Cognitive control depletion reduces pre-stimulus and recollection-related measures of strategic retrieval (version 1)

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Cognitive control depletion reduces pre-stimulus and recollection-related measures of strategic retrieval [version 1; peer review: 1 approved, 3 approved with reservations]

Jane E Herron

Cardiff University Brain Research Imaging Centre (CUBRIC), School of Psychology, Cardiff University, Cardiff, CF24 4HQ, UK

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Abstract

Background: The ability to strategically retrieve task-relevant information from episodic memory is thought to rely on goal-directed executive processes, and there is evidence that neural correlates of strategic retrieval are sensitive to reserves of cognitive control. The present study extended this work, exploring the role of cognitive control in the flexible orienting of strategic retrieval processes across alternating retrieval goals.
Method: Pre-stimulus cues directed participants to endorse memory targets from one of two encoding contexts, with the target encoding context alternating every two trials. Items from the nontarget encoding context were rejected alongside new items. One group of participants completed a Stroop task prior to the memory test in order to deplete their reserves of cognitive control, while a second group performed a control task. Event-related potentials (ERPs) were recorded throughout the memory task, and time-locked to both pre-stimulus cues and memory probes.
Results: Control participants' pre-stimulus ERPs showed sustained divergences at frontal electrode sites according to retrieval goal. This effect was evident on the first trial of each memory task, and linked with the initiation of goal-specific retrieval orientations. Control participants also showed enhanced ERP correlates of recollection (the 'left parietal effect') for correctly classified targets relative to nontargets on the second trial of each memory task, indexing strategic retrieval of task-relevant information. Both the pre-stimulus index of retrieval orientation and the target/nontarget left parietal effect were significantly attenuated in participants that completed the Stroop task.
Conclusions: The reduction of pre-stimulus and stimulus-locked ERP effects following the Stroop task indicates that available reserves of cognitive control play an important role in both proactive and recollection-related aspects of strategic retrieval.

Keywords

Memory, ERP, retrieval orientation, strategic retrieval, pre-retrieval, cognitive control

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3 **Timm Rosburg**, University Psychiatric Clinics Basel, Basel, Switzerland

4 **Joshua Koen**, University of Notre Dame, Notre Dame, USA

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Corresponding author: Jane E Herron (herronj1@cardiff.ac.uk)

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Introduction

The retrieval of episodic information in accordance with current goals is enabled by an ensemble of memory control processes which occur prior to, during and after the reactivation of the episodic trace. Many of these processes are closely tied to 'retrieval orientations', goal-directed memory states that facilitate the retrieval of relevant contextual details[1]. The real-time nature of event-related potentials (ERPs) allows memory control processes to be isolated according to their latency and functional properties. Task-switching memory studies have revealed that pre-stimulus cues signalling the onset of different source memory tasks elicit sustained slow-wave ERPs that diverge at frontal electrode sites according to retrieval goals[2]. This effect occurs only when a new memory task begins, linking it with processes involved in the initiation of orientations (e.g. task-set configuration) rather than their maintenance throughout tasks[3]. Importantly, these pre-retrieval measures predict whether criterial source judgments associated with the upcoming test items will be correct or incorrect[4,5], indicating that pre-retrieval control processes could act as gateways to memory.

It is assumed that a retrieval orientation will be tonically maintained while that retrieval goal remains in place[1]. Many electrophysiological and neuroimaging studies have tested this theory by contrasting neural activity elicited by new items between tasks with different retrieval goals, the assumption being that orientations influence how memory probes are processed. This approach allows task-specific processing of memory probes to be identified without confounding this with differences in retrieved content. A large body of ERP and fMRI research supports this view[6–24], and an individual differences analysis demonstrated that this index is positively correlated with memory accuracy[25]. However, this is an indirect measure of retrieval orientation, reflecting task-specific processes operating downstream from those directly involved in sustaining the orientation. This was confirmed by an fMRI study separating item-related neural activity from sustained supra-item neural activity, which found reliable and dissociable effects of retrieval goal in both measures[26].

More recently, it was reported that pre-stimulus ERPs elicited by a neutral fixation asterisk differed according to distinct retrieval goals which were each maintained throughout separate tasks, and it was proposed that this effect directly reflected the ongoing maintenance of retrieval orientations[27]. One group of participants in this study completed a Stroop task[28] between study and test. This consists of colour names printed in incongruently coloured ink, and participants must name the colour of the ink. Overcoming this interference requires participants to exercise cognitive control, the depletion of which impairs performance on further tasks requiring cognitive control[29,30] including the recollection of autobiographical memories[31,32]. The Stroop task eliminated the pre-stimulus ERP orientation effect observed in the control group, indicating that orientation maintenance depends on available reserves of cognitive control. Although memory accuracy was not impaired, the Stroop group showed enhanced ERP measures of post-stimulus monitoring at right frontal sites, indicating an increased reliance on post-retrieval processing in the absence of pre-retrieval orientations.

An earlier study by Elward *et al.*[33] examined how the Stroop task influenced ERP measures of strategic retrieval. Concrete nouns were encoded in two different tasks (specify the item's function or rate how easy/difficult it would be to draw), and participants were instructed to accept test items from a specified encoding task on one key ('targets') while rejecting test items from the non-specified task ('nontargets') on the same key as unstudied items[34]. 'Strategic retrieval' refers to the prioritised retrieval of goal-specific contextual information, and manifests as larger recollection effects for targets than for nontargets. The ERP correlate of recollection is enhanced positivity at parietal electrode sites between 500–800ms, and this is often significantly larger for targets than for nontargets[12,22,35,36]. Elward *et al.*[33] found that participants with high working memory capacity (measured using O-span performance) showed ERP evidence of strategic retrieval, but that this was eliminated following the Stroop task. In contrast, the more recent study described above observed ERP evidence of strategic retrieval that was equivalent across control and Stroop participants[27].

The present study examined the effects of cognitive control depletion on goal-directed memory retrieval further. The same encoding and retrieval tasks used in ERP studies described above[27,33] were used here in conjunction with the Stroop manipulation. The two retrieval tasks were, however, interleaved in a task-switching memory paradigm, with pre-stimulus cues signifying the memory task. The purpose of this was twofold; a task-switching design would allow ERP measures of retrieval orientation *initiation* to be captured, and their susceptibility to cognitive control depletion evaluated. Second, switching between different memory tasks requires a greater degree of cognitive control, and it was predicted that ERP measures of strategic retrieval would consequently be more vulnerable to the Stroop manipulation. There were therefore two principal experimental hypotheses: i) participants completing the Stroop task would show attenuated pre-stimulus ERP measures of retrieval orientation initiation on the first trial of each memory task when compared with controls, and ii) item-locked ERP measures of strategic retrieval (i.e. greater positivity for targets than for nontargets between 500–800ms) would be evident in the control group but reduced in the Stroop group.

Methods

Participants

Participants were Cardiff University undergraduate students who responded to a request for experimental volunteers hosted by the institution's online experimental management system. Inclusion criteria required participants to be aged 18–30, right-handed, speak native English, and have normal or corrected-to-normal vision. Participants gave informed written consent prior to the experiment and were remunerated for their time at a rate of £7.50/hr. Ethical approval was granted by Cardiff University's School of Psychology ethics committee (approval number EC.15.08.11.4184GA2). The experimental dataset consisted of behavioural and electrophysiological data collected

from 50 participants, and the data collection methods are detailed below. Two datasets were discarded due to excessive ERP artifacts, and the remaining 48 participants were alternately allocated to the Stroop group (N=24) or the control group (N=24). This sample size was determined by power calculations based on prior studies which indicated that a sample size of 24 will have 95% power to detect a retrieval orientation initiation ERP effect at $p<0.05$ at the group level ($\omega_p^2=0.10$[3]), a sample size of 20 will have 95% power to detect a strategic retrieval ERP effect at $p<0.05$ ($\omega p^2=0.14$[27]), and that a sample size of 20 will have 95% power to detect a Stroop/control group x retrieval goal interaction in pre-retrieval ERPs at $p<0.05$ ($\eta^2_p = 0.016$[27]). The control group (21 female) were aged 18–24 (mean age: 19.8 years), and the Stroop group (19 female) aged 18–30 (mean age: 21 years; $t(1,23) = 1.31$, $p = 0.20$, n.s.).

Design

Data collection took place in CUBRIC's EEG Lab2 between the 26th October 2016 and the 25th May 2017. Stimuli from the Medical Research Council (MRC) psycholinguistic database[37] consisted of 240 concrete and imageable nouns (integer normative values of concreteness[38] and imageability[39] both ranged from 550–700[37]) with a frequency of 1–15 per million[40] and a letter range of 3–10. Words were shown in white letters on a black computer screen 1.2m from the participant and were presented at central fixation with maximum visual angles of 0.5° (vertical) and 2.2° (horizontal). A single study phase was followed by the Stroop/control task and then by the memory test. Six lists of 40 words were created. Four lists were used in the study phase (160 words). Cues ("FUNCTION" or "DRAW") preceding each study word specified the encoding task, each of which was performed for two consecutive trials. Participants either verbally stated the function of the item, or verbally stated whether the item would be easy or difficult to draw. Cues were presented for 300ms, the screen was blanked for 2000ms, then the study word presented for 300ms. Participants verbally responded before pressing a response key. The next study trial started 1000ms after this keypress. After study, Stroop participants read aloud from five sheets of A4 paper containing five columns of equiprobable colour names ('red', 'green', 'blue' and 'yellow') for 6.5 minutes[27,33]. Word colour and colour meaning were incongruent for 75% of items. Participants were instructed to state the ink colour and to prioritise accuracy over speed. Control participants were given colour names printed in black ink and were instructed to read these aloud.

The memory test contained all six wordlists (240 words); 80 words had been encoded in the function task, 80 in the drawing task, and 80 were new items. These were randomised and preceded either by a "FUNCTION?" or "DRAW?" cue. Each cue-type preceded equal numbers of each stimulus type and was presented for two consecutive trials. The memory test was a cued exclusion task; participants responded on one key to words studied in the specified encoding task ('targets') and on another key to both words from the non-specified encoding task ('nontargets') and new words. The hand used for each response type was counterbalanced across participants. Wordlists were counterbalanced so that each word served as a target, a nontarget and a new item following each cue-type an equal number of times. Test trials began with the 'FUNCTION?' or 'DRAW?' cue (300ms) followed by a blank screen (2000ms) and then the test word (300ms). The screen was blanked until the participant responded, and the next trial began 1000ms later.

Electroencephalogram (EEG) acquisition

EEG was recorded from 32 active electrodes embedded in a cap using a BioSemi ActiveTwo Mk1 electrode system, which incorporated a BioSemi ActiveTwo AD-box ADC-8. Electrode locations were distributed across the scalp and were based on the International 10–20 system[41]. These included midline (Fz, Cz, Pz, Oz,) and left/right hemisphere locations (FP1/FP2, F7/F8, F5/F6, F3/F4, F1/F2, T7/T8, C5/C6, C3/C4, C1/C2, P7/P8, P5/P6, P3/P4, P1/P2, O1/O2). Six further single electrodes were placed on both mastoid processes, above and below the left eye (vertical electrooculogram; VEOG) and from both outer canthi (horizontal electrooculogram; HEOG). EEG (range: DC-419 Hz) was sampled at 2048 Hz and referenced to two linked electrodes positioned midway between POz and PO3/PO4. EEG data was pre-processed using EEGLAB 14[42], a non-proprietary MATLAB toolbox that can also be run using Octave. The continuous EEG data were downsampled to 200 Hz, bandpass filtered (0.1–30 Hz) using EEGLAB's new finite impulse response filter and re-referenced to linked mastoids. Eye movement correction was applied using the extended 'runica' infomax independent component analysis[42,43]. Components reflecting blinks and saccadic eye movements were identified by visual examination of component topographies, time courses, and spectra. These were corrected by back-projecting all but these components to the data space. The ERPLAB toolbox[44] was then used to create cue-locked and stimulus-locked event-related potentials. These functions are also available within EEGLAB. Cue-locked ERPs were 2000ms in length with an additional 200ms pre-cue baseline. Stimulus-locked ERPs were 1500ms in length with an additional 200ms pre-stimulus baseline. Trials containing EEG artifact were eliminated using the ERPLAB moving window peak-to-peak threshold algorithm and artifact rejection was then visually verified. The proportion of cue-locked ERP trials rejected due to artifact was 0.06 in both groups. The proportions of item-locked ERP trials rejected due to artifact were 0.05 in the control group and 0.04 in the Stroop group.

Statistical analysis

All first-stage behavioural and electrophysiological analyses employed mixed model ANOVAs using a non-proprietary analysis program called ALAS (version ALASBIG.exe) which incorporates the Greenhouse-Geisser non-sphericity correction[45]. All reported results include the epsilon-corrected degrees of freedom. The design of each ANOVA is specified below under the relevant behavioural and ERP subheadings. The mean amplitude ERP values subjected to these analyses were calculated using the ERPLAB toolbox[44].

Results

Behavioural analyses

Accuracy data (see Table 1) and reaction time data[46] (see Table 2) were each analysed with a mixed model ANOVA incorporating the within-subjects factors of Retrieval Task (function/draw), Switch/Stay (first/second trial within each retrieval task), and Item Type (target/nontarget/new) and the between-subjects factor of Group (Stroop/control).

The ANOVA conducted on accuracy data revealed main effects of Retrieval Task [$F_{(1,46)} = 14.25$, $p < 0.001$, $\eta^2_p = 0.24$] and Item Type [$F_{(1.7,77.0)} = 59.03$, $p < 0.001$, $\eta^2_p = 0.58$] and a number of interactions, the highest order of which was Group x Switch/Stay x Retrieval Task x Item Type [$F_{(1.8,82.9)} = 3.38$, $p = 0.044$, $\eta^2_p = 0.07$]. These interactions reflected differential effects of the experimental factors of interest on accuracy to each item type; whereas target accuracy was not influenced by any factor (all F's < 1), accuracy to new items was significant higher on switch than on stay trials [$F_{(1,46)} = 7.12$, $p = 0.01$, $\eta^2_p = 0.13$]. Nontarget accuracy showed a more complex pattern, with main effects observed for Switch/Stay [$F_{(1,46)} = 6.05$, $p = 0.018$, $\eta^2_p = 0.12$] and Retrieval Task [$F_{(1,46)} = 11.51$, $p = 0.001$, $\eta^2_p = 0.20$] both of which were moderated by group (Group x Switch/Stay; [$F_{(1,46)} = 12.17$, $p = 0.001$, $\eta^2_p = 0.21$], Group x Retrieval Task [$F_{(1,46)} = 4.55$, $p = 0.038$, $\eta^2_p = 0.09$]). The first of these interactions arose because nontarget accuracy increased from switch to stay trials for control participants only [$F_{(1,23)} = 16.06$, $p = 0.001$, $\omega p^2 = 0.38$]. The Group x Retrieval Task interaction reflected greater nontarget accuracy in the Function than the Draw retrieval task for the Stroop group only [$F_{(1,23)} = 12.38$, $p = 0.002$, $\omega p^2 = 0.31$].

Table 1. Mean response accuracy (%) to each item type separated by Retrieval Task, Switch/Stay, and Group (Stroop/control). 95% confidence intervals in parentheses.

	Control		Stroop	
	Switch	Stay	Switch	Stay
Function				
Target	85 (± 4.0)	81 (± 4.0)	81 (± 4.8)	81 (± 6.4)
Nontarget	75 (± 6.4)	85 (± 4.4)	84 (± 4.4)	84 (± 4.8)
New	96 (± 1.6)	96 (± 2.0)	97 (± 1.6)	96 (± 2.8)
Drawing				
Target	78 (± 6.4)	80 (± 4.4)	83 (± 4.4)	83 (± 4.0)
Nontarget	78 (± 4.8)	79 (± 4.8)	76 (± 5.6)	75 (± 6.0)
New	96 (± 2.0)	92 (± 4.0)	95 (± 2.8)	95 (± 3.2)

The ANOVA conducted on RTs associated with accurate responses revealed main effects of Switch/Stay [$F_{(1,46)} = 9.43$, $p = 0.004$, $\eta^2_p = 0.17$] and Item Type [$F_{(1.7,80.5)} = 121.80$, $p < 0.001$, $\eta^2_p = 0.73$]. The former reflected faster responses on stay trials. Pairwise comparisons revealed that nontarget responses were slower than target responses [Item Type: $F_{(1,46)} = 49.31$, $p < 0.001$, $\eta^2_p = 0.52$], which were in turn slower than new item responses [Item Type: $F_{(1,46)} = 93.19$, $p < 0.001$, $\eta^2_p = 0.67$].

ERP analyses

Pre-stimulus ERPs. Cue-locked ERPs preceding correct responses to all test items were averaged and separated according to retrieval task (function/draw), switch/stay trial status and group (Stroop/control). Figure 1 shows that frontal ERPs elicited by the function cue were more positive going than ERPs elicited by the draw cue. This effect was visually larger in magnitude in control than Stroop participants, and larger on switch than on stay trials.

The mean numbers of trials (minimum-maximum) forming averaged ERPs for each cue type were; control function switch: 48 (32-58), control function stay: 49 (33-56), control

Table 2. Mean reaction times (ms) associated with correct responses to each item type separated by Retrieval Task, Switch/Stay and Group (Stroop/control). 95% confidence intervals in parentheses.

	Control		Stroop	
	Switch	Stay	Switch	Stay
Function				
Target	1018 (± 140)	962 (± 140)	1090 (± 120)	1057 (± 150)
Nontarget	1273 (± 200)	1120 (± 190)	1187 (± 130)	1156 (± 120)
New	843 ± (120)	819 (± 140)	850 (± 130)	756 (± 72)
Drawing				
Target	1010 (± 120)	1034 (± 180)	1067 (± 190)	975 (± 89)
Nontarget	1150 (± 150)	1106 (± 130)	1143 (± 110)	1183 (± 150)
New	785 (± 120)	789 (± 120)	768 (± 94)	736 (± 96)

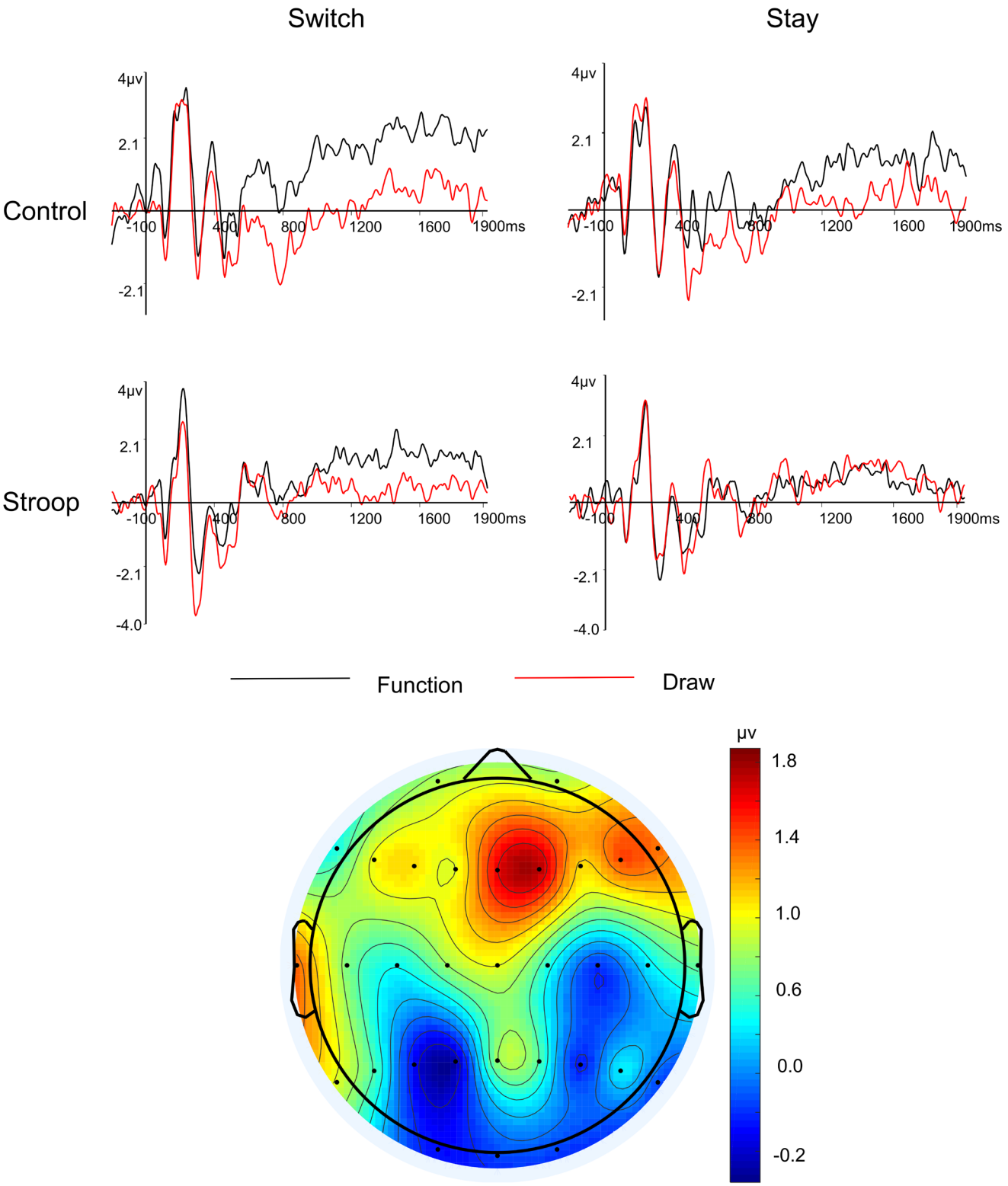

Figure 1. Upper: Pre-stimulus ERPs associated with Function and Draw cues at the superior right frontal electrode site (F2), separated by switch/stay trial status and group (Stroop/control). Amplitude (μv) is plotted on the y-axis across time (ms) on the x-axis. Lower: Voltage map shows the scalp distribution of the Function-Draw preparatory ERP effect observed on switch trials in the control group (scale bar indicates magnitude of effect in μv), maximal in amplitude at F2.

draw switch: 47 (32-55), control draw stay: 48 (37-55), Stroop function switch: 49 (43-56), Stroop function stay: 49 (41-58), Stroop draw switch: 48 (38-57), Stroop draw stay: 48 (39-58). Preparatory ERP effects of cue-type have previously been reported between 700–1900ms[3]. The analysis of cue-related ERPs therefore included mean amplitude measurements between 700–1900ms from 24 electrode sites (F7/F8, F5/F6, F3/F4, F1/F2, T7/T8, C5/C6, C3/C4, C1/C2, P7/P8, P5/P6, P3/P4, P1/P2). The global mixed-model ANOVA incorporated within-subjects factors of Retrieval Task (function/draw), Switch/Stay, Anterior/Central/Posterior, Hemisphere and Site (inferior/mid-lateral/superior/midline) and one between-subjects factor of Group (Stroop/control). Significant effects involving Group were followed by repeated measures ANOVAs within each group.

The global ANOVA revealed interactions between Group x Retrieval Task x Site [$F_{(2.2,103.0)} = 3.57$, $p = 0.027$, $\eta^2_p = 0.07$] and Retrieval Task x Hemisphere x Site [$F_{(2.9,132.1)} = 2.96$, $p = 0.037$, $\eta^2_p = 0.06$]. The repeated measures ANOVA of control group data revealed a Retrieval Task x Anterior/Posterior interaction [$F_{(1.5,34.6)} = 5.80$, $p = 0.012$, $\omega p^2 = 0.16$], reflecting greater positivity for Function than Draw ERPs maximal at frontal sites. A Switch/Stay x Retrieval Task x Anterior/Posterior x Hemisphere interaction [$F_{(1.7,39.4)} = 4.07$, $p = 0.030$, $\omega p^2 = 0.11$] obtained in the same analysis confirmed that this effect was larger in magnitude on switch trials where the effect was largest in magnitude at right frontal electrode sites (see Figure 1). Post-hoc analysis of control group ERPs at frontal electrode sites confirmed a main effect of Retrieval Task on switch trials [$F_{(1,23)} = 6.50$, $p = 0.018$, $\omega p^2 = 0.18$] but not on stay trials. The repeated measures ANOVA of Stroop data indicated no effect of Retrieval Task, either in the global analysis of 24 electrode sites or when analysis was restricted to frontal sites.

Item ERPs. Item-related ERPs were formed for correctly classified targets, nontargets and new items, separated by switch/stay trial status and group (Stroop/control). In order to obtain ERPs with good signal-to-noise, each item-related ERP was a weighted average of ERPs from both retrieval tasks. Figure 2 shows that target ERPs at left parietal electrode sites were more positive going than nontarget and new item ERPs on stay trials in the control group, and that this target prioritisation was not visually evident to the same degree on switch trials or for Stroop participants.

The mean numbers of trials (minimum-maximum) forming control group ERPs were; switch target: 31 (22-39), switch nontarget: 30 (18-37), switch new: 37 (29-40), stay target: 31 (24-37), stay nontarget: 31 (19-39), stay new: 36 (28-40). Trial numbers in the Stroop group were; switch target: 32 (21-37), switch nontarget: 31 (19-38), switch new: 37 (31-40), stay target: 32 (23-40), stay nontarget: 31 (16-38), stay new: 36 (29-40). As ERP measures of strategic retrieval have previously been obtained between 500-800ms[22,35,47], analysis of item-related ERPs incorporated mean amplitude measurements during this time window from the same 24 electrode sites described above. The global ANOVA incorporated within-subjects factors of Item Type (target/nontarget/new), Switch/Stay, Anterior/Central/Posterior, Hemisphere, and Site (inferior/mid-lateral/superior/midline) and one between-subjects factor of Group (Stroop/control). Effects of Item Type (Target/Nontarget/New) were followed up with pairwise comparisons (see Table 3). Once constrained to pairs of experimental conditions, mixed-model ANOVAs revealing significant effects of Group were followed up with repeated measures ANOVAs within each group.

The global analysis revealed a number of interactions involving Item Type (Item Type x Hemisphere [$F_{(1.9,85.3)} = 10.19$, $p < 0.001$, $\eta^2_p = 0.18$], Item Type x Site [$F_{(3.3,149.6)} = 4.28$, $p = 0.005$, $\eta^2_p = 0.09$], Item Type x Anterior/Posterior x Hemisphere [$F_{(3.1,141.9)} = 3.91$, $p = 0.010$, $\eta^2_p = 0.08$], Item Type x Hemisphere x Site [$F_{(4.7,217.1)} = 5.08$, $p < 0.001$, $\eta^2_p = 0.10$]) as well as higher level interactions between Group x Switch/Stay x Item Type x Site [$F_{(3.5,160.2)} = 3.07$, $p = 0.023$, $\eta^2_p = 0.06$] and Switch/Stay x Item Type x Anterior/Posterior x Hemisphere x Site [$F_{(8.8,404.2)} = 1.98$, $p = 0.042$, $\eta^2_p = 0.04$]. The pairwise comparison of targets and new items revealed significant effects of Item Type including Group x Switch/Stay x Item Type x Site (see Table 3). Repeated measures ANOVA of control targets/new items revealed Item Type x Anterior/Posterior x Hemisphere [$F_{(2.0,45.3)} = 6.85$, $p = 0.003$, $\omega p^2 = 0.20$] and Switch-Stay x Item Type x Site [$F_{(2.0,46.1)} = 3.98$, $p = 0.025$, $\omega p^2 = 0.11$] interactions. These reflected greater positivity for targets with a left posterior focus which increased in magnitude from switch to stay trials (see Figure 2). Post-hoc analyses indicated significant effects of Item Type both on switch trials (Item Type x Anterior/Posterior x Hemisphere x Site: [$F_{(4.5,103.5)} = 2.89$, $p = 0.021$, $\omega p^2 = 0.07$]) and on stay trials (Item Type x Site: [$F_{(1.8,40.5)} = 5.05$, $p = 0.014$, $\omega p^2 = 0.14$], with main effects of Item Type at the left parietal maxima (switch: [$F_{(1,23)} = 4.36$, $p = 0.048$, $\omega p^2 = 0.12$], stay: [$F_{(1,23)} = 6.45$, $p = 0.018$, $\omega p^2 = 0.18$]). Repeated measures ANOVA of Stroop targets/new items revealed an Item Type x Hemisphere x Site interaction [$F_{(2.3,53.5)} = 4.13$, $p = 0.017$, $\omega p^2 = 0.11$]. This crossover interaction reflected a small positivity for targets at left hemisphere sites and an effect of reversed polarity at inferior right hemisphere sites, neither of which were significant in post-hoc analyses.

The pairwise comparison of targets and nontargets revealed effects of Item Type including Group x Switch/Stay x Item Type x Site (see Table 3). These reflected greater positivity for targets than nontargets, an effect that was largest in magnitude for control participants on stay trials (see Figure 2). Repeated measures ANOVA of control targets/nontargets revealed a main effect of Item Type [$F_{(1,23)} = 4.64$, $p = 0.042$, $\omega p^2 = 0.13$] and interactions between Item Type x Site [$F_{(1.3,30.7)} = 5.60$, $p = 0.017$, $\omega p^2 = 0.15$] and Switch/Stay x Item Type x Hemisphere [$F_{(1,23)} = 4.54$, $p = 0.044$, $\omega p^2 = 0.12$]. Post-hoc analyses indicated a right-lateralised positivity for targets on switch trials (Item Type: [$F_{(1,23)} = 5.65$, $p = 0.026$, $\omega p^2 = 0.17$], Item Type x Hemisphere: [$F_{(1,23)} = 7.19$, $p = 0.013$, $\omega p^2 = 0.20$]) and greater positivity for targets maximal towards the midline on stay trials (Item Type x Site [$F_{(1.7,39.0)} = 6.84$, $p = 0.004$, $\omega p^2 = 0.19$] (see Figure 2). No effects of item type were obtained in the repeated measures ANOVA of targets and nontargets in the Stroop group.

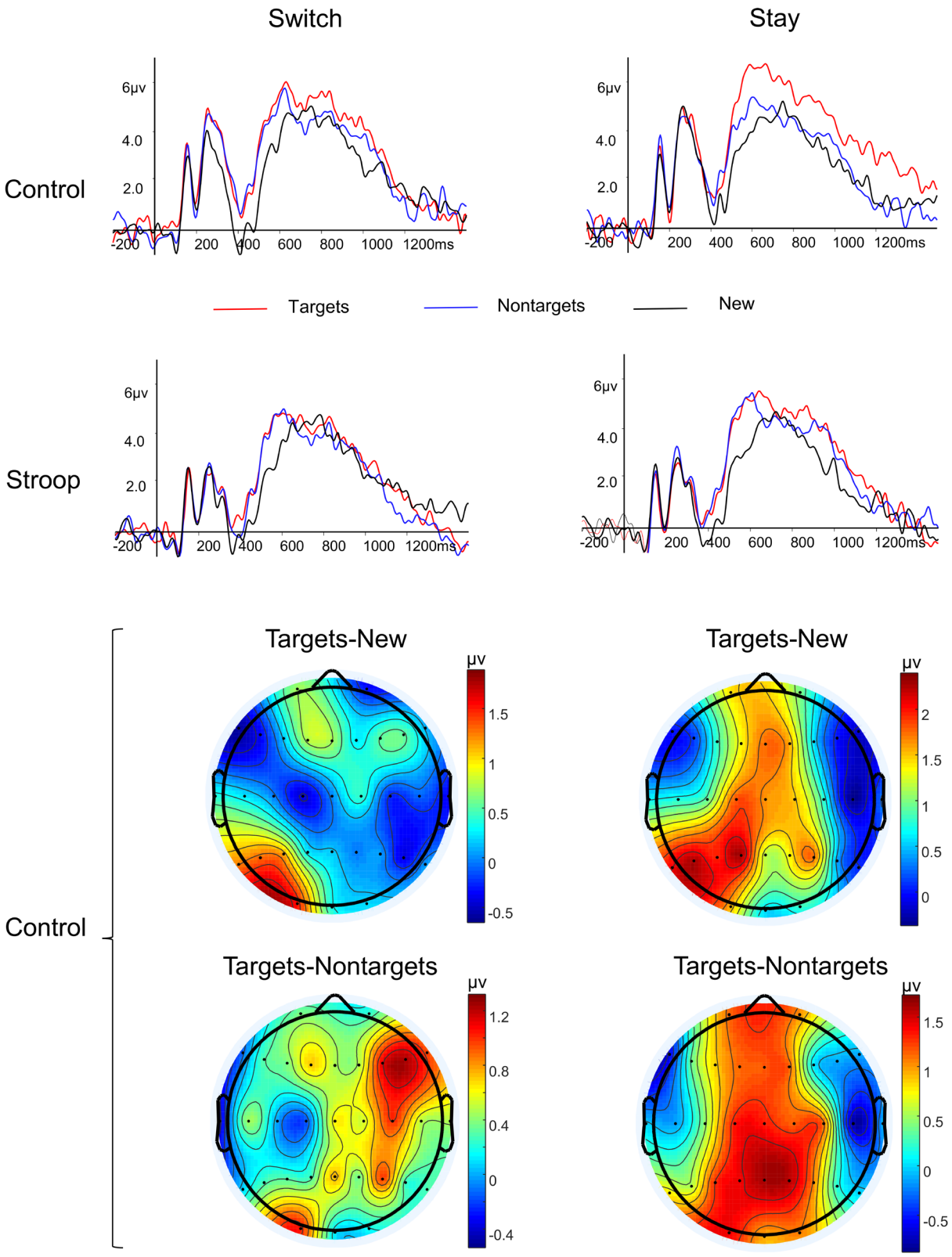

Figure 2. Upper: Item-locked ERPs associated with correctly classified targets, nontargets and new items at a left parietal electrode site (P3), separated by switch/stay trial status and group (Stroop/control). Amplitude (μv) is plotted on the y-axis across time (ms) on the x-axis. Lower: Voltage maps show the scalp distributions of the 500–800ms Target-New and Target-Nontarget ERP effects observed on switch and on stay trials in the control group (scale bars indicate magnitude of effect in μv).

Table 3. Results ($p < 0.05$) of mixed model ANOVAs conducted on stimulus-locked ERPs associated with correct responses to each pair of item types (Target/Nontarget/New) during the 500–800ms latency region. GP = Group (Stroop/control), SW = Switch/Stay, IT = Item Type, HM = Hemisphere, AP = Anterior/Central/Posterior, ST = Site (inferior/mid-lateral/superior/midline).

	Target/Nontarget	Target/New	Nontarget/New
IT x HM	$F_{(1,46)} = 10.94$, $p = 0.002$, $\eta^2_p = 0.19$	$F_{(1,46)} = 10.94$, $p = 0.002$, $\eta^2_p = 0.19$	$F_{(1,46)} = 15.49$, $p < 0.001$, $\eta^2_p = 0.25$
IT x ST	$F_{(1.6,74.4)} = 6.67$, $p = 0.004$, $\eta^2_p = 0.13$	$F_{(1.6,74.4)} = 6.67$, $p = 0.004$, $\eta^2_p = 0.13$	
IT x AP x HM	$F_{(1.8,84.8)} = 4.69$, $p = 0.014$, $\eta^2_p = 0.09$	$F_{(1.8,84.8)} = 4.69$, $p = 0.014$, $\eta^2_p = 0.09$	$F_{(1.8,83.8)} = 5.42$, $p = 0.008$, $\eta^2_p = 0.12$
IT x AP x ST	$F_{(4.0,185.4)} = 2.87$, $p = 0.024$, $\eta^2_p = 0.06$	$F_{(4.0,185.4)} = 2.87$, $p = 0.024$, $\eta^2_p = 0.06$	$F_{(2.6,120.3)} = 5.56$, $p = 0.002$, $\eta^2_p = 0.11$
IT x HM x ST	$F_{(2.4,112.0)} = 6.82$, $p = 0.001$, $\eta^2_p = 0.13$	$F_{(2.4,112.0)} = 6.82$, $p = 0.001$, $\eta^2_p = 0.13$	
GP x SW x IT x ST	$F_{(1.7,79.4)} = 4.52$, $p = 0.018$, $\eta^2_p = 0.09$	$F_{(1.7,79.4)} = 4.52$, $p = 0.018$, $\eta^2_p = 0.09$	
SW x IT x AP x HM x ST	$F_{(5.0,230.5)} = 2.94$, $p = 0.014$, $\eta^2_p = 0.06$	$F_{(5.0,230.5)} = 2.94$, $p = 0.014$, $\eta^2_p = 0.06$	

A topographic analysis of control group target/nontarget effects assessed whether different neural generators were recruited on switch and on stay trials. Difference scores (formed by subtracting nontarget from target mean amplitudes) were rescaled using the max-min method to remove changes in effect magnitude from changes in topography[48]. A repeated measures ANOVA comprised the factors of Switch/Stay, Anterior/Posterior, Hemisphere and Site (inferior/mid-lateral/superior/midline). A Switch/Stay x Site interaction [$F_{(2.0,45.3)} = 3.36$, $p = 0.044$, $\omega p^2 = 0.09$] indicated that different neural generators gave rise to the distinct scalp distributions evident on switch and on stay trials (see Figure 2).

Finally, the pairwise comparison of nontargets and new items revealed several interactions involving Item Type (see Table 3), reflecting greater positivity for nontargets at left posterior inferior sites and greater positivity for new items maximal at right central superior sites. No moderating effects of Group or Switch/Stay were observed. Post-hoc analyses indicated that the positivity observed for nontargets maximal at P7 [$F_{(1,46)} = 9.31$, $p = 0.004$, $\omega p^2 = 0.15$] and the negativity observed for these items at right hemisphere sites [$F_{(1,46)} = 5.57$, $p = 0.023$, $\omega p^2 = 0.09$] were both statistically significant.

Discussion

The impact of cognitive control reserves on ERP measures of goal-directed memory retrieval was examined via two experimental hypotheses. First, it was predicted that performing a Stroop task before the memory test would attenuate ERP measures of retrieval orientation initiation. Second, it was predicted that ERP measures of strategic retrieval (i.e. prioritised recollection of targets) in a task-switching design would be attenuated in participants who first completed the Stroop task. Both hypotheses were supported by the findings and will be discussed in turn.

A series of studies from our lab have demonstrated the sensitivity of ERPs to different episodic goals during the pre-stimulus interval[2,3,11,27]. We have also recently shown that this measure predicts the success or failure of criterial recollection[5,49]. Most of these studies have employed task switching designs in which different pre-stimulus cues signal the episodic content to be retrieved. The purpose of this design is to induce the initiation of different retrieval orientations many times within a single testing session, and ERPs typically diverge according to task goals when a new memory task begins ('switch' trials). Because these divergences are reduced on subsequent trials within the testing sequence, pre-stimulus ERP effects observed on switch trials have been attributed to processes that initiate retrieval orientations, but which are not required to sustain them across subsequent items within that task. Pre-stimulus ERPs obtained from the control group here are consistent with this account; preparatory 'function' ERPs showed a significant positive shift relative to 'drawing' ERPs on switch trials only. As in previous studies, this was a temporally sustained effect with a frontal distribution. The control group data therefore confirmed that the paradigm had captured the ERP index of retrieval orientation initiation obtained in previous studies. Importantly, this effect was attenuated - and not statistically significant - in the Stroop group. This extends the discovery that cognitive control depletion reduces ERP measures of retrieval orientation maintenance[27] to processes involved in their initiation. Both components of retrieval orientation are sensitive to reserves of cognitive control available during retrieval.

The Stroop task also influenced neural correlates of strategic retrieval. The response requirements of the memory test used here are borrowed from the exclusion task[34]; studied items from a specified encoding context require a positive response while those from the alternate context are 'excluded' on the same response key as new items. These response requirements encourage participants to treat items from the specified context as memory 'targets' and to constrain retrieval processing accordingly, and neural evidence for this comes in at least three different forms. First, neural activity associated with identical unstudied items differs between exclusion tasks with different retrieval goals (see Introduction). Second, pre-stimulus ERPs also differ according to target designation[11,27]. Third, ERP measures of recollection associated with nontargets are significantly smaller than those associated with targets, this being the

parietal old/new effect in ERP studies[12,22,35,36] and activation in angular gyrus in their fMRI counterpart[18]. This third aspect is termed 'strategic retrieval' and there was evidence for this in control participants here, with target ERPs eliciting greater positivity than both nontargets and new items. Importantly, participants who completed the Stroop task showed no evidence of strategic retrieval on either switch or stay trials, as target and nontarget ERPs did not differ. This indicates that the combined cognitive load of task-switching and Stroop performance prevented these participants from engaging memory control processes necessary for flexible strategic retrieval.

Similarly, Elward *et al.*[33] found that ERP correlates of strategic retrieval observed in participants with high working memory capacity were eliminated following the Stroop task, even when retrieval tasks were blocked. This finding contrasted with a second study[27], which found ERP evidence of strategic retrieval in the same pair of blocked memory tasks following Stroop performance. The cause for this discrepancy may lie in the overall amount of cognitive depletion. Elward *et al.*'s participants completed the O-span test of working memory capacity in addition to the Stroop task before encoding, which may have imposed a further cognitive load. The present study administered the Stroop task between study and test, but the convergence of the present findings with those of Elward *et al.* suggests that the point at which the Stroop task was administered was less important than the degree to which reserves of cognitive control were taxed by other aspects of the experiment. Here, requiring participants to attend to pre-stimulus cues and switch between retrieval tasks increased the cognitive load during retrieval. It is likely that this made strategic retrieval more vulnerable to disruption when reserves of cognitive control were depleted by the Stroop task than in the blocked paradigm employed previously[27].

The control group data also showed that task-switching influences strategic retrieval more generally, as the topographies of the target/nontarget effects differed between switch and stay trials. The switch trial effect was focused over right frontal electrode sites whereas the stay trial effect was largest at superior parietal sites. This is perhaps surprising given that ERP correlates of retrieval orientation were evident on switch trials for this group. One interpretation is that there is a delay between the initiation of a retrieval orientation and the effective operation of downstream processes that support parietally distributed strategic retrieval ERP effects. An alternative account is that the two are not intrinsically linked; that strategic retrieval is not always a consequence of – and does not necessarily require – a goal-directed memory state. For example, it has been proposed that strategic retrieval can arise either as a consequence of top-down cognitive control processes (such as proactive retrieval orientations) or from bottom-up processes such as the ease of access to nontarget representations[22,50]. Evidence for this second view comes from the blocked version of this study[27], where correlates of strategic retrieval were evident for the Stroop group in the absence of correlates of retrieval orientation. These participants showed enhanced ERP measures of post-retrieval monitoring at right frontal sites relative to controls, indicating that reactive control was used to compensate for reduced proactive control. The right frontal distribution of the target/nontarget effect on switch trials in the present study suggests that this may also have occurred here, but that post-retrieval monitoring was not required to the same degree on stay trials once target recollection was prioritised at the point of retrieval.

Levels of memory accuracy and associated reaction times for targets were not affected by the Stroop/control manipulation. This replicates previous studies that found equivalent levels of memory accuracy for Stroop and control participants[27,33]. It is notable that memory responses in all three studies were self-paced. Imposing a response deadline could potentially decrease memory accuracy in Stroop participants, as this would limit their opportunity to engage post-retrieval monitoring processes. It is also possible that cognitive control depletion results in more nuanced memory deficits that cannot be detected with relatively blunt measures such as accuracy and RT, such as the qualitative details of memories. The task-switching manipulation did introduce subtle differences in response accuracy between the two groups of participants. Nontarget accuracy increased from switch to stay trials in the control group, and this behavioural shift was accompanied by the emergence of parietal target/nontarget ERP effects on stay trials. Strategic retrieval was therefore associated with an improved ability to exclude nontargets rather than to identify targets for this group. This behavioural shift in nontarget accuracy was absent in Stroop participants.

In conclusion, pre-stimulus ERP correlates of retrieval orientation initiation were observed on switch trials in a control group and eliminated in a group of participants who first completed the Stroop task. Similarly, established ERP correlates of strategic retrieval (enhanced correlates of recollection for memory targets versus nontargets) were evident in the control group and eliminated in the Stroop group. Task-switching at test also influenced strategic retrieval processing, with ERP correlates of target versus nontarget recollection shifting from a frontal to a parietal distribution for control group participants. In combination, the ERP data indicate that depleting reserves of cognitive control impairs the ability to modulate strategic memory processing in response to changing retrieval goals.

Data availability

Underlying data

Open Science Framework: Cognitive control depletion reduces pre-stimulus and recollection-related measures of strategic retrieval. https://doi.org/10.17605/OSF.IO/5KURQ[46]

This project contains the following underlying data:

- Behavioural data (raw behavioural data obtained for each participant, provided as *.csv files, accuracy codes are specified in the outcodes.txt file)

- ERP files (event-related potentials for each participant, provided as *.erp files)

- Raw EEG data (raw EEG data for each participant, provided as *.bdf files)

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Version 1

Reviewer Report 14 October 2019

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Joshua Koen
Department of Psychology, University of Notre Dame, Notre Dame, IN, USA

This paper reports an ERP study examining the impact of cognitive control depletion on two retrieval processes associated with retrieval of task-relevant contextual details: retrieval orientation and strategic retrieval. The author predicted that depletion of cognitive control resources would eliminate ERP correlates of retrieval orientation and strategic retrieval. Two groups of participants studied words while making one of two semantic judgments for a subsequent exclusion-based recognition test. Following the encoding phase, one group of participants completed a Stroop task to deplete cognitive control resources. The control group completed a simple reading task. The exclusion memory test adopted a local task-switching approach whereby participants were given a pre-stimulus cue indicating which condition (i.e., encoding task) was the target mnemonic information on a given trial. The test was setup such that memory performance and ERPs could be examined for stay trials and switch trials. The results were largely consistent with the hypothesis. The control group showed significant ERP pre-stimulus retrieval orientation effects (on switch trials) and a larger left parietal old/new effect for correctly judged target versus non-target items (on stay trials). This latter finding is evidence of prioritized (or strategic) retrieval. These effects were reported absent in the Stroop group.

This is a well-designed study that makes a significant contribution to the field. The methods and analysis are sound and sufficient information is provided to replicate the methods (and the raw data are also available).

I have a few minor comments:

1. I was rather surprised that memory was not affected in any appreciable way by the Stroop manipulation. The hypothesis driving much of this research is that cognitive control depletion will negatively affect retrieval processes associated with recollection. I do wonder if part of this null effect might be driven by not providing separate estimates of recollection and familiarity. The accuracy measures reported do not necessarily isolate (i.e., exclusion tests are not process pure), and thus the contribution of familiarity might be masking effects.

2. One of the curious behavioural findings was the interaction showing improved exclusion of non-targets from switch to stay trials in the Control group, but not in the Stroop group. I found it

surprising that, in the Control group, exclusion of non-targets on Switch trials were *lower* (.75) than Stay trials (.85) and both Switch and Stay trials in the Stroop group (.84 for both). This result does not seem to fit with the main conclusions that depletion of cognitive control resources reduces strategic retrieval. Instead, it seems to suggest that Stroop participants are better able to reject non-targets on Switch trials and indicates cognitive control depletion might benefit performance somehow (one possibility is a trade off between recollection and familiarity). Admittedly, this is finding is only specific to one of the tasks, so it might not be that important (which, if this is the case, discussion of this result should be de-emphasized in the conclusion).

3. The post-hoc tests for interactions involving group never directly compared groups. Instead, these tests only examined if memory-related effects were significant *within* a group. It is unclear if the lack of significance in the Stroop group reflects a significantly reduced effect relative to the Control group. I would have liked to see this comparison. To be clear, I do not believe any of the main conclusions would be undermined by results from this comparison, but just might require a little more nuance. It also might be useful to have a figure plotting the target-new and target-non-target effects from the 500-800ms time window from P3 (or another representative electrode). This would provide some sense of variability to readers, which is currently difficult to get at.

4. I also would have liked to see the ERP results for the earlier 300-500ms time window that is typically associated with familiarity (i.e., the FN400). I understand the focus of the left parietal old/new effect given the hypothesized role of cognitive control and the retrieval processes being studied on recollection (both here and in many prior studies). However, this does not mean that such reductions in resources might not also be present for familiarity. This analysis might shed some light on if participants in the Control group relied more on familiarity.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Cognitive Neuroscience of Memory, Memory and Aging, EEG/ERP, fMRI

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 17 Oct 2019

Jane E. Herron, Cardiff University, Cardiff, UK

Thank you for your constructive feedback. I had already submitted version 2 before receiving your review, but hopefully some of your comments have been addressed in this new version. For example, between group contrasts of the effects of interest (subtraction waveforms) have now been added to the manuscript as this was raised by another reviewer. Figure 2 shows the target, nontarget and new ERPs at P3 together with scalp maps of the target-new and target-nontarget effects between 500-800ms; is there further data that would be helpful to see? Thank you for your interesting comments about potential contributions of familiarity to performance, I will take a look at the ERP effects between 300-500ms before submitting a further version. While I have extended the discussion of the insensitivity of memory accuracy to the Stroop manipulation in version 2, I hadn't considered that familiarity and recollection may be affected differently, and it will be interesting to see how the 300-500ms ERP data informs that possibility.

Competing Interests: No competing interests were disclosed.

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Timm Rosburg
Forensic Department, University Psychiatric Clinics Basel, Basel, Switzerland

The event-related potential (ERP) study of Herron addresses the question how two forms of strategic retrieval (prioritization of target over nontarget retrieval, as well as initiation of retrieval orientation) are affected by ego depletion. Ego depletion (or cognitive control depletion) refers to the idea that volitional acts draw on a limited resource and, by this, effortful acts of cognitive control have some detrimental effect on the performance in subsequent tasks[1]. In the study of Herron, participants encoded object words in two conditions. After this, participants performed either a cognitively demanding Stroop task or, as control condition, an easy reading task. At test, participants performed a memory exclusion task, with pre-stimulus retrieval cues indicating which category of old items had to be considered as targets. Old items of the second study condition had to be rejected as nontargets, together with newly presented items. Importantly, the designated target category switched after two test items each (resulting in one switch and one stay trial in succession). In the control condition, participants showed a pre-stimulus retrieval orientation effect in switch trials and a larger left-parietal old/new effect for targets than for nontargets in stay trials. Both effects were abolished after ego depletion. Herron concludes that both forms of strategic retrieval are susceptible to cognitive control depletion.

Overall, the study is well-designed and state-of-the-art. Moreover, the study nicely complements previous studies in the field. With regard to the technical qualities of the study, I only have few remarks. With regard to the significance of the findings, I would like to make some comments, which are intended as thought-provoking impulse rather than as categorial critique. These comments primarily concern the presumed neurocognitive correlates of strategic retrieval.

Left-parietal old/new effect and strategic retrieval
Strategic retrieval has been defined as cognitive control processes initiated in order to optimize retrieval success, as well as to minimize retrieval effort[2]. The prioritization of target information over nontarget information has been considered as one form of strategic retrieval (initially discussed in[3]). Target prioritization may manifest in a significantly larger left-parietal old/new effect for target information than for nontarget information, as outlined by Herron. One problem with this definition is that ERPs in episodic memory studies are calculated on the basis of correct responses, i.e. hits for targets and correct rejections (CRs) for nontargets. However, in memory exclusion tasks, the CR rate for nontargets is usually larger than the hit rate[4,5]) because the CR rate is inflated by the percentage of nontargets that have been forgotten. Such trials would be included in calculating the ERPs and lead to some diminishment of the left-parietal old/new effect as correlate of recollection for nontargets, as compared to targets. In an alternative approach, target prioritization has been defined as the absence of a left-parietal old/new effect for nontargets[6]. An absent left-parietal old/new effect for nontargets suggests that source information of nontargets has not been retrieved and the target identification is primarily based on the retrieval of target information (= target prioritization) and not on a recall-to-reject strategy[7]. This operationalization is not perfect either as the absence of nontarget effects might be due to the lack of statistical power.

Notwithstanding this methodological problem, let us assume that at the memory exclusion test participants retrieve to some extent nontarget information in addition to target information, because they actively seek to retrieve the nontarget information or maybe simply because this nontarget information is easily accessible and comes to mind, when encountering the nontarget retrieval cue[8]. What would be the consequences when a participant seeks to prioritize target information and override this kind of volitional or incidental recollection[9]? - If successful, the consequences of such strategical retrieval should be seen for the left parietal old/new effect for targets *and* for nontargets because a more extensive retrieval of target information should make the retrieval of nontarget information unnecessary. This pattern has, however, not been observed in the current study. The left-parietal old/new effect for nontargets did vary neither between trials (switch vs. stay) nor between groups (ego depletion vs. control). Both factors selectively affected target retrieval: A larger left-parietal old/new effect for targets than for nontargets was only present at stay trials in the control condition. This might suggest that switching to a new target category as well as having performed a cognitive demanding task beforehand diminishes the resources available for target identification and target retrieval rather than affecting strategic retrieval. Importantly, similar effects of task switching on the left-parietal old/new effect have previously been observed in recognition and source memory tasks[10,11]. Impaired retrieval of target information in switch trials or following an ego depletion task might affect target prioritization, but the current findings do, from my point of view, not provide evidence for an impaired prioritization of target information after ego depletion.

Retrieval orientation and strategic retrieval
For post-stimulus ERPs, the benefits of adopting an appropriate retrieval orientation are empirically relatively well validated and also highly plausible[4,12,13,14,15]. One could argue that the retrieval orientation effect reflects, to some extent, the preparedness of a rememberer for retrieving the targeted episodic information. For pre-stimulus ERPs, the observed retrieval orientation effects are not easy to

conceptualize: In one study[16], task preparatory pre-stimulus ERP effects were evident in switch but not in stay trials, similar to the current study. One possible cause for this non-observation could be that sustained activity is difficult to detect by conventional ERP recordings[16]. In another study[17], it was found that the task preparatory pre-stimulus ERP effects predicted subsequent retrieval success. In a further follow-up study, the pre-stimulus retrieval orientation effects varied in polarity between switch and stay trials, whereby only the retrieval orientation effects in switch trials showed an association with retrieval accuracy[18]. The authors linked the pre-stimulus effect in switch trials to the initiation of retrieval orientation operations, whereas the pre-stimulus effect in stay trials was linked to the maintenance of retrieval orientation operations.

The current study does not report on the association between pre-stimulus retrieval orientation effects and retrieval accuracy, but it appears that the pre-stimulus retrieval orientation effect and the left-parietal old/new effect did not co-vary because the largest retrieval orientation effect was observed in switch trials of the control condition, whereas the largest left-parietal old/new effect was observed in stay trials of the control condition. Moreover, the retrieval accuracy was the same in the two groups even though the retrieval orientation effect varied between them. Thus, the suppression of the retrieval orientation effect had apparently no consequence on the retrieval accuracy.

A maybe more fundamental question is whether retrieval orientation can be considered as form of strategic retrieval or whether it reflects, as proposed above, more or less just the preparedness of a rememberer for retrieving the targeted episodic information. The term ‘strategic’ implies that there is some cognitive process contributing to the retrieval outcome, which is not necessarily in place by default. The term also suggests that this process could be instructed or trained and would lead to some improvement in retrieval accuracy. I am aware of just one study which instructed participants to prioritize target information at retrieval[19]. However, this study revealed no impact of instruction on retrieval accuracy (as compared to another group not receiving such instruction). The ERP data revealed no evidence for an effectiveness of this instruction either. Thus, the empirical evidence for retrieval orientation as process of strategic retrieval is, at best, scarce. This principle issue requires some further research and, from my point of view, one should be cautious to label retrieval orientation as ‘strategic’ pre-retrieval process.

Stroop as ego depletion task
The effects of the task (Stroop vs. control) on the ERPs are surprisingly large. What does it mean for the work as scientist, if 6.5 min of a cognitively demanding task already have such a strong detrimental effect on cognition? Should scientists be more careful when they spend their time racking their brains to solve the world´s mysteries? – Apparently, the 6.5 min of the Stroop task had some considerable impact on the subsequent retrieval processes. However, again I would encourage to be more cautious to attribute the consequences of the task to ego depletion because the fact that the task was intended for this purpose does not mean that ego depletion is the cause for its consequences. Among others, such a task could modulate arousal and motivation.

Some technical notes
Overall, the paper is well written. However, the author might consider the following issues: (a) The thresholds for the artifact detection are not specified and should be added. (b) The ALAS software tool is not further specified and no reference is provided. Some additional information would be helpful. (c) In Figure 1, the scaling of the ordinate should be 2.0 (and not 2.1). Moreover, it should be µV (and not µv). (d) I would recommend to use a different color scaling for the voltage map in Figure 1. Blue colors should indicate negative and red colors positive voltage values. In its current form, the color intensity provides the initial impression that the negative and positive amplitude values were equally large. Moreover, the time range needs to be indicated.

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Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Psychophysiology and clinical neurophysiology

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 09 Oct 2019

Jane E. Herron, Cardiff University, Cardiff, UK

Thank you for your considered and interesting discussion of the cognitive processes and existing data regarding strategic retrieval. I have now noted and discussed the disconnect between pre-retrieval correlates of retrieval orientation and memory accuracy at the group level, and the discrepancy between this and item-related analyses which do link pre-retrieval ERPs with memory accuracy. I have also included your helpful observation that modulation of the target/nontarget retrieval ERP effects appear to have been driven by target rather than nontarget ERPs in the discussion. I have addressed each of the technical notes; automated artifact-detection thresholds have been added to the manuscript, the ALAS software tool and documentation have been uploaded to the accompanying Open Science Framework dataset (there is no published reference for this as far as I am aware), and the topographic maps and labelling have been amended as requested.

Competing Interests: No competing interests were disclosed.

Reviewer Report 09 September 2019

https://doi.org/10.21956/wellcomeopenres.16759.r36336

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Rachael Elward
London South Bank University, London, UK

The paper is the latest in a series of EEG experiments examining how cognitive control processes associated with memory retrieval are influenced by the prior completion of a Stroop Task. The Stroop Task is thought to require cognitive control resources which can become depleted from over-use. This depletion impairs the ability to engage in effective cognitive control strategies in subsequent tasks. Here, the authors employed a “task switching” paradigm which allows for an EEG investigation of the initiation of a retrieval orientation; a state that facilitates the retrieval of goal-relevant contextual details. The authors predict that the completion of a Stroop task will disrupt the engagement of a retrieval orientation because such a state requires cognitive control resources. This would be consistent with the idea that strategic retrieval processes are vulnerable to resource depletion. The results are consistent with this idea. These data have important implications for understanding the relationship between cognitive control processes and memory retrieval.

The study is well conducted with good power, sufficient trial numbers for all analyses and is technically sound. The manuscript is clearly written and with sufficient detail to allow for replication.

I have two issues that I would like to raise.

1. In Table 3, all the statistical results in the Target/Non-Target column are identical to that of the Target/New column. This looks to be an error? If so, this needs to be addressed before the article is indexed in it's final form.

2. I would have liked to have seen a direct comparison of the magnitude of the EEG effects of interest between groups. When there is a significant interaction, such as in Group X Retrieval Task X Site interaction on page 7, all follow up tests involve repeated-measures ANOVAs within each group. From these follow-up tests, the authors report that there is evidence of a retrieval orientation in the control group, but no such evidence in the Stroop Group. A more direct comparison of the influence of the Stroop task on these EEG effects would be to conduct follow-up comparisons across the groups on subtraction waveforms (e.g. switch minus stay, or target minus non-target effects). Particularly, I would like to be able to make the statement “the difference in left parietal old/new effects for targets and non-targets was larger in the control group than in the Stroop group” but I am not sure that an analysis has been conducted that permits that statement. I can only state that there are significant effects of item type in the control group that are not significant in the Stroop group. If these outcomes are not reported because the group effects are not significant, then this impacts the interpretation of the results. The article is scientifically sound, however, without these analyses.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Cognitive Neuroscience (EEG / fMRI / Neuropsychology), Memory Retrieval, Strategic Control of Memory, Developmental amnesia.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 09 Oct 2019

Jane E. Herron, Cardiff University, Cardiff, UK

Thank you for drawing my attention to the statistical results presented in Table 3 which were duplicated in error. This table has now been amended, with the correct results entered for the Target/New contrast. This does not change the main finding, which is that the Target/New ERP effect was influenced by both the Stroop manipulation and switch/stay trial status. I have now also added follow-up comparisons of the ERP effects of interest across the groups on subtraction waveforms as requested. Significant effects of group were obtained in the analyses of i) pre-retrieval ERPs (Function-Draw) at mid-frontal sites between 700-1900ms, ii) target-new ERPs at the parietal maxima of this effect between 500-800ms, and ii) target-nontarget ERPs at the parietal maxima of this effect between 500-800ms.

Competing Interests: No competing interests were disclosed.

Reviewer Report 30 August 2019

https://doi.org/10.21956/wellcomeopenres.16759.r36195

Axel Mecklinger
Experimental Neuropsychology Unit, Department of Psychology, Saarland University, Saarbrücken, Germany

The paper explores cognitive control process which occur prior to, during or after the recovery of memory episodes. It is assumed that retrieval orientations, brain states that bias the retrieval of specific memory contents over others play a central role during memory control. The study combines a memory task with either a Stroop task that makes demands on cognitive control resources or a control tasks that does not draw on cognitive control resources. Both tasks were conducted between the encoding and retrieval phase of the memory task. The critical manipulation was that in the retrieval phase two memory tasks were interwoven in a task-switching paradigm with pre-retrieval (task) cues specifying the memory task. The targeted memory contents changed after every two trials. This elegant design allows to explore electrophysiological (ERP) measures of the initiation of task-specific retrieval orientations upon presentation of the task cue on the one hand and of strategic retrieval, i.e. the prioritized retrieval of targeted over non-targeted memory contents otherwise. The question was how both processes depend on the availability of cognitive control resources (so-called cognitive control depletion).

Remarkably, memory performance was not affected by the Stroop/control manipulation as one would expect under the assumption that the Stroop task but not the control task makes strong demands on cognitive control. However, strong effects were found for ERP measures of memory control. First, the control group showed strong and sustained ERP slow wave differences to the task cues on the first of the two memory trials (switch trials), which reflects the initiation of task specific retrieval orientations. Second, the control group also showed reliable ERP correlates of recollection for targeted memory contents over nontargeted contents, reflecting the successful prioritisation of targets over nontargets. Notably, both effects were virtually absent for participants who completed the Stroop task between the encoding and retrieval phase.

These results provide strong support for the author's predictions, namely that performing the Stroop task before memory retrieval attenuates the ERP indices of the initiation of retrieval orientations, a proactive form of controlled memory retrieval and also diminished the ERP correlate of retrieving task relevant information, a recollection-related form of cognitive control.

This is a well conducted and appropriately designed study that complements a series of three studies in which the author successfully applied a Stroop vs control group manipulation to explore how strategic retrieval processes and their ERP correlates are modulated by the availability of cognitive control reserves. Methods and results are clearly and accurately presented. The work is technically sound and the study design is highly appropriate to disclose the predicted electrophysiological effects. The implementation of a power analysis, the report of single trial numbers used for ERP averaging as well as the combined analyses of cued-locked and stimulus-locked ERPs are particularly strong points. Also, the behavioral and the subject ERP data are made available allowing the reproducibility of most of the results. For a complete reproduction of the ERP data the provision of the raw EEG data would have been desirable. Last but not least the discussion is very sound and well balanced and the main conclusions on the susceptibility of strategic memory retrieval to the availability of cognitive resources are always warranted by the data at hand. Laudably, alternative views (e.g. retrieval orientations are not necessarily a consequence of top town control process but can also arise from bottom up processes such as the ease with which nontarget information can be assessed, Rosburg & Mecklinger, 2017[1]) are adequately elaborated.

One aspect that deserves further elaboration is the observation that effects of the Stroop/control

manipulation were present for a variety of measures in the cue-locked and stimulus-locked ERPs but virtually absent for behavioral measures of memory accuracy. As acknowledged by the authors this disconnect between behavioral and ERP measures could imply that the effects of this manipulation were too subtle to be reflected in standard memory performance scores in particular when self-paced memory responses were employed as it was the case in the present study. Conversely, however, this disconnect also sheds light on an actual debate concerning the reliability of cognitive control (ego) depletion effects. Ego depletion effects have been criticized for being unreliable, not replicable or the sole result of inappropriate research practices such as p-hacking, publication bias or underpowered study designs. As revealed by a recent review paper (Friese et al. 2019[2]) there is in fact neither sufficient evidence for the presence or for the absence of ego depletion effects. While the absence of behavioral effects of the Stroop/control manipulation in the present study could be a direct reflection of insufficient power, the fact that robust ERP effects were obtained in the cue- and stimulus-locked analyses could suggest that these effects do exist but can only be disclosed with sufficiently sensitive measures, such as ERP measures of memory control processes. Further ERP studies with combined behavioral and ERP measures of cognitive control depletion are warranted to further explore this intriguing possibility.

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Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Neurocognition of memory, language and cognitive control

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 09 Oct 2019

Jane E. Herron, Cardiff University, Cardiff, UK

Thank you for raising the interesting point regarding the ego depletion replication controversy. While this was not the primary motivation for the current study, I agree that the relative (and dissociable) sensitivities of the behavioural and the electrophysiological data in an appropriately powered study are interesting and could inform and influence this debate. A paragraph to this effect has been added to the discussion. The raw EEG data (*.bdf format) have been uploaded to the Open Science Framework and are now more clearly labelled ('Raw EEG data').

Competing Interests: No competing interests were disclosed.