

SUPPLEMENTAL INFORMATION

Reward reduces conflict by enhancing attentional control and biasing visual cortical processing

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Supplemental Results and Discussion

Behavioral results

To further investigate our results, the RT data (Fig. S1A) were submitted to subsequent 2 x 2 analyses. A 2 *motivation* (reward, no-reward) x 2 *congruency* (incongruent, neutral,) ANOVA revealed a significant interaction between *motivation* and *congruency* ($F(1,49) = 5.44, p < .05$), and showed that *interference* (incongruent vs. neutral) was reduced during the reward (24 ms) relative to the no-reward (36 ms) condition. A second 2 *motivation* (reward, no-reward) x 2 *congruency* (neutral, congruent) ANOVA revealed a significant interaction between *motivation* and *congruency* ($F(1,49) = 5.88, p < .05$), and showed that *facilitation* (congruent vs. neutral) was also reduced during the reward (17 ms) compared to no-reward (27 ms) condition.

A potential concern with the above results is that the reduction in interference with reward may have been driven by the general speeding up of RT across the three rewarded conditions. To probe this question, we normalized the RTs of congruent and incongruent trials relative to the RT for neutral ones (ratios were determined separately for the reward and non-reward conditions). Both the interference ($t(49) = 1.98; p < .05$) and facilitation ($t(49) = 2.08; p < .05$) effects were significantly reduced during the reward compared to no-reward condition. These results indicate that it is unlikely that the observed changes in behavioral performance with reward were a simple reflection of overall faster RTs.

A parallel 2 x 3 ANOVA on mean accuracy data (Fig. S1B) also revealed a main effect of *motivation* ($F(1,49) = 30.53, p < .001$), as participants were more accurate during the reward (96%) relative to the no-reward condition (93%), a main effect of *congruency* ($F(2,98) = 61.13, p < .001$), as participants made fewer errors during congruent (3%) and neutral (5%) trials compared to incongruent (10%) ones. As with the RT data, a statistically significant *motivation* x *congruency* interaction was observed ($F(2,98) = 13.64, p < .001$). Additional 2 x 2 analyses on accuracy were also run. A 2 *motivation* (reward, no-reward) x 2 *congruency* (incongruent, neutral) ANOVA revealed a significant interaction between *motivation* and *congruency* ($F(1,49) = 20.65, p < .001$), as *interference* (incongruent vs. neutral) was reduced during the reward (2%) relative to the no-reward (7%) condition. A second 2 *motivation* (reward, no-reward) x 2 *congruency* (neutral, congruent) ANOVA revealed no statistically significant interaction ($F(1,49) = 0.01, p = .91$).

It is important to note that, although participants exhibited reduced interference scores during the reward compared to the no-reward condition, no speed-accuracy trade-off was observed, as participants were more accurate during the reward condition. During rewarded trials, RTs were faster across all conditions (vs. no-reward) and not slower, so any of the observed effects were not a simple reflection of a more cautious mode of responding. In addition, facilitation scores were reduced during the reward vs. no-reward condition, too.

Functional MRI results

Localizer data

In bilateral parahippocampal gyrus, surprisingly, we observed reduced activation during the reward vs. no-reward condition, irrespective of congruency (Fig. S3A). This result was

unexpected because we had anticipated that during the reward condition increased visual processing would have been observed, especially because house/building stimuli were task relevant. We believe that this pattern of results was due to a contamination from the processing of the reward strings (including the “2000” string and the cumulative points) shown following the critical compound target stimulus, for the following reasons.

The representation of objects in visual cortex appears to follow a center vs. periphery organization in which objects relying on central vision, such as faces and words, engage more lateral occipito-temporal visual cortex, including the fusiform gyrus, and objects that are linked to more peripheral vision, such as buildings and scenes, engage more medial occipito-temporal visual cortex, including the parahippocampal gyrus [1, 2]; see Fig. S3C.

