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Research Report

Behavioral and electrophysiological evidence for a dissociation between working memory capacity and feature-based attention

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ABSTRACT

When attending to visual objects with particular features, neural processing is typically biased toward those features. Previous work has suggested that maintaining such feature-based attentional sets may involve the same neural resources as visual working memory. If so, the extent to which feature-based attention influences stimulus processing should be related to individuals' working memory capacity. Here we used electroencephalography (EEG) to record brain activity in 60 human observers while they monitored stimulus streams for targets of a specific color. Distractors presented at irrelevant locations evoked strong electrophysiological markers of attentional signal enhancement (the N2pc and P_D components) despite producing little or no behavioral interference. Critically, there was no relationship between individual differences in the magnitude of these feature-based biases on distractor processing and individual differences in working memory capacity as measured using three separate working memory tasks. Bayes factor analyses indicated substantial evidence in support of the null hypothesis of no relationship between working memory capacity and the effects of feature-based attention on distractor processing. We consider three potential explanations for these findings. One is that working memory and feature-based attention draw upon distinct neural resources, contrary to previous claims. A second is that working memory is only related to feature-based attention when the attentional template has recently changed. A third is that feature-based attention tasks of the kind employed in the current study recruit just one of several subcomponents of working memory, and so are not invariably correlated with an individual's overall working memory capacity.

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Theoretical accounts suggest links between working memory, the ability to temporarily store and manipulate information, and selective attention, the ability to prioritise processing of some stimuli over others. This suggested link often assumes that working memory and selective attention recruit a central pool of executive control resources (e.g., Awh et al., 2006; Baddeley, 2003; Bundesen, 1990; Chun, 2011; Cowan, 1988; Engle, 2002; Lavie, Hirst, Viding, & De Fockert, 2004). Support for such a link has been found in some situations (e.g., Redick & Engle, 2006) but not others (e.g., Burnham, Harris, & Suda, 2011). Thus, the relationship between working memory and selective attention may not extend to *all* aspects of the two constructs (Awh et al., 2006). Here, we investigated the proposed link by examining the relationship between neural indices of a specific aspect of selective attention—feature-based attention, indexed via the N2pc and P_D event-related potential (ERP) components—and three measures of working memory.

An observer's attentional set—the feature properties which define the observer's search goals—can enhance neural signals associated with the target feature across the entire visual field (Maunsell & Treue, 2006), and produce attentional capture by distractors possessing target features (*contingent capture*; Folk, Remington, & Johnston, 1992). Electrophysiological studies have found effects of attentional set on a marker of attentional allocation (the N2pc component; e.g., Lien, Ruthruff, Goodin, & Remington, 2008) and also a marker of attentional suppression (the P_D component; Hickey, Di Lollo, & McDonald, 2009; Harris, Jacoby, Remington, Travis, & Mattingley, 2019). The N2pc component is a well-studied correlate of attentional allocation that manifests as a negative-going deflection in the EEG signal recorded at posterior electrodes contralateral to a lateralised attended stimulus, relative to the signal at ipsilateral electrodes (Eimer, 1996). The N2pc is typically observed around 200–300 ms following onset of an attention-capturing stimulus, but is absent or reduced following stimuli that do not match the current task goals (Becker, Harris, York, & Choi, 2017; Eimer, 1996; Grubert & Eimer, 2015; Harris, Dux, Jones, & Mattingley, 2017; Lien et al., 2008, 2010). In contrast, the P_D component is a contralateral posterior positivity (Hickey et al., 2009; Sawaki & Luck, 2010) that is thought to be a correlate of attentional suppression or disengagement (for review, see Gaspelin & Luck, 2017). It is typically observed contralateral to the location of a task-irrelevant distractor, either instead of an N2pc (e.g., Sawaki & Luck, 2010) or, in the case of attentional disengagement, following an N2pc component (e.g., Sawaki, Geng, & Luck, 2012; Sawaki & Luck, 2013).

Previous studies have found relationships between working memory capacity (WMC) and a number of aspects of selective attention (for review, see Kiyonaga & Egner, 2013). Studies investigating the relationship between WMC and feature-based attention, however, have yielded less conclusive results. Burnham et al. (2011) found no correlation between WMC, measured using the operation span task (O Span; Turner & Engle, 1989), and contingent capture. Fukuda and Vogel (2009) had participants search through streams of letters for a target letter of a specific color that was preceded by irrelevant flanker objects of either the target color or a different color. They found that interference from target-colored distractors on behavioral responses to the target was inversely correlated with participants' visual WMC as measured using a change detection task (Luck & Vogel, 1997). In a subsequent study, Fukuda and Vogel (2011) found that performance on the change detection task was only inversely correlated with the magnitude of behavioral interference at a distractor-target SOA of 150 ms, but not at 50, 250, or 350 ms. They concluded that WMC is not associated with feature-based attentional capture, but with control processes related to the rate at which observers can disengage after attention has been captured elsewhere.

The results of the three studies discussed above do not provide a conclusive answer to whether there is a relationship between feature-based attention and WMC. The change detection task used by Fukuda and Vogel (2009; 2011) primarily tapped individuals' visual short-term memory (VSTM) capacity, and did not emphasize contributions of the *central executive* component of working memory, which some theories assume is responsible for the relationship between working memory and attention. Furthermore, all three previous studies relied solely on the indirect behavioral outcomes of feature-based attention; Fukuda and Vogel (2009; 2011) did employ electroencephalography (EEG), but only in experiments that cued participants to spatial locations, not target features. Behavioral measures such as response times are the final outcome of a series of processing stages, making it difficult to definitively state where processes such as working memory may have their influence. Other measures, such as the N2pc and P_D components, provide a more direct index of feature-based neural response modulations.

Some studies have suggested that working memory may only be involved in controlling feature-based attention when target features are highly variable and thus require regular updating (e.g., Woodman, Luck, & Schall, 2007). These studies suggest that under constant target conditions (such as are typical in attentional capture paradigms; e.g., Folk et al., 1998) the control of feature-based attention is transferred to long-term memory. This proposal is at odds with the common view that working memory is responsible for storing attentional templates, and with studies that have shown correlations between working memory capacity and behavioural indices of attentional capture under constant target-feature conditions (e.g., Fukuda & Vogel, 2009, 2011).

In the present study we investigated the relationship between WMC and feature-based attention under constant target-feature conditions. We developed a dynamic visual search paradigm with electrophysiological measures—specifically the N2pc and P_D components—that allowed us to probe feature-based signal enhancement more directly than in past work. Participants monitored stimulus streams for targets of a specific color while distractors were presented at irrelevant lateral locations. We also employed three separate measures of visual WMC: two of these measures were used in previous studies of the relationship between WMC and feature-based attentional capture, namely the O Span task (emphasising the central executive component of working memory; Engle, 2002) and a Change Detection task (emphasising the VSTM component of working memory; Cowan, 2001). In addition, we used a third paradigm called the Location Tracking task (described below), which requires both VSTM and the central executive. We employed Bayes factor analyses to determine the strength of support for the null hypothesis in our correlation analyses (Dienes, 2014).

There are a number of ways in which feature-based attentional capture might relate to WMC. If WMC is related to attentional control, and thus the ability to resist capture by irrelevant stimuli (Fukuda & Vogel, 2009), then we would expect to observe a negative correlation between N2pc magnitude and at least one of the measures of WMC (most likely the change-detection measure; Fukuda & Vogel, 2009). Alternatively, if WMC is associated with the disengagement of attention following involuntary attentional capture (Fukuda & Vogel, 2011), we would expect a positive correlation between the magnitude of the P_D component and at least one of the measures of WMC. Finally, if the Bayes factor analyses show support for the null hypotheses in the correlations between our electrophysiological measures of attentional capture and WMC, despite the presence of significant N2pc and P_D components, this would imply that WMC is not associated with the capture or disengagement of feature-based attention under constant target-feature conditions.

1. Materials and methods

1.1. *Participants*

Human subjects were recruited at a location which will be identified if the article is published. In total, 84 human participants (48 female, aged between 18 and 32 years) took part in the experiment. Twenty-four of these participants were excluded for either poor behavioral performance on the O Span task ($N = 9$) or excessive eye-movement violations in the critical Visual Search task ($N = 15$), as described in detail below. We replaced any excluded participants until we had 60 participants (34 female, aged between 18 and 32 years) in our final included dataset. This sample-size was determined a priori and is far larger than is typical for EEG studies of this kind (e.g., the largest sample size of any EEG study reviewed above was 24 participants; $M = 13.70$, $SD = 4.24$). This sample size gave us a 90% chance of detecting correlations above $r = .405$. All participants reported normal or corrected-to-normal vision and had normal color vision as established with the Ishihara test. The University's Human Research Ethics Committee approved all procedures. We obtained written informed consent from each participant prior to each testing session. Participants were financially reimbursed for their time.

1.2. *Stimuli and apparatus*

Stimulus presentation and response recording were controlled using Cogent software (Cogent 2000 toolbox: FIL, ICN, and Wellcome Department of Imaging Neuroscience) in Matlab version 7.13 (www.mathworks.com), running on a desktop computer. Visual stimuli were presented against a black background on an LCD monitor at a screen resolution of 1280 × 1024 pixels and a refresh rate of 60 Hz. Participants were seated at a viewing distance of 44 cm from the monitor, maintained using a chin rest.

1.3. *Pre-registration and open practices*

We report how we determined our sample size, all data exclusions, all inclusion/exclusion criteria, whether inclusion/exclusion criteria were established prior to data analysis, all manipulations, and all measures in the study. The procedures and analysis for this study were not pre-registered prior to the research being conducted. The data for this experiment have not been made publicly available as this experiment did not have ethical approval for releasing the data and participants did not provide consent for their data being placed in a public repository. The data will be shared upon request via an email to the corresponding author, following approval by the local ethics committee. All experiment and analysis code for this experiment is publicly available for download from the Open Science Framework at: https://osf.io/nehpf/

1.4. *Procedure*

Participants took part in two separate testing sessions. In the first session, which lasted for 60 min, participants completed the three WMC measures described below. In the second session, which lasted for 90 min, participants completed the Visual Search task described below.

1.5. *WMC measures*

The order in which the three WMC measures were completed was counterbalanced across participants. The tasks are illustrated in Fig. 1 (see caption for further details). The first measure was the O Span task developed by Foster et al. (2015; available for download from those authors at http://englelab.gatech.edu/tasks.html; see also Unsworth, Heitz, Schrock, & Engle, 2005). The basic procedure is illustrated in Fig. 1a. Participants were given a series of math problems to solve, interspersed by a series of letters they were required to hold in memory. After several problem–letter pairs (between three and seven), the participant was prompted to report all letters for that trial in correct order. Each participant completed a standardized training procedure followed by three blocks of five trials (one for each of the five trial lengths). To ensure participants couldn't artificially inflate their scores by neglecting the math component of the O Span task, nine participants who failed to correctly answer at least 85% of the math problems were excluded from further analysis and testing (as recommended by Conway et al., 2005).

The second measure of WMC was a Change Detection task, similar to that described by Fukuda and Vogel (2011). The basic procedure is illustrated in Fig. 1b. On each trial participants were presented with a brief (duration = 150 ms) array of colored squares and had to hold each square's color and location in memory. After a retention interval of 900 ms, a single probe square was presented at one of the previously occupied locations, and the participant made an un-speeded response as to whether the probe square was the same color as the square

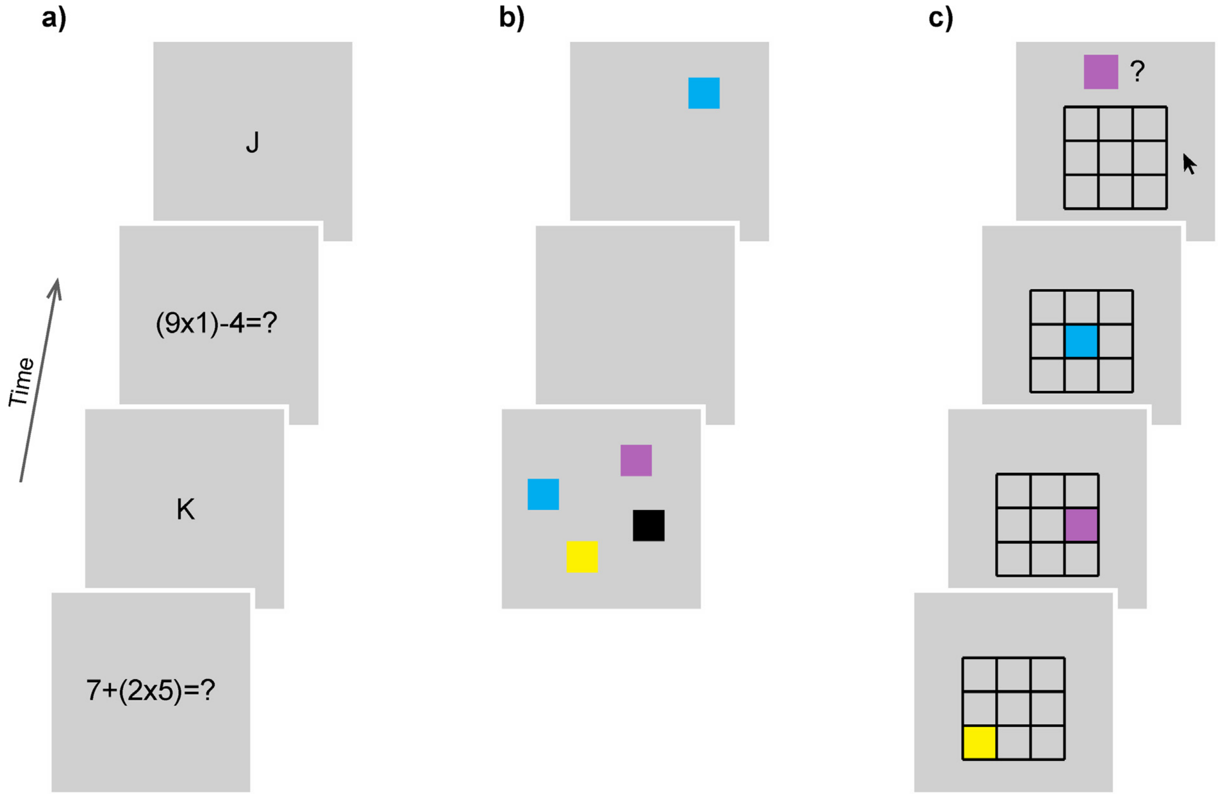

Fig. 1 – WMC task paradigms. (a) O Span task. (b) Change Detection task. Squares were .65° wide and high, presented against a gray background. Their colors were randomly selected without replacement from seven possibilities (white, red, blue, green, black, yellow, and purple) – aside from trials involving eight squares, in which case a random one of the colors appeared twice. The squares were randomly located within an imaginary box 9.8° wide and 7.3° high, with the constraint that the center of each square was at least 2° away from the center of all other squares present. The color of the probe square was the same as the corresponding square in the memorized array on half of the trials. On the other half of trials, the color of the probe square was randomly selected from the remaining six possible colors. Correct responses were followed by a high-pitched tone, and incorrect responses were followed by a low-pitched tone. The memory array for the next trial was presented 500 ms after the participant's response. (c) Location Tracking task. Colored squares (1.3° wide and high) were presented one at a time within a 3 × 3 grid (black lines, .05° wide). The colors used in each trial were randomly selected without replacement from 5 possibilities (red, blue, green, yellow, and purple). The selected colors were presented in random order, with each color appearing an unpredictable number of times (between two and five) during a trial. Each square was presented for 2400 ms during the three-color trials, and 2800 ms during the four- and five-color trials. There was a fixed inter-stimulus interval (ISI) of 500 ms between consecutive colored squares.

that had previously occupied that location. Participants completed 6 practice trials and then 60 test trials for each of three possible array sizes (4, 6, and 8). The order in which the array sizes were completed (4, then 6, then 8), as well as the colors and locations of every single square presented, were identical for each participant, to remove these possible sources of variance in participants' WMC estimates.

The third WMC measure was a Location Tracking task essentially identical to the spatial-figural updating task described by Wilhelm, Hildebrandt, and Oberauer (2013). The basic procedure is illustrated in Fig. 1c. Participants were presented with a series of colored squares in random locations and were required to keep track of where each color had appeared most recently. At the end of the trial, participants were prompted to click in the location they remembered each color appearing most recently using a computer mouse. There could be three, four, or five different colors presented within each trial, giving rise to three difficulty levels. Participants completed eight trials per difficulty level. The order in which the difficulty levels were completed (three, then four, then five), as well as the colors and locations of every single square presented, were again identical for each participant, to remove these possible sources of variance in participants' WMC estimates.

1.6. *Visual search task*

Fig. 2 illustrates the key elements of the visual stimuli used in the Visual Search task. Participants fixated a central cross and covertly monitored fields of randomly moving dots above and below fixation for brief periods in which the dots changed to

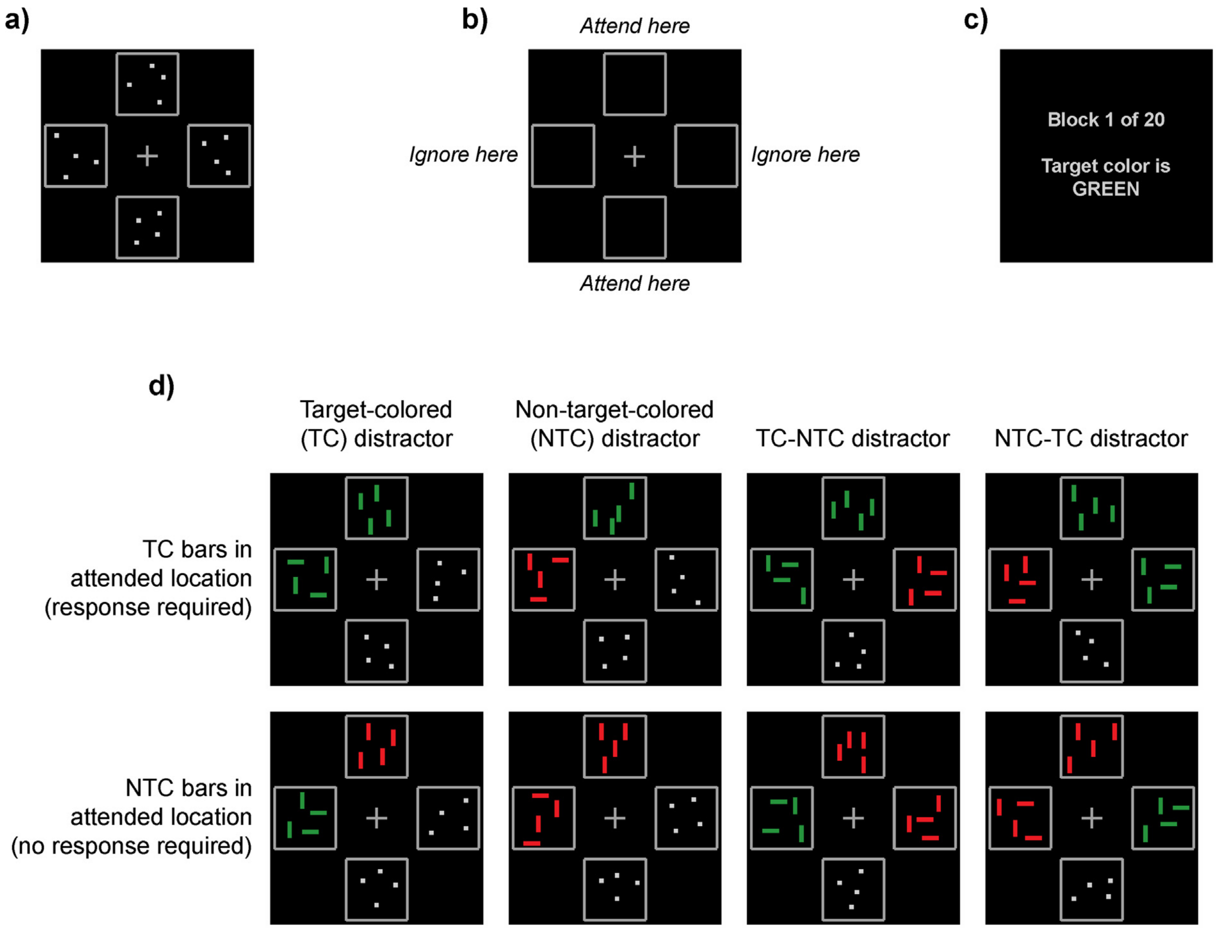

Fig. 2 – Visual Search task. (a) The central plus sign was gray and .6° wide and high. Each of the four dot fields consisted of 20 Gy square dots .1° wide and high (note that there are only 4 dots per location in this figure for clarity). Each dot field was enclosed in a gray box 3° wide and high, centered 4° from fixation. Each dot moved to a random new location within its bounding box on each screen refresh (i.e., 60 times per second), creating the appearance of dynamic noise. (b) Participants were instructed to monitor for target-colored (TC) bars in the upper and lower boxes and ignore all stimuli presented in the left and right boxes. (Note: the labels "Attend here" and "Ignore here" were not present in the actual display.) (c) At the start of each block, participants were informed of the target color (green or red) for that block. (d) Examples of the different types of bar events that could occur during a block. For the purposes of these examples, the target color is GREEN. During each event, all dots in one of the two attended locations (the upper location in these examples) changed into either target-colored (upper row) or non-target-colored (lower row) bars for 167 ms, although they continued to change locations at a rate of 60 Hz. All the bars in the attended location were one of the two cardinal orientations (vertical in these examples), and participants had to report the orientation of TC but not non-target-colored (NTC) bars in the attended locations. At the same time, bars appeared in one or both of the ignored locations to satisfy one of the four distractor conditions (listed at the top of the four columns of display panels). Bars in the distractor locations were half vertical and half horizontal so as not to favor one of the two response options. Bars in the distractor locations persisted for 467 ms, but changed locations at a rate of 60 Hz. All bars were .4° long and .1° thick. The distractor- and attended-location bars always onset simultaneously. The onset asynchrony between consecutive bar events was varied randomly between 1500 ms and 2500 ms in intervals of 16.67 ms (square distribution).

either red or green bars. Whenever participants detected such bars, they had to report their orientation (horizontal or vertical) by pressing one of two keys on a keyboard as quickly as possible. The task was performed continuously during 20 blocks of 64 trials each. The blocks lasted approximately two minutes. The target color (red or green) switched after every block, with the specific order of colors counterbalanced across participants. We varied target color within participants to prevent the search task becoming highly automatized, as this might have reduced the recruitment of executive control resources during the search task, which might in turn have reduced any potential relationship between feature-based attention and working memory (for discussions, see Carlisle, Arita, Pardo, & Woodman, 2011; Woodman et al., 2007).

Colored bars could also appear within randomly moving dot fields to the left and right of fixation, which the participants were instructed to ignore. These lateral bars served as distractors. There were four different types of distractors, defined relative to the current target color. These were: Target-colored (TC) distractor (bars the same color as the target appeared in one lateral location only), non-target colored (NTC) distractor (bars the color other than the target appeared in one lateral location only), TC-NTC distractor (TC bars in the left location and NTC bars in the right location), and NTC-TC distractor (NTC bars in the left location and TC bars in the right location). The TC-NTC and NTC-TC conditions were considered separately due to concerns regarding known spatial asymmetries in attentional processing (e.g., pseudoneglect; Bowers & Heilman, 1980; Jewell & McCourt, 2000). We present the behavioral results separately to demonstrate that these conditions did not differ, and then collapse these conditions together for the EEG analysis. We included the TC and NTC distractor types to allow us to measure the influence of the distractors on participants' behavioral responses, but we did not expect strong behavioral interference due to the irrelevant nature of the distractor locations (Ruthruff & Gaspelin, 2018; see Discussion). The TC-NTC and NTC-TC distractor types were the main conditions of interest as they allowed us to measure the influence of participants' feature-based attentional set on electrophysiological responses to the distractors. If participants can prioritize the processing of TC objects, we would expect electrophysiological indices of feature-based signal enhancement (the N2pc; Lien et al., 2008) and attentional suppression (the P_D; Sawaki et al., 2012) to be stronger at electrodes contralateral to the TC distractor, even when the otherwise comparable NTC distractor is present in the opposite visual field. Note that although most studies of lateralized visual-evoked potentials such as the N2pc and P_D components have involved static rather than dynamically moving stimuli like those featured in the present study, previous studies have also demonstrated the same lateralized components using dynamic stimuli (e.g., Leblanc, Prime, & Jolicœur, 2008). Analysis of these lateralized attention-related components requires that the visual display be balanced for physical salience across the vertical midline. Otherwise, lateralized effects in the ERP may be spuriously inflated by physical stimulus differences rather than being driven by differences in attentional processes (for discussions, see Luck, 2005; Woodman, 2010). For this reason, we did not examine ERP components under the TC and NTC distractor conditions, because these displays contained gray dots on one side and colored bars on the other.

Each possible combination of attended bar color (red, green), attended bar location (upper, lower), attended bar orientation (horizontal, vertical), distractor type (TC, NTC, TC-NTC, NTC-TC), and distractor location (left, right) occurred once during each block, in random order. Participants completed two practice and then 20 experimental blocks. During the practice but not experimental blocks, correct responses to target bars were followed by a high-pitched tone, and incorrect responses were followed by a low-pitched tone. During the experimental blocks, any response made when TC bars were not present was followed by a low-pitched tone to avoid prolonged situations in which a participant was erroneously monitoring for the wrong color. At the end of each block participants were informed of the percentage of target events they correctly responded to during that block (hit rate), and their average reaction time (RT) on target events they responded to correctly.

1.7. *Electroencephalography*

Continuous electroencephalogram (EEG) data were recorded using a BioSemi Active Two system (BioSemi, Amsterdam, Netherlands), digitized at a 1024 Hz sample rate with 24-bit A/D conversion. The 64 active scalp Ag/AgCl electrodes were arranged according to the international standard 10–10 system for electrode placement (Oostenveld & Praamstra, 2001) using a nylon head cap. The standard BioSemi reference and ground electrodes were used during recording. Eye movements were monitored using bipolar horizontal electro-oculographic (EOG) electrodes placed at the outer canthi of each eye, and bipolar vertical EOG electrodes placed above and below the left eye.

Offline EEG data analysis was performed using Brain Electrical Source Acquisition (BESA 6.0; MEGIS Software GmbH, Gräfelfing, Germany) and a purpose-built Matlab script. Noisy scalp channels, identified by visual inspection of the data, were replaced by a spherical spline interpolation of the voltages recorded at all other scalp electrodes (an average 1.6 electrodes per participant were replaced, ranging between 0 and 8, and never including PO7 or PO8 - the electrodes used in the main analyses). The data for the scalp electrodes were then re-referenced to the average of all 64 scalp electrodes and segmented into epochs from 100 ms before to 400 ms after the onset of each distractor event. The average voltage in the 100 ms prestimulus interval was used as a baseline for each epoch. Epochs in which the difference between the maximum and minimum voltage exceeded 50 μV in the HEOG channel or 100 μV in any other channel were automatically rejected to remove epochs contaminated by eye movements, blinks, and other artifacts. Fifteen participants were excluded from further analysis for having more than 30% of epochs in any condition rejected for violating these criteria. An average of 21% of epochs were rejected for violating these criteria in the 60 participants included in the final analyses. The accepted epochs were then averaged together, separately for each distractor type (TC-NTC, NTC-TC). Data were then collapsed across distractor type by combining all data for electrodes contralateral to the TC distractor (i.e., electrodes left of the midline when the TC distractor was on the right, and electrodes right of the midline when the TC distractor was on the left), and separately combining data for electrodes ipsilateral to the TC distractor. An average of 560 epochs (ranging between 454 and 644 epochs) contributed to these waveforms for each participant. To check the effectiveness of the artifact rejection procedure in removing trials containing horizontal eye movements, we computed averaged HEOG waveforms separately for each distractor type. The maximum amplitude in this averaged HEOG waveform in any participant in any condition was 1.8 μV, well below the 3.2 μV cutoff value commonly used to detect the presence of residual eye movements in ERP studies with lateralized stimuli (Woodman & Luck, 2003; see also; Lins, Picton, Berg, & Scherg, 1993).

2. Results

2.1. WMC *measures*

To estimate WMC based on the O Span task, we followed the recommendations of Conway et al. (2005) and used a partial-credit unit scoring procedure. This procedure involves giving participants one point for each letter recalled correctly and in the correct serial position, and then dividing the total number of points by the total number of letters to which the participant was exposed. This yields a proportion of correctly recalled letters between 0 and 1. The mean proportion correct for the 60 participants included in the final analysis was .85, ranging between .37 and 1. To assess the reliability of the O Span measure we calculated a proportion correct score separately for each of the three blocks of trials. The Spearman-Brown corrected correlations between these scores were all statistically significant (at a two-tailed alpha level of .05; all $r \geq .636$, all $P < .001$), indicating that the O Span measure was reliable.

To estimate WMC based on the Change Detection task, we calculated K scores using the standard formula K=(H + CR−1) N, where H is the hit rate, CR is the correct rejection rate, and N is the array size (Cowan, 2001). The mean K score (averaged across array size) for the 60 included participants was 2.07 (SD = .87), ranging between .42 and 3.69. The Spearman-Brown corrected correlation between individuals' K scores on the odd versus even numbered trials was statistically significant ($r = .74$, $P < .001$), indicating that the measure was reliable.

To estimate WMC based on the Location Tracking task, we calculated the accuracy (proportion of correctly recalled locations) across all trials. The mean accuracy was .77 (SD = .11), ranging between .55 and .96. The Spearman-Brown corrected correlation between individuals' accuracy on the odd versus even numbered trials was statistically significant ($r = .89$, $P < .001$), indicating that the measure was reliable.

The correlations between individuals' scores on each of the three measures are depicted in Fig. 3. The Location Tracking task requires both VSTM and the central executive, so scores on this measure were expected to correlate with the other working memory tasks. As predicted, performance on the Location Tracking task was significantly correlated with performance on both the O Span task, $r = .43$, $P = .001$ (Fig. 3b), and the Change Detection task, $r = .48$, $P < .001$ (Fig. 3c), but there was no significant correlation between performance on the O Span task and the Change Detection task, $r = .18$, $P = .163$ (Fig. 3a). One participant's overall score on the O Span task was more than 2.5 SD away from the group mean. Excluding this participant did not change the pattern of correlations between the three WMC measures: O Span vs. Change Detection $r = .11$, $P = .398$; O Span vs. Location Tracking $r = .40$, $P = .002$; Location Tracking vs. Change Detection $r = .46$, $P < .001$. For the two statistically significant correlations, the amount of variance accounted for by the correlations is only moderate, suggesting that each of the three measures accounted for a sizeable amount of unique variance in WMC.

2.2. *Visual search task: behavioral results*

Fig. 4 shows the hit rates (Fig. 4a) and RTs (Fig. 4b) observed on the Visual Search task. We restricted our behavioral analyses to the TC and NTC distractor conditions; it is not possible to measure the influence of the different distractor colors on behavior in the TC-NTC or NTC-TC conditions, because any effect on behavioral responses could not be conclusively attributed to either distractor color if both colors are present. The results for the TC-NTC and NTC-TC are included in Fig. 4 only for completeness.

Each participant was exposed to 160 target events per distractor condition. Target events to which participants responded incorrectly (an average of 6%) were excluded from the RT analysis. Hit rates did not differ significantly between the TC and NTC distractor conditions, $t(59) = .08$, $P = .933$, Cohen's $d_z = .01$, indicating no effect of distractor color on accuracy. In contrast, RTs were significantly longer in the TC than in the NTC distractor condition, $t(59) = 2.65$, $P = .010$, Cohen's $d_z = .34$, although as expected this effect was quite small ($M = 3.5$ ms), and when split between odd and even trials it did not correlate within participants, Spearman-Brown

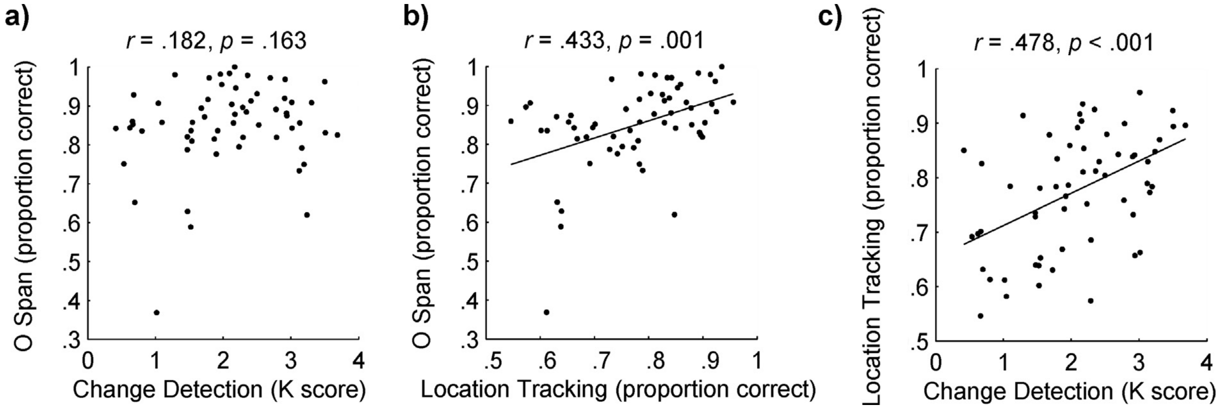

Fig. 3 – Correlations between the three WMC measures.

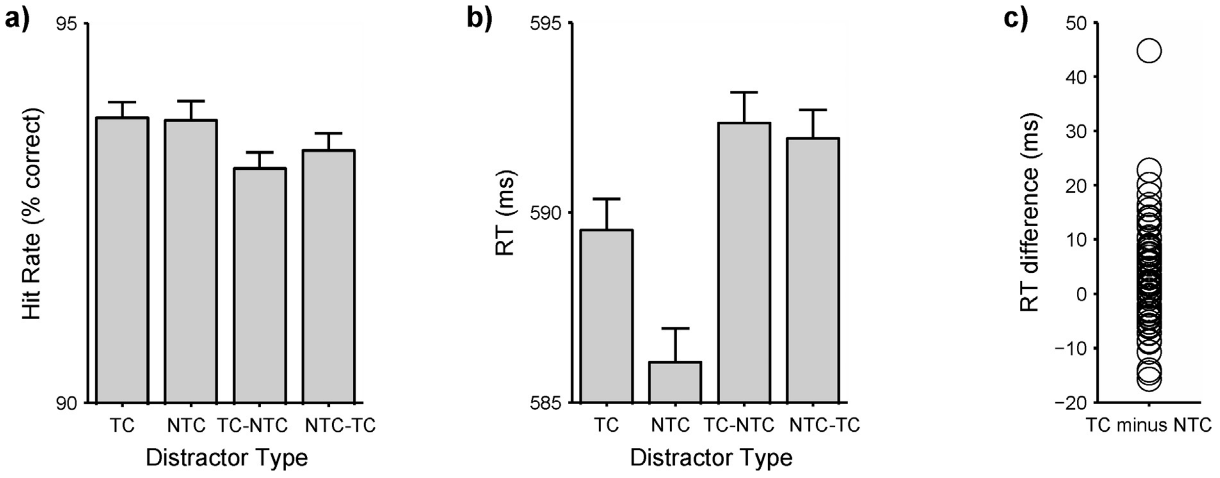

Fig. 4 – Behavioral performance on the Visual Search task. (a) Mean hit rates for each distractor condition. (b) Mean RTs for each distractor condition. (c) Individual scores for the RT difference between the TC and NTC distractor conditions. Error bars represent within-subjects standard errors of the means (Cousineau, 2005).

corrected $r = .08$, $P = .758$. Thus, our results are consistent with previous demonstrations of irrelevant locations producing little or no behavioral attentional capture (Ruthruff & Gaspelin, 2018). One participant's RT difference between the TC and NTC distractor conditions was more than 2.5 SD away from the group mean (see Fig. 4c). Excluding this participant from the analyses did not change the overall pattern of results; there was still no significant difference in hit rates between the TC and NTC distractor conditions, $t(58) = .00$, $P > .999$, Cohen's $d_z < .01$, and there was still a small but significant difference in RTs between these conditions, $t(58) = 2.46$, $P = .017$, Cohen's $d_z = .32$. TC distractors may have impaired performance to a greater extent than NTC distractors, even at irrelevant locations, but did so in a weak and inconsistent manner. For completeness these RT difference scores were used for correlation with the WMC scores in the analyses that follow, but our critical hypotheses were in relation to the EEG results, as described below.

2.3. *Visual search task: electrophysiological results*

Fig. 5a displays the grand average waveforms associated with the combined TC-NTC and NTC-TC conditions at electrodes PO7/8, displayed separately for the ipsilateral and contralateral electrodes relative to the location of the TC distractor. Fig. 5b displays the difference wave created by subtracting the ipsilateral from the contralateral waveforms in Fig. 5a. We chose to analyze the N2pc and P_D components in the contralateral minus ipsilateral difference wave from electrodes PO7 and PO8, as this is common practice when analysing these components (Luck, 2012). The analogous grand average waveform from the HEOG channel for the combined TC-NTC and NTC-TC conditions is plotted in Fig. 5c. As can be seen, there is very little activity in the grand average waveform for the HEOG channel, indicating that the artifact rejection procedure was effective in removing trials contaminated by horizontal eye movements, and suggesting that any observed contralateral differences at PO7/8 in the remaining trials were not due to eye movements.

We used a “summed area” approach to calculating N2pc and P_D amplitudes proposed by Sawaki et al. (2012). These authors point out that the time windows used in traditional mean amplitude analyses are typically based on visual inspection of the grand average waveform, collapsed across all participants and conditions. Although time windows selected in this way are appropriate for grand averaged data, they do not necessarily reflect the relevant waveforms for each participant or each condition. To allow for variations in the latency of the N2pc and P_D components across participants and conditions, Sawaki et al. (2012) suggested taking a very broad time window (100–400 ms post stimulus onset [shaded gray in Fig. 5b]) and defining the N2pc amplitude as the summed negative area within that window, and the P_D amplitude as the summed positive area within that window. The grand mean N2pc and P_D amplitudes calculated using this summed area approach are indicated by the vertical black bars in Fig. 5d. As the summed area approach takes the sum of the negative or positive differences across time, the resulting measurements have units of μV per millisecond. We also present all the EEG analyses calculated using the typical time-window approach to ERP definition (Luck, 2014) (see Supplementary Materials).

As pointed out by Sawaki et al. (2012), because their summed area method divides the data into the two components by grouping together all the data points of the same valence, N2pc and P_D amplitudes calculated using this method are statistically biased away from zero. As such, one-sampled comparisons between the amplitude of these components

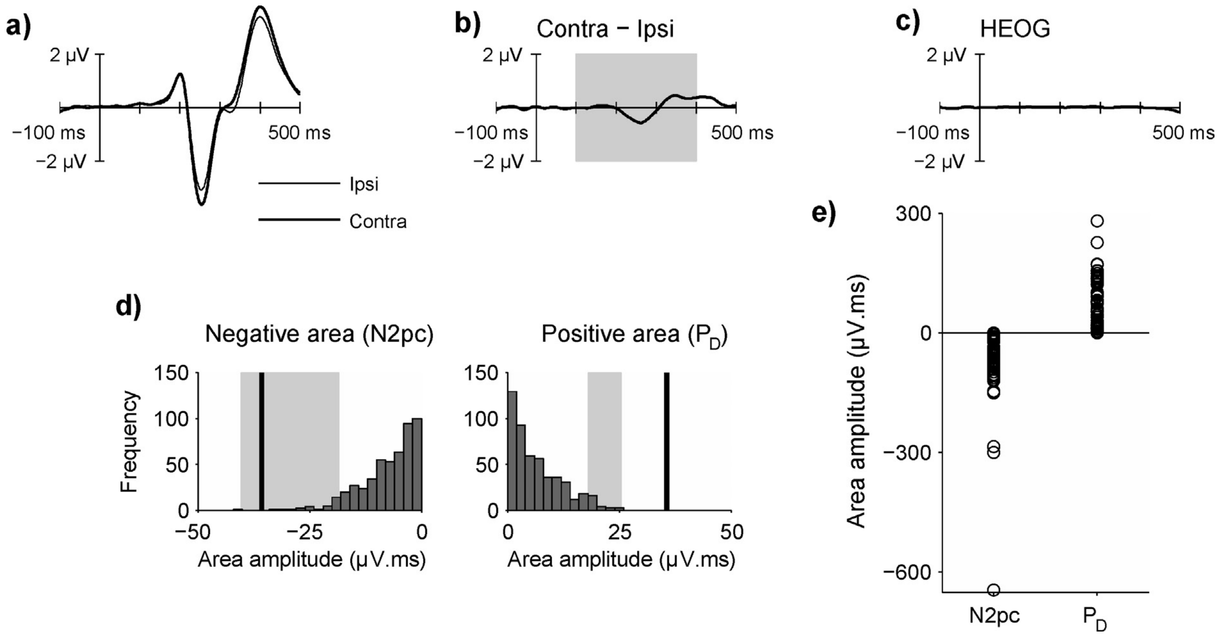

Fig. 5 – Electrophysiological results for the Visual Search task. (a) Grand average waveforms associated with the combined TC-NTC and NTC-TC conditions at electrodes PO7/8, displayed separately for the ipsilateral and contralateral electrodes relative to the location of the TC distractor. Note that a 30 Hz low-pass filter has been applied to the waveforms displayed in Panels a–c for display purposes only. These filters were not applied to the analyzed data. (b) Difference wave created by subtracting the ipsilateral from the contralateral waveforms in Panel a. The shaded area indicates the time window used for the summed area calculations. (c) Grand average waveform at the HEOG channel. Positive voltages indicating deflections towards the TC distractor and negative voltages indicating deflections towards the NTC distractor. (d) Evaluation of the reliability of the observed N2pc and P_D component amplitudes. The dark gray bars represent binned histograms of null distributions generated by a permutation analysis for each component. The light gray shading indicates the top 5% of these null distributions. The black lines indicate the observed amplitudes. (e) Summed area amplitudes for the N2pc and P_D components for each individual participant.

and zero are not appropriate to assess their reliability. Instead, we assessed their reliability using the nonparametric permutation test proposed by Sawaki et al. (2012). This test involved generating a distribution of positive and negative summed area values that could be expected by chance, and then comparing the observed values to these null distributions. The null distributions were obtained by randomly relabelling the laterality of each stimulus of interest for each participant (in our case, whether the distractor was TC-NTC or NTC-TC), re-averaging these dummy data, generating a dummy difference wave, calculating dummy positive and negative summed areas, and repeating this entire process 500 times.

The gray vertical bars in Fig. 5d represent binned histograms of the obtained dummy positive (right plot) and negative (left plot) summed areas. The shaded areas in these plots indicate the range of the 5% of these null distributions with the highest absolute amplitude. As the observed value for each component has a higher amplitude than at least 95% of the permutated values (i.e., the vertical black bars fall above the lower bound of their respective shaded areas), each component can be said to be reliably present. There was one outlier participant (defined as having an observed amplitude greater than 2.5 SD away from the group mean) for the N2pc component, and one for the P_D component. Excluding these participants from the analyses did not change the overall pattern of results; the observed overall summed area values remained higher than at least 95% of the permutated values for the relevant null distributions. Thus, in line with the notion that the observers' feature-based attentional set influenced distractor processing, TC distractors evoked reliable indices of attentional capture (N2pc component) and attentional suppression (P_D component), even in the presence of an NTC distractor in the opposite visual field. These results replicate previous findings of an effect of feature-based attentional set on these components (e.g., Lien et al., 2008; Sawaki et al., 2012).

We then calculated N2pc and P_D amplitudes for each individual participant, again using the summed area method. These amplitudes are plotted in Fig. 5e. These individual component amplitudes were then correlated with the WMC scores in the analyses that follow. We also checked that the ERP components were themselves reliable by splitting each participant's dataset in two and separately analysing only the odd-numbered or even-numbered presentations of each distractor condition. The Spearman-Brown corrected correlations between component amplitudes calculated based on these separate halves of the data were statistically significant for both the N2pc component ($r = .72$, $P < .001$) and the P_D component ($r = .61$, $P < .001$), indicating that these electrophysiological measures were reliable.

For the sake of completeness, we also calculated the correlations between our three measures of the effects of feature-based attention. Reaction time difference scores did not correlate with either N2pc amplitudes ($r = -.11$, $P = .402$) or P_D amplitudes ($r = -.06$, $P = .653$), consistent with the negation of behavioral interference from these stimuli (Ruthruff & Gaspelin, 2018). There was a negative correlation between N2pc and P_D amplitudes ($r = -.47$, $P < .001$), indicating that larger (more negative) N2pc amplitudes were associated with larger (more positive) P_D amplitudes. The lack of reliable positive correlations between these measures suggests that, as we expected, these measures reflect distinct aspects of feature-based attention. We return to elaborate on this