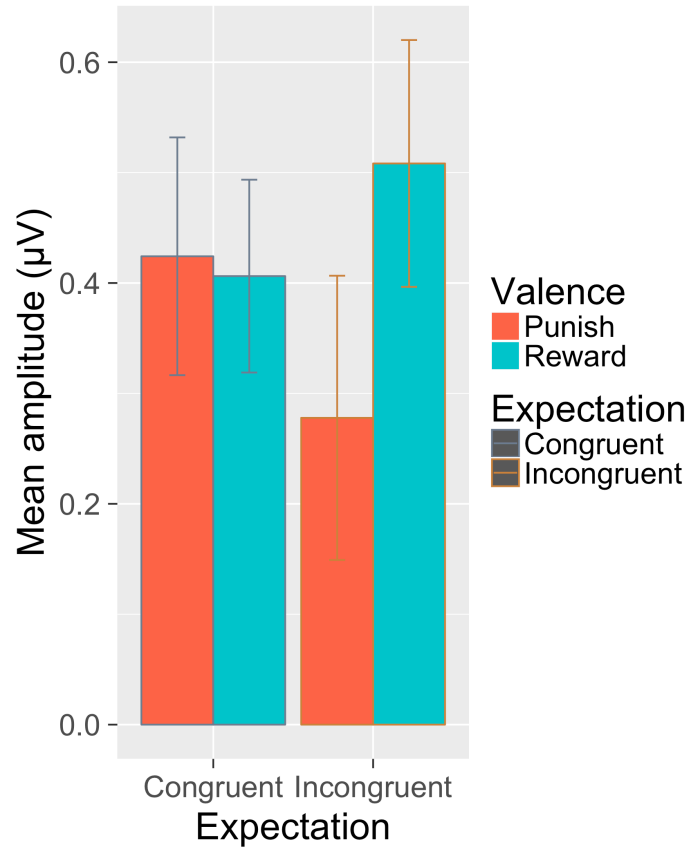
*Figure 3.* Mean RTs.

Conditions are from the Expectation x Dot Validity ANOVA. Error bars represent standard error of the mean.



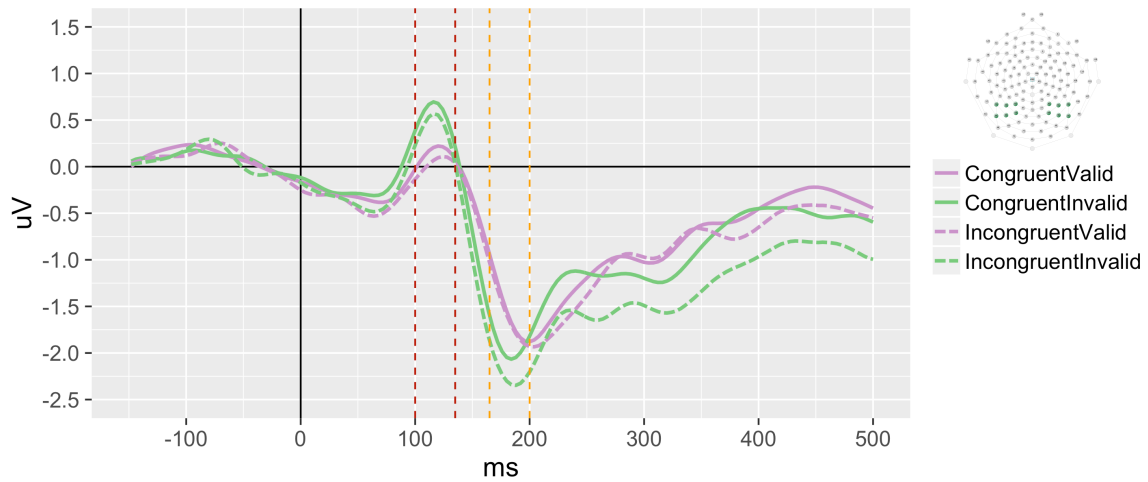
*Figure 4.* Waveform across Time over Medial Frontal Leads.

The electrode layout used to extract the MFN is shown on the upper right corner. MFN mean amplitudes to each condition were extracted over 225-275ms (between dotted red vertical lines).



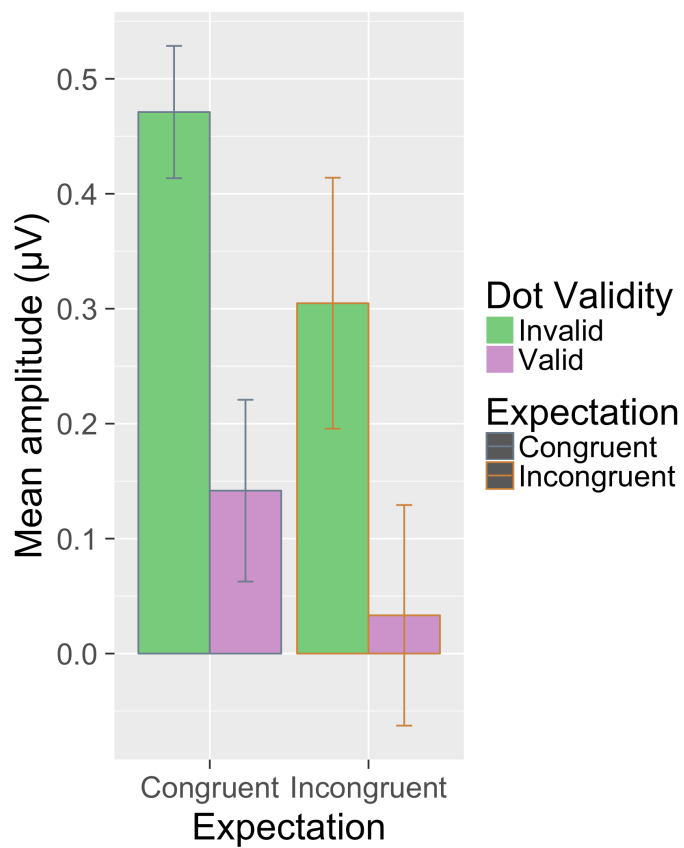
*Figure 5.* Mean MFN Amplitudes.

Amplitudes were extracted over 225-275ms at each of the conditions in the Expectation x Valence ANOVA. Error bars represent standard error of the mean.



*Figure 6.* Waveform across Time over Occipitotemporal Leads.

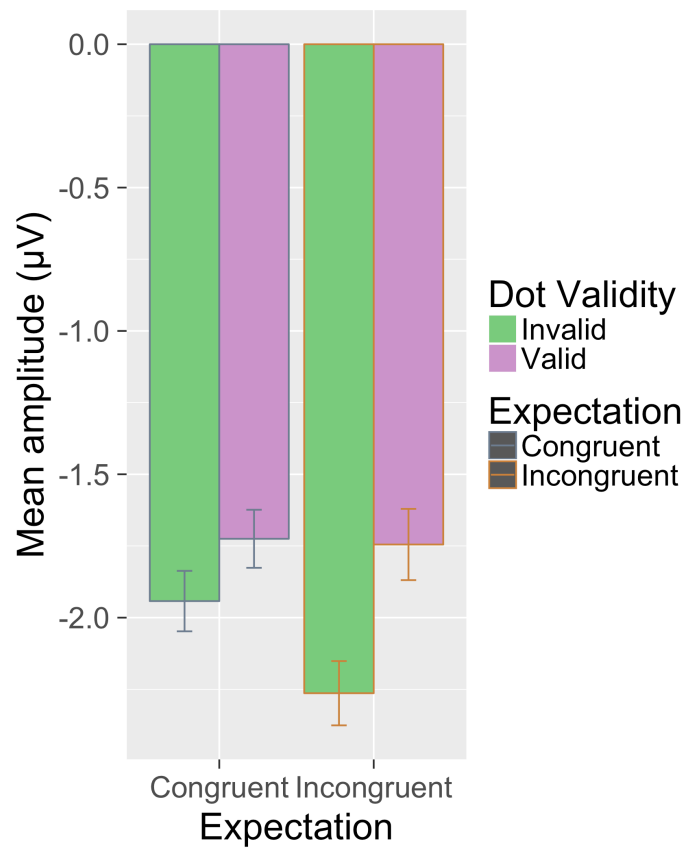
The electrode layout used to extract the P1 and N1 is shown on the upper right corner. P1 mean amplitudes to each condition were extracted over 100-135ms (between dotted red vertical lines). N1 mean amplitudes to each condition were extracted over 165-200ms (between dotted orange vertical lines).



*Figure 7.* Mean P1 Amplitudes.

Amplitudes were extracted over 100-135ms at each of the conditions in the Expectation x Dot Validity ANOVA. Error bars represent standard error of the mean.





*Figure 8.* Mean N1 Amplitudes.

Amplitudes were extracted over 165-200ms at each of the conditions in the Expectation x Dot Validity ANOVA. Error bars represent standard error of the mean.

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## Appendix: IRB Approval Letter



RESEARCH INTEGRITY AND COMPLIANCE  
 Institutional Review Boards, FWA No. 00001669  
 12901 Bruce B. Downs Blvd., MDC033 • Tampa, FL 33612-4799  
 (813) 974-5638 • FAX (813) 974-7091

May 19, 2015

Constanza de Dios  
 Psychology  
 4202 E Fowler Ave  
 PCD 4118G  
 Tampa, FL 33620-7200

RE: **Expedited Approval for Initial Review**  
 IRB#: Pro00021975

Title: The Influence of Motivational Salience on Attention Selection

**Study Approval Period: 5/19/2015 to 5/19/2016**

Dear Ms. de Dios:

On 5/19/2015, the Institutional Review Board (IRB) reviewed and **APPROVED** the above application and all documents outlined below.

**Approved Item(s): Protocol Document(s):** [MSAS Protocol Version 1 5/4/2015](#)  
**Consent/Assent Document(s)\*:** [MSAS consent Version 1.pdf](#)

\*Please use only the official IRB stamped informed consent/assent document(s) found under the "Attachments" tab. Please note, these consent/assent document(s) are only valid during the approval period indicated at the top of the form(s).

It was the determination of the IRB that your study qualified for expedited review which includes activities that (1) present no more than minimal risk to human subjects, and (2) involve only procedures listed in one or more of the categories outlined below. The IRB may review research through the expedited review procedure authorized by 45CFR46.110 and 21 CFR 56.110. The research proposed in this study is categorized under the following expedited review category:

(4) Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing.

(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

As the principal investigator of this study, it is your responsibility to conduct this study in accordance with IRB policies and procedures and as approved by the IRB. Any changes to the approved research must be submitted to the IRB for review and approval by an amendment.

We appreciate your dedication to the ethical conduct of human subject research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

Kristen Salomon, Ph.D., Vice Chairperson USF Institutional Review Board