As discussed in the context of our localizer runs, words in particular are known to robustly recruit the left fusiform gyrus, and buildings and scenes are known to engage the parahippocampal gyrus, bilaterally. Intriguingly, our localizer data suggest that viewing letter strings not only activated more lateral temporal visual regions, but it also deactivated (relative to fixation) medial occipito-temporal visual regions, including the parahippocampal gyrus (Fig. S3D).

In this context, it is worth considering that, following the target phase, a 0.8-s display was shown containing a number that indicated the points obtained in each trial, namely the string “0000” or “2000”, in addition to showing the total accumulated points. It stands to reason that the “2000” string and the string displaying the increased cumulative points are considerably more attention grabbing than the strings shown during the no-reward condition. Accordingly, during the reward condition, the enhanced processing of the number displays may have led to a larger *reduction* in activation in the parahippocampal gyrus relative to the no-reward condition.

If this effect was strong enough to offset any increased processing of the house/building item during the reward condition (for instance, due to increased attention), a main effect of reward in the “reverse direction” than originally anticipated (i.e., no-reward > reward) would have been observed (Fig. S3E).

The above interpretation is also supported by pilot data (N=6) in which a similar conflict task was performed, but during which no reward feedback was provided at the end of the trial (as in the present case). Evoked responses in the parahippocampal gyrus were greater during the reward relative to the non-reward condition, consistent with enhanced processing of the scene items during the former condition (Fig. S3B), and as originally expected for the current study.

In summary, although tentative, our explanation for the absence of an effect of reward on parahippocampal responses is related to a potential contamination of responses in this region by the reward outcome display. Accordingly, our paradigm did not provide a “clean” way to index house- or building-related activity. Therefore, in addition to the mediation analysis involving the left fusiform gyrus, we did not attempt one via the parahippocampal in which an *amplification* effect would have been expected (given that scenes were task relevant).

Additional Network Analysis

In addition to the right IPS ROI, cue-related responses from the pre-SMA/SMA and right FEF ROIs also exhibited significant correlations with conflict-related activity in the medial PFC ROI at the target phase (see results in the main text). Therefore, for completeness, we ran two additional mediation analyses: one employing pre-SMA/SMA cue-related responses as the initial variable, another employing right FEF cue-related responses as the initial variable. The results are shown in Table. S1 and revealed that there was little evidence for a mediation effect (product

of *a* and *b*) in the case of the right FEF, but in the case of the pre-SMA/SMA, the mediation value nearly crossed the statistical significance critical boundary.

Estimation of cue and target responses: Potential “spill-over” effects

The ability to adequately estimate cue and target activity was an essential component of our study. However, given the sequential nature of the two phases, i.e., the impossibility of randomizing their order, it was important to evaluate any potential problems with response estimation. We investigated this issue by performing a series of computer simulations, as described next.

For each subject, simulated BOLD responses were determined by assuming that responses to the cue were sustained during the entire cue-target interval. Target responses were assumed to be transient (modeled for 2 sec from the start of the target to the end of the outcome). In addition, cue responses were assumed to be influenced by reward; target responses were assumed to be sensitive to conflict, as is typically observed in the medial PFC. In other words, no assumption of an effect of reward during the target phase was made to allow us to evaluate potential spill-over effects of reward from the cue phase. Simulated BOLD responses further assumed the exact trial sequence of each participant, namely the same order of correct and incorrect responses, and so on. The magnitudes of cue and target responses were chosen so as to mimic the magnitudes observed in the actual fMRI data of the medial PFC. The magnitudes of target responses for each congruency condition during reward and no-reward conditions were chosen to be the same, namely, in theory we should not observe any main effect of *motivation* or *motivation x congruency* interaction if the estimation of target responses was indeed not contaminated by the cue phase. No additional noise was added to the simulated BOLD signal.

