SUPPLEMENTAL MATERIALS

TO ACCOMPANY

Capture and control:

Working memory modulates attentional capture by reward-related stimuli

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This document has 3 sections:

S1. Analysis of value-modulated attentional capture across blocks of visual search.

S2. Analysis of effect of distractor–target separation.

S3. Analysis of saccade latency.

S1. Analysis of value-modulated attentional capture across blocks of visual search

Our primary analyses collapsed across blocks of the visual search task to maximize sensitivity to effects of most interest – specifically, the effect of reward on oculomotor capture as a function of memory load. Here we report analyses of these data broken down by task-blocks (recall that there were five blocks each of high and low memory load). Here we analysed proportion of omission trials using ANOVA with factors of distractor type (high-reward vs low-reward), memory load (high load vs low load) and block (1-5). We report here only significant effects involving block, since findings not involving block are reported in the main text.

Experiment 1

Data are shown in Figure S1A. ANOVA revealed a marginal three-way interaction between memory load, block and distractor type, $F(4,116)=2.36$, $p=.057$, $\eta_p^2=.08$. Follow-up two-way ANOVAs for the different memory load conditions revealed a marginal block × distractor type interaction under conditions of both high load $F(4,116)=2.5$, $p=.05$, $\eta_p^2=.08$ and low load $F(4,116)=2.3$, $p=.06$, $\eta_p^2=.07$. Figure S1A does not indicate a clear, systematic change across blocks for either of these effects: the interaction showed a marginal quadratic trend on high-load trials $F(1,29) = 4.0$, $p = .056$ but did not show a significant linear or quadratic trend on low-load trials, Fs<1. Notably, the VMAC score (difference in omissions on high-relative to low-reward trials) did not differ significantly between Blocks 1 and 5 for either the high-load condition $t(29)=1.2$, $p=.26$ or low-load condition $t(29)=0.28$, $p=.78$.

Experiment 2

Single distractor trials. Data are shown in Figure S1B. ANOVA revealed a main effect of block, $F(4,164)=3.26$, $p=.028$, $\eta_p^2=.074$. Proportion of omissions was lowest in intermediate blocks, with block showing a significant quadratic trend, $F(1,41)=15.4$, $p<.001$, $\eta_p^2=.27$.

Both-distractor trials. Data are shown in Figure S1C. ANOVA revealed a significant interaction between block and distractor type, $F(4,164)=2.60$, $p=.038$, $\eta_p^2=.06$. There was a tendency for the effect of distractor type to increase over blocks, with the interaction showing a marginal linear trend, $F(1,41)=3.05$, $p=.088$, $\eta_p^2=.07$.

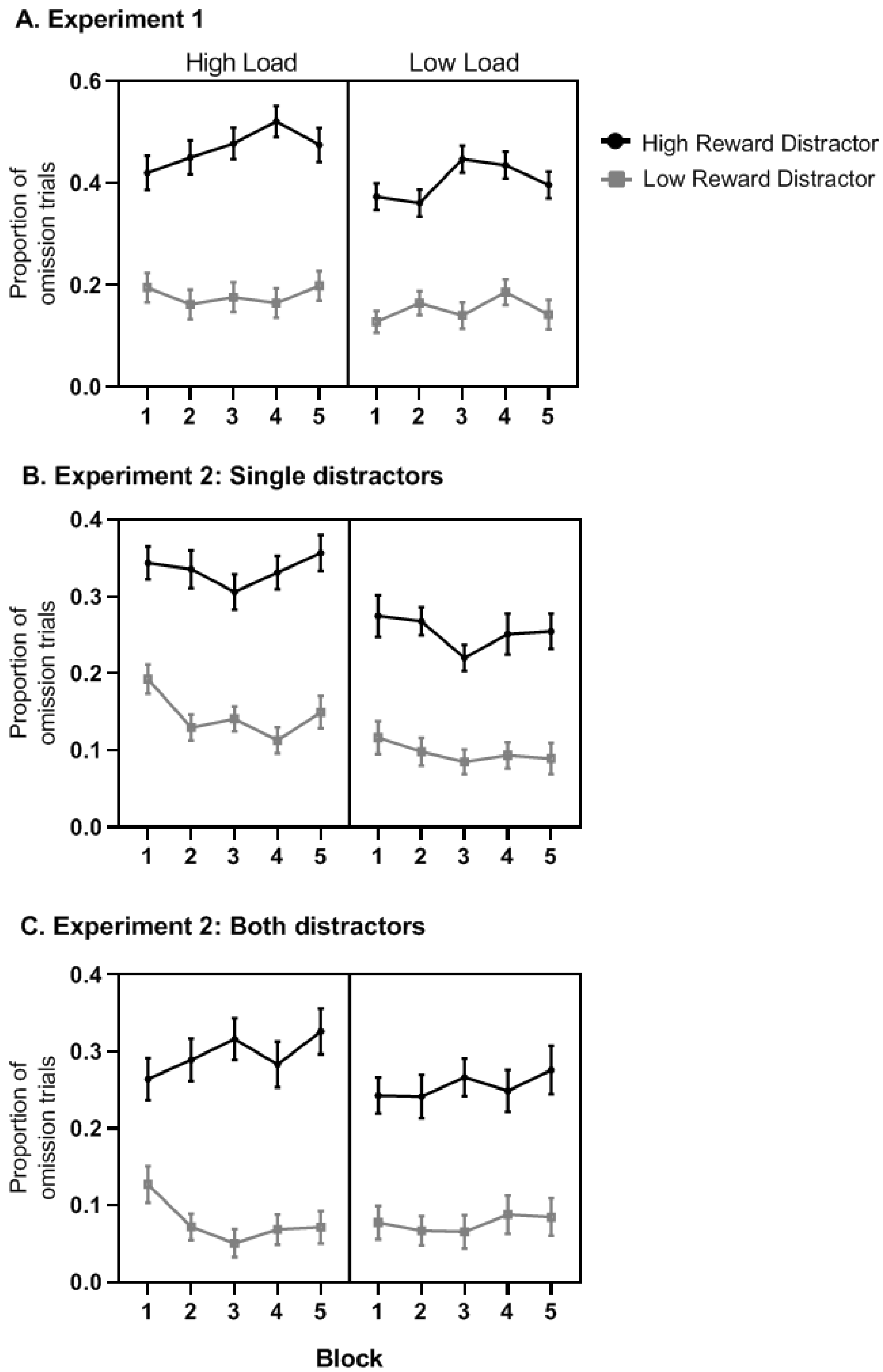

Figure S1. Proportion of omission trials caused by looking at the high-reward versus the low-reward distractor (our contrast showing the effect of reward) across blocks of trials with high versus low memory-load, for (A) Experiment 1, (B) single-distractor trials of Experiment 2, and (C) both-distractor trials of Experiment 2. Error bars show within-subjects SEM.

Discussion

Overall, performance was relatively stable over blocks of the visual search task, with some evidence of a tendency for the effect of reward to increase across blocks as participants gained more experience with the task. The critical finding of our primary analyses—the distractor type × memory load interaction—did not vary significantly over blocks in any case (the interaction did approach significance in Experiment 1, but there was no clear and systematic change in the interaction across blocks). The relatively weak effect of block is perhaps unsurprising, since participants were explicitly instructed regarding all stimulus–reward contingencies at the outset: they were not required to learn these contingencies via trial-by-trial experience.

S2. Analysis of effect of distractor–target separation

In the following analyses we examined whether the distance between the target and the coloured distractor influenced the proportion of omission trials. There were six evenly spaced stimulus locations in the search display (see Figure 1 in the main text). In Experiment 1 the colour-singleton distractor could be located either two or three positions away from the target (i.e., there was a polar angle of either 120° or 180° between distractor and target). In Experiment 2, the coloured distractor location(s) were either adjacent to the target (60° polar angle) or two positions away. For each experiment, we analysed proportion of omission trials using ANOVA with factors of distractor type (high-reward vs low-reward), memory load (high load vs low load) and target–distractor distance. We report here only significant effects involving distance, since findings not involving distance are reported in the main text.

Experiment 1

Data are shown in Figure S2A. The ANOVA revealed a marginal three-way interaction between memory load, distractor type and target–distractor distance (two or three locations), $F(1,29)=4.0$, $p=.054$, $\eta_p^2=.12$. We conducted separate ANOVAs for the high versus low memory load conditions. Under low load, there were no significant effects involving distance, all $F<1$. Under high load, there was a significant distractor type × distance interaction, $F(1,29)=8.0$, $p=.008$, $\eta_p^2=.22$, with a greater effect of reward on attentional capture when distractors were closer to the target. Paired t-tests revealed that there was no significant effect of distance for the low-reward distractor $t(20)=0.40$, $p=.70$. However, participants made significantly more omissions on high-reward distractor trials when the target–distractor was shorter, $t(29)=2.73$, $p=.01$.

Experiment 2

Single distractor trials. Data are shown in Figure S2B. ANOVA revealed a significant main effect of distance, $F(1,41)=51.3$, $p<.001$, $\eta_p^2=.56$, with participants making more omissions overall when the distractor was located adjacent to the target than when it was two positions away. There were no further effects involving distance, all $F<1.89$, $p>.22$.

Both-distractor trials. Data are shown in Figure S2C. ANOVA revealed a marginally significant interaction between memory load, distractor condition and target–distractor distance, $F(1,41)=3.1$, $p=.08$, $\eta_p^2=.07$. We therefore conducted separate ANOVAs for the high versus low memory load conditions. Under low load, there was a significant main effect of distance, $F(1,41)=47.4$, $p<.001$, $\eta_p^2=.54$, with participants more likely to look at the distractor when it was adjacent to the target than two positions away. Under high load, there was a significant distractor type × distance interaction, $F(1,41)=11.1$, $p=.002$, $\eta_p^2=.21$, with a greater effect of reward on omissions when distractors were closer to the target (or phrased differently, a greater effect of distance for high-reward distractors than low-reward distractors).

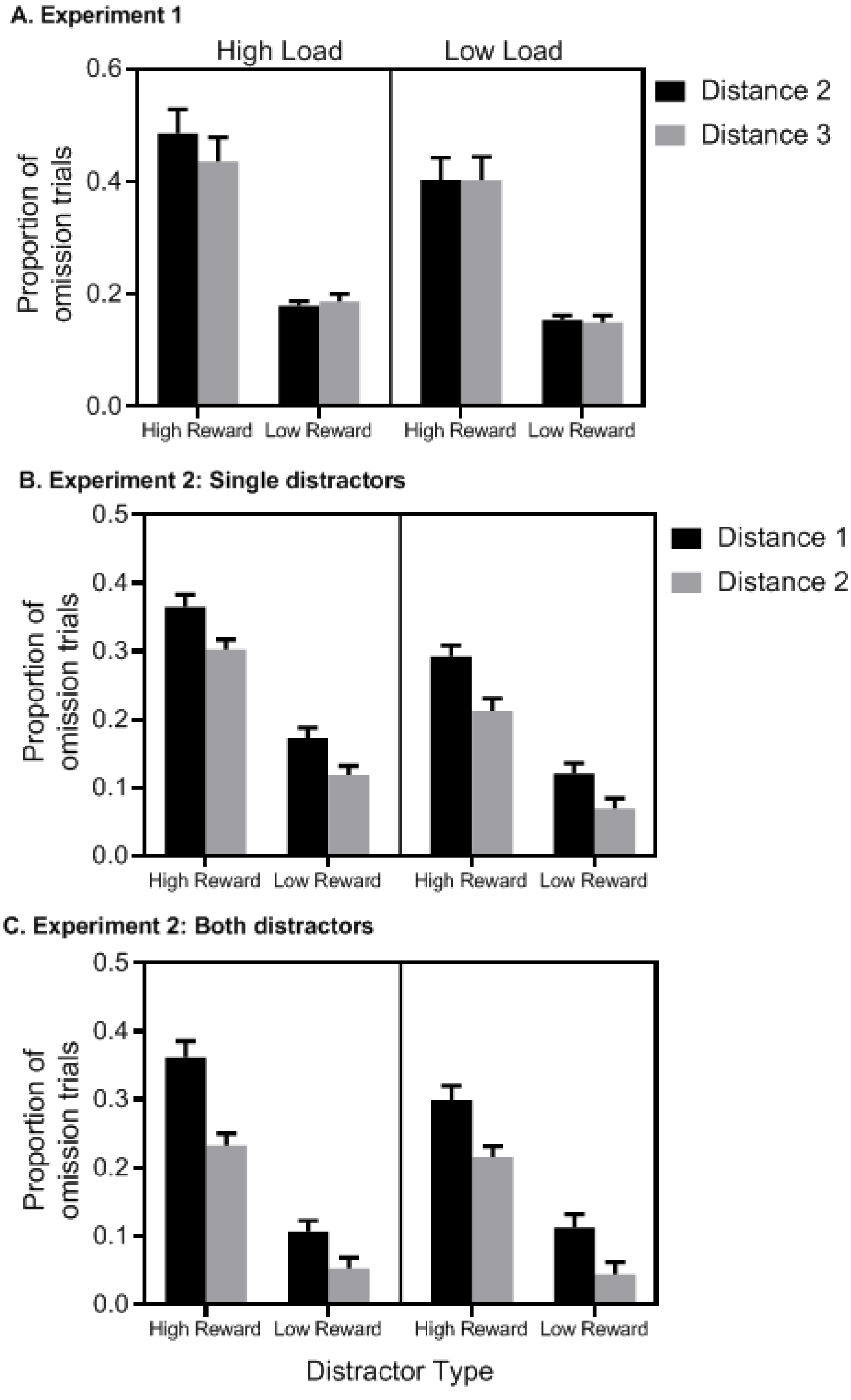

Figure S2. Proportion of omission trials caused by looking at the high-reward versus the low-reward distractor as a function of memory load and distractor–target distance. Distances of 1, 2, and 3 indicate that the coloured distractor was 1, 2, or 3 stimulus locations away from the target respectively. Data are shown for (A) Experiment 1, (B) single-distractor trials of Experiment 2, and (C) both-distractor trials of Experiment 2. Error bars show within-subjects SEM.

Discussion

Overall, there was a tendency for more omission trials when the coloured distractor was closer to the target. One interpretation is that the distractor was more likely to capture attention when it was closer to the target, consistent with previous findings (e.g., Gaspar & McDonald, 2014; Hickey & Theeuwes, 2011; Mounts, 2000). An alternative, however, is that non-systematic inaccuracy in participants' eye-movements (or in the measurement of those movements by the eye-tracker) meant that gaze was more likely to be recorded in the area surrounding the distractor (triggering reward omission) when this distractor was closer to the target. Of more interest is the finding that the effect of proximity to the target was particularly pronounced for high-reward distractors under high memory load. This finding cannot be ascribed to noise in (measurement of) eye-movements since such noise would equally affect low-reward trials. Instead it is consistent with the idea that high-reward distractors are particularly likely to drive automatic attentional capture under high memory load (when executive control of attention is limited), with this capture influenced by distractor–target separation as suggested by previous research.

S3. Analysis of saccade latency

We analysed the latency of the first saccade made after presentation of the search display, using the raw data from the eye-tracker (sampled at 300 Hz). Saccades were detected using a velocity-threshold identification algorithm (Salvucci & Goldberg, 2000) with a velocity criterion of 40^{o} visual angle per second. Following our previous protocols (Le Pelley, Pearson, Porter, Yee, & Luque, 2018; Pearson et al., 2016) we excluded trials in which the latency of the first saccade was less than 80 ms (anticipatory saccades), no gaze was recorded within 2.53° (100 pixels) of the fixation point within the first 80 ms, or in which no saccade was registered.

For the analyses of first saccade latency in Experiment 1 and for the single-distractor trials of Experiment 2, we used ANOVA with factors of distractor type (high-reward versus low-reward), memory load (high load versus low load), and omission category (whether the trial was an omission trial or not). Saccade latencies are generally shorter when participants saccade to the (highly salient) colour-singleton distractor than to the (less salient) shape singleton target (see Figure S1A and S1B; see also Pearson et al., 2016). If we did not include omission category as a factor, then differences in overall saccade latency on high- versus low-reward trials could be driven by the fact that participants were more likely to saccade to the distractor (and less likely to saccade to the target) on high-reward trials. Including omission category as a factor allows us to compare like with like: the effect of distractor type in trials in which participants either did, or did not, saccade to the distractor.

For the analysis of saccade latency in both-distractor trials of Experiment 2, we examined only omission trials and categorised trials depending on whether gaze was captured by the high- or low-reward distractor. We then examined the latency of initial saccades made in the direction of that particular distractor (defined as saccades with an endpoint that fell within a polar angle of 30° to the left or right of the respective distractor location).

For brevity we report only significant effects involving the factors of distractor type – there no significant effects involving memory load in any of the analyses (all $F<1.9$, $p>.19$).

Experiment 1

Data of three participants were not included in the saccade latency analysis because they did not make any omissions on at least one of the trial types.

Data are shown in Figure S3A. ANOVA revealed a significant distractor type × omission category interaction, $F(1,26)=9.32$, $p=.005$, $\eta_p^2=.26$. Whereas there was a trend for faster latencies on high- versus low-reward omission trials, $t(26)=1.9$, $p=.06$, participants were slower to initiate their first saccade on high- relative to low-reward non-omission trials, $t(26)=3.3$, $p=.003$.

Experiment 2

Single-distractor trials. Data of eight participants were not included in the saccade latency analysis because they did not make any omissions on at least one of the trial types. Data are shown in Figure S3B. ANOVA revealed a significant distractor type × omission category interaction, $F(1,33)=11.0$, $p=.002$, $\eta_p^2=.25$. Saccade latency was significantly slower on low- versus high-reward omission trials, $t(33)=2.4$, $p=.024$, whereas this pattern was reversed on non-omission trials, with slower saccades on high-reward than low-reward trials, $t(33)=2.6$, $p=.014$.

Both-distractor trials. Data of twenty participants were not included in the saccade latency analysis because they did not have any omission trials on which they made a saccade towards one type of distractor (such that saccade latency for that type of distractor was undefined).

Data are shown in Figure S3C. ANOVA revealed a marginally significant effect of distractor type, $F(1,21)=4.1$, $p=.056$, $\eta_p^2=.16$ with a trend towards faster saccades to the high-reward distractor than to the low-reward distractor.

Discussion

These analyses suggest that, in general, participants were faster to initiate saccades towards high-reward distractors than low-reward distractors on omission trials; on non-omission trials (when participants did *not* look at the distractor) they were slower to initiate saccades when a high-reward distractor was present in the display. No significant effects of memory load were found.

These findings may suggest that on high-reward trials in which participants were able to successfully ignore the distractor, covert attention was initially directed towards the high-reward distractor but then supressed before the initial saccade. This suggestion is consistent with the Competitive Integration Model of Godijn and Theeuwes (2002). In developing this model, these authors discuss the *remote distractor effect*, which is the finding that saccades to a target take longer to initiate when a physically salient distractor is presented away from the target. They argue that this leads to competition between an exogenous process (driven by the salience of the distractor) and an endogenous process (goal-directed attention to the target) on a saccadic priority map, which ultimately slows down the latency of the winning saccade to the target. Our findings with regard to saccade latency indicate that the magnitude of reward signalled by a distractor also influences this competition, potentially in a similar way to physical salience (see also Pearson et al., 2016).

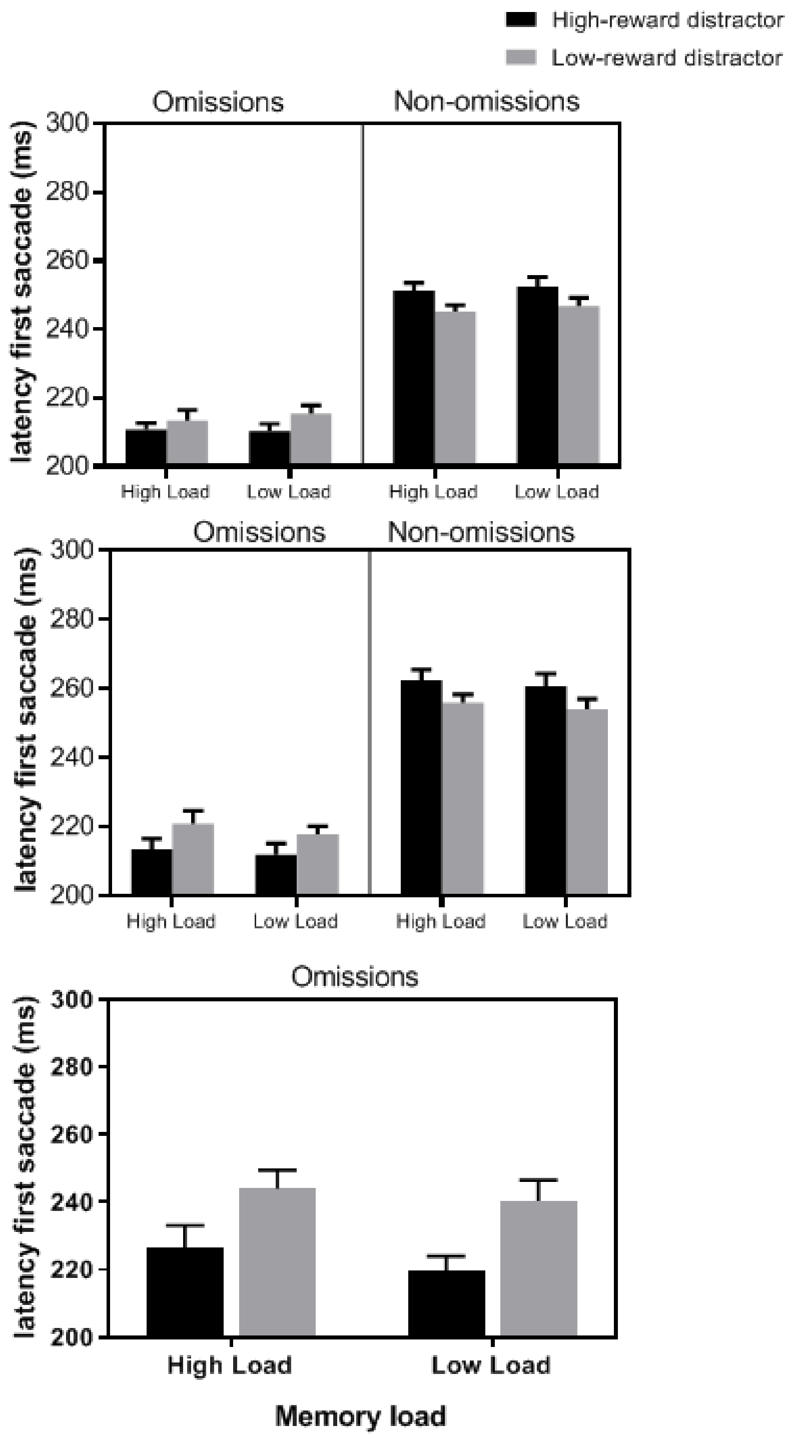

Figure S3. Latency of the first saccade (measured from onset of the search display) in **(A)** Experiment 1 and **(B)** single-distractor trials of Experiment 2, as a function of distractor type in the search display (high-reward or low-reward), memory load (high load or low load), and omission category (whether the trial was an omission trial or not). **(C)** Latency of the first saccade in both-distractor trials of Experiment 2 that were omission trials, as a function of whether the saccade was made in the direction of the high-reward or low-reward distractor, and whether memory load was high or low. Error bars represent within-subject SEM.

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