The main question was then: Does the sustained reward signal from the cue spill-over into the target? To answer this question, we estimated the simulated responses by utilizing the exact same procedure employed to estimate the responses in the actual fMRI study (i. e., not assuming any shape for cue and target phases).

As shown in Fig. S4A, some contamination of target responses by cue activation was observed (corresponding to the difference between the solid and dashed curves). This contamination was largest at 2.5 s following target onset, but at other times the spill-over was very modest in size relative to the actual responses to the cue and target stimuli. In the present context, our main goal was to assess potential contributions of a spill-over to a motivation by congruency interaction. Spill-over contributions to a potential interaction were evaluated by considering the following index: $[(\text{Incong} - \text{Neut})_{\text{REWARD}} - (\text{Incong} - \text{Neu})_{\text{NO-REWARD}}]$ (Fig. S4B). As can be seen, the spill-over contribution was negligible.

The above results demonstrate that the peak target-related activity around 5 and 7.5 sec after target onset was not contaminated in a significant fashion by cue signals when the latter are sustained during the cue-target interval. However, it is conceivable that our motivation manipulation affected the extent to which cue activity was itself sustained. In particular, signals may have been sustained during the reward condition, but transient during the no-reward condition, as subjects may have had a greater incentive to succeed in the former condition. Accordingly, a second simulation was run, exactly as described above, except that cue-related responses were sustained only during reward trials. Could this then lead to motivation x congruency effects during the target phase? Again, the spill-over effect of reward was largest at 2.5 sec following target onset and was quite small at 5 and 7.5 sec following target onset. Critically, the effect of cue-phase spill-over on the motivation x congruency interaction was

negligible for all time points, and displayed a pattern nearly indistinguishable from the one shown in Fig. S4B. In summary, our simulations illustrate that the estimation of target-related responses was not contaminated in a way that biased our findings. Even though our simulations did not include a noise component (which, naturally, is found in fMRI data), including it would not have altered our conclusions. This is because random noise would be expected to add or subtract to our signals in an unsystematic fashion. Thus, although this would have increased the variability in the estimated responses, noise would not be expected to distort the estimates in a way that favored some conditions over others.

Reward outcome/delivery responses

In the present study, target- and outcome-related contributions to evoke responses could not be separated because of their close proximity (200 ms). However, the main focus of the present study was to investigate *motivation* x *congruency* interactions, which are indexed by [(Incong – Neut)_{REWARD} – (Incong – Neut)_{NO-REWARD}] and [(Cong – Neut)_{REWARD} – (Cong – Neut)_{NO-REWARD}] terms. Accordingly, common outcome-related activity would be expected to be “subtracted out” during corresponding motivational condition, thus having minimal impact on the interaction terms themselves.

At the same time, at the target phase, the main effect of *motivation* was clearly influenced by the reward outcome. Thus, the regions reported in Table 2 were likely engaged partly because of reward outcome processing.

Table S1: Mediation analysis results

	Path Coefficients (p-values)				
Initial Variable	a	b	c'	c	ab
right Intraparietal sulcus	-0.37 (.01)	0.79 (.004)	-0.49 (.07)	-0.78 (.005)	-0.29 (.05)
Supplementary Motor Area	-0.17 (.03)	0.85 (.002)	-0.23 (.12)	-0.37 (.01)	-0.14 (.07)
right Frontal Eye Field	-0.23 (.12)	0.85 (.001)	-0.59 (.03)	-0.78 (.006)	-0.19 (.15)

Supplementary Figure captions

Figure S1. Behavioral results. (A) Subjects were faster during the reward relative to no-reward condition. Importantly, reduced interference and facilitation reaction time effects were also observed during the reward condition. (B) Subjects were also more accurate and showed reduced interference during the reward condition. Cong, congruent trials; Incong, incongruent trial; Neut, neutral trials. Error bars represent standard error of the mean.

Figure S2. Trial-based response estimation. Actual fMRI signal and data fit (for all separate trials combined) from a voxel in right IPS. This type of fit, which was observed throughout the main regions targeted in the present study, illustrates that the technique employed provided an adequate model of the time series. TR, repetition time.

Figure S3. Scene-related responses in parahippocampal gyrus. (A) Mean deconvolved responses in the ROI defined from the localizer run. (B) Mean deconvolved responses based on data from a separate pilot study. (C) Results from the Levy et al. (2001) study showing that stimuli such as faces and words that require central vision activate more lateral occipito-temporal visual cortex (red), whereas building and houses that rely more strongly on peripheral vision activate more medial occipito-temporal visual cortex (blue). (D) In the present study, during the localizer run, regions of medial occipito-temporal cortex (including parahippocampal gyrus) exhibited “deactivation” during word blocks (thresholded at $P < .05$, FDR corrected). (E) In the present study, during the main experimental runs, a main effect of reward (thresholded at $P < .05$, FDR corrected) was observed in similar medial occipito-temporal sites. Blue indicates decreased

responses during the reward vs. no-reward condition, which was interpreted as due to a contamination from the processing of the number strings during the reward outcome/delivery phase. Cong, congruent trials; Incong, incongruent trial; Neut, neutral trials; Rewd, reward condition; No-Rewd, no-reward (control) condition.

Figure S4. Cue and target estimation simulations. (A) Estimated target phase responses during reward trials under two different scenarios. In the “NoCue” case, responses were estimated without any cue phase response in the simulated data and using only target phase regressors, whereas in the “SustCue” case, responses were estimated when sustained cue phase signals were present in the simulated data; in this case both cue and target phase regressors were present in the model (as in the actual fMRI data analysis). Some “spill-over” from the cue to the target phase is discernible, particularly at the 0 and 2.5 sec time points. The spill-over is minimal, however, at the 5 and 7.5 sec time points that were used to index response magnitude at the target phase (in the actual fMRI data analysis). (B) The sustained-cue scenario was used to estimate the extent of signal spill-over that could contribute to a motivation by interference interaction during the target phase. Spill-over contributions are shown at each time point. The next-to-last bar (magenta) shows the average of the spill-over contributions at 5 and 7.5 sec after trial onset and the last bar (red) shows the actual interaction score observed in the MPFC ROI (see Fig. 4B). It can be seen that the magnitude of the spill-over from sustained cue signals cannot account for the effect observed in the actual data.

References

1. Hasson, U., et al., *Eccentricity bias as an organizing principle for human high-order object areas*. Neuron, 2002. **34**(3): p. 479-90.
2. Levy, I., et al., *Center-periphery organization of human object areas*. Nat Neurosci, 2001. **4**(5): p. 533-9.

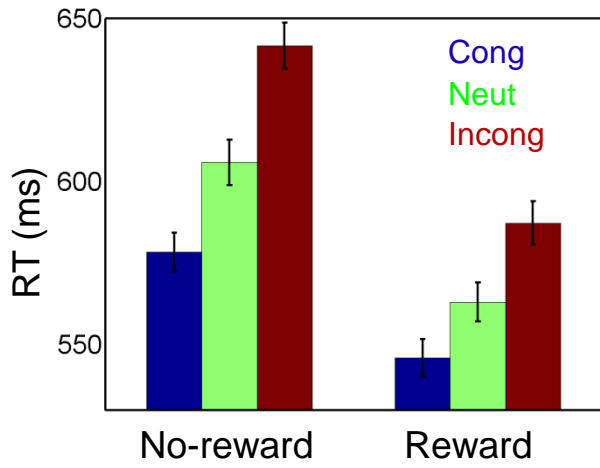
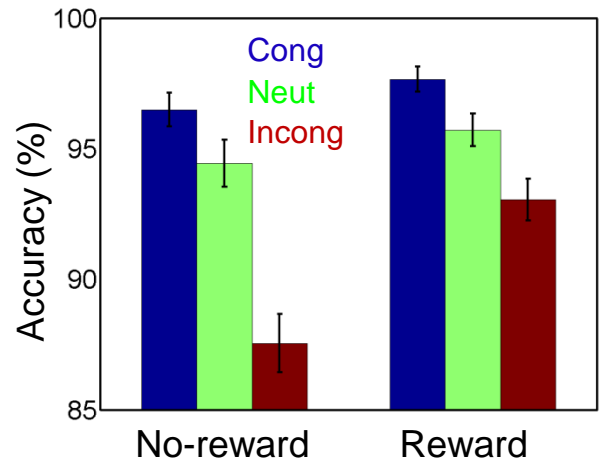
A**B**

Figure S1

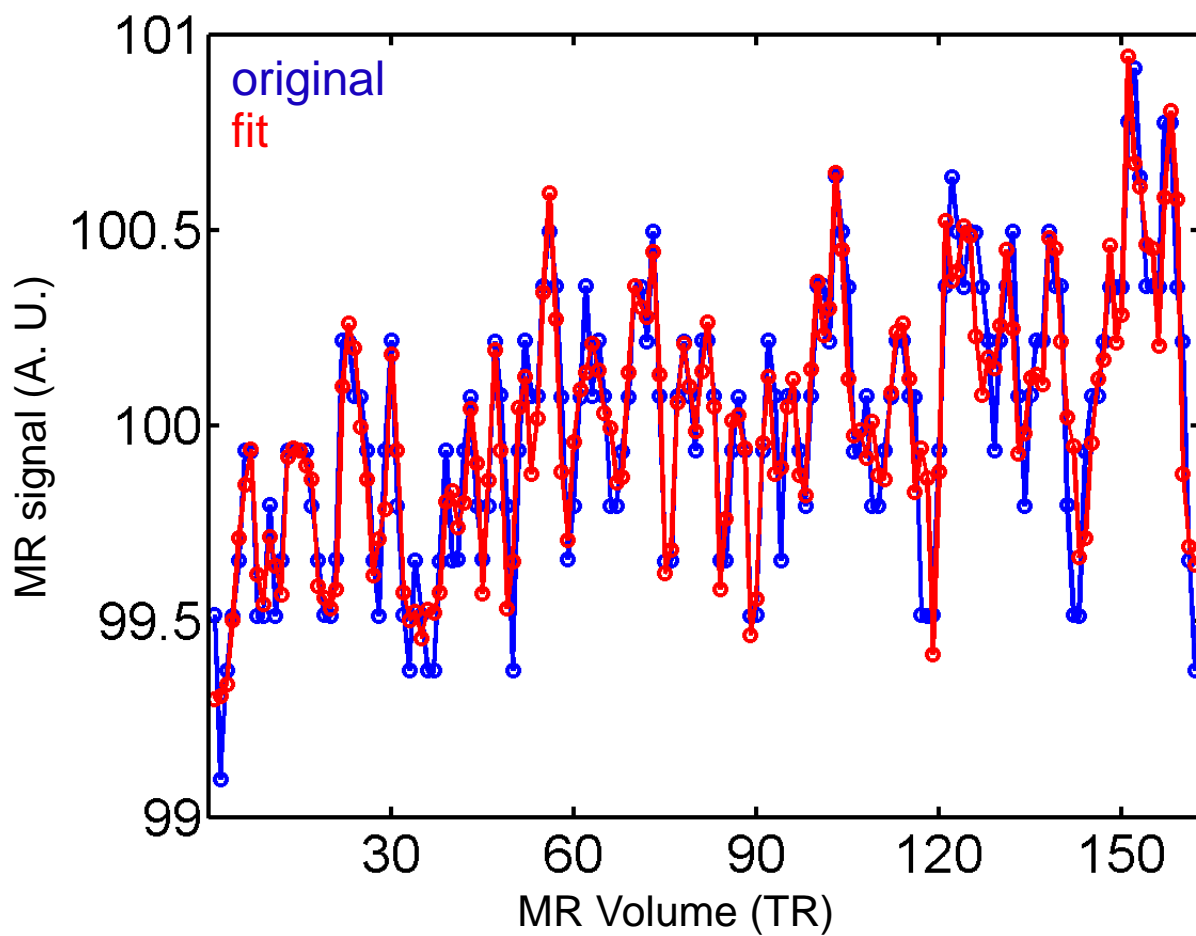
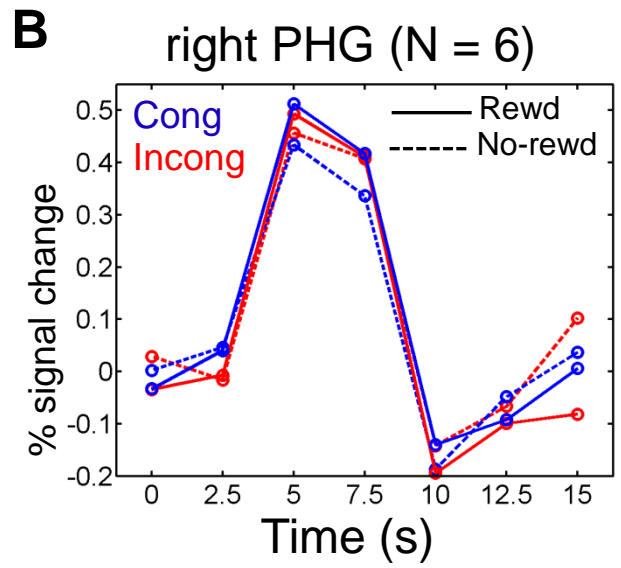
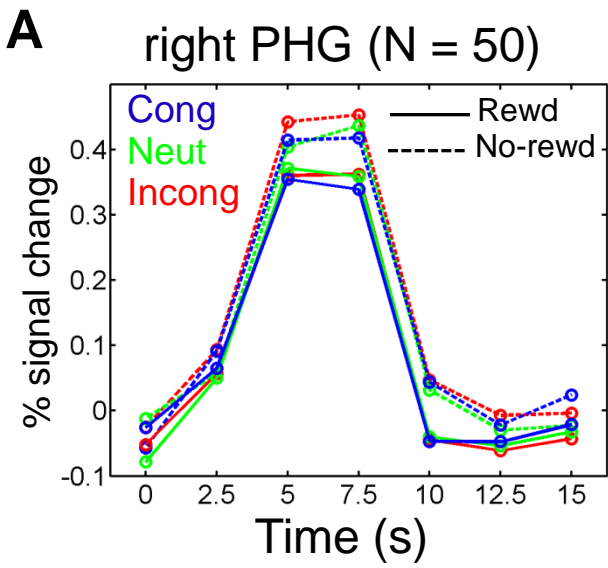
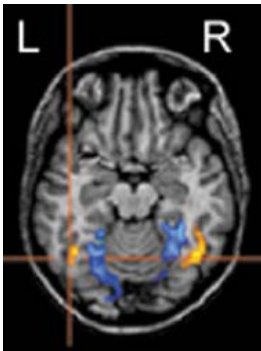


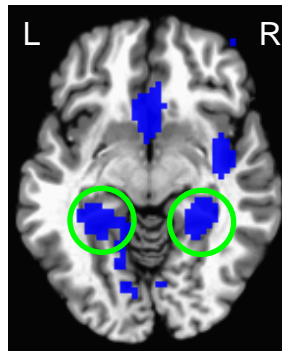
Figure S2



C Levy et al. (2001) (Fig. 2A)



D "Word" blocks of localizer run



E Main effect of *Reward* during conflict runs

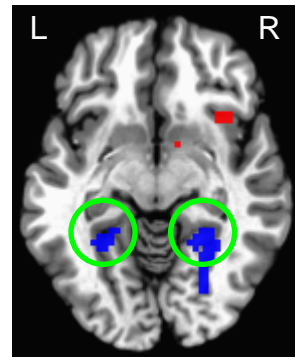


Figure S3

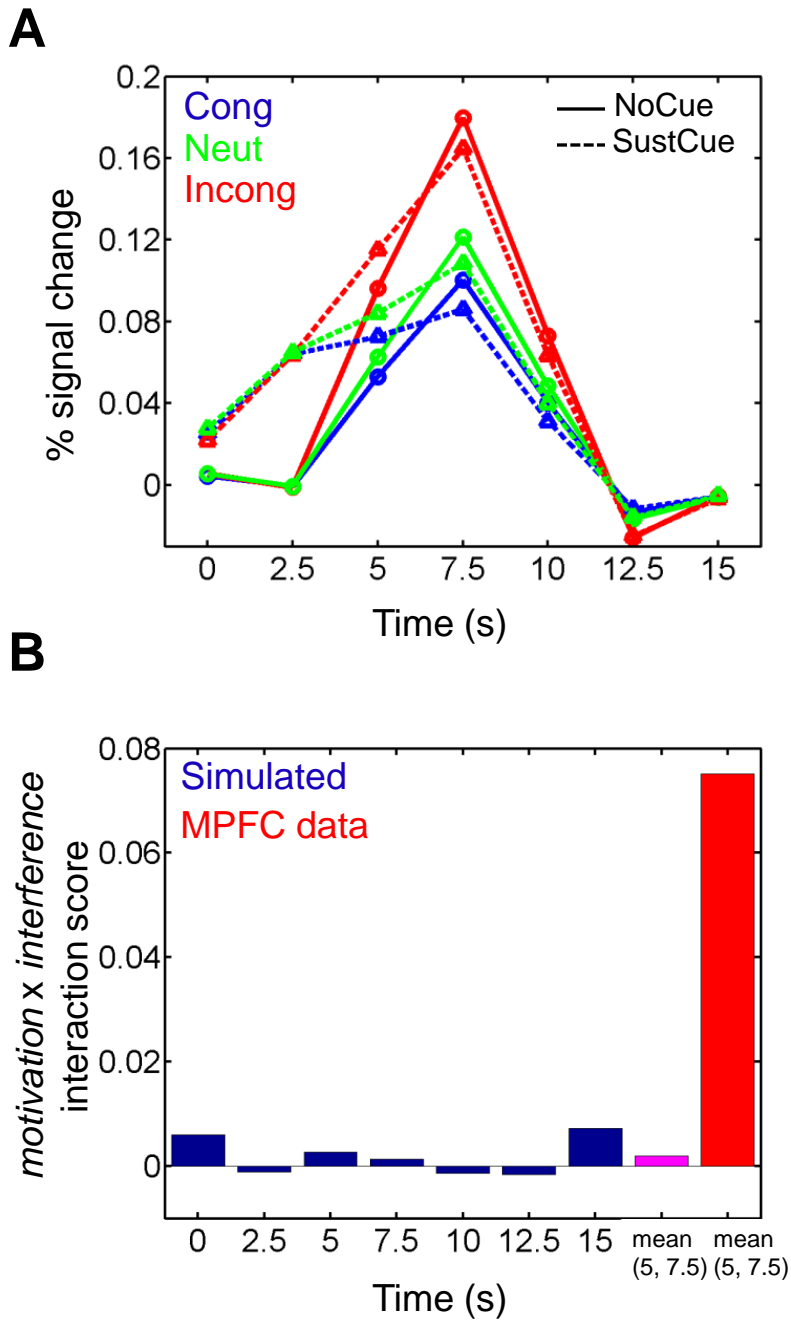


Figure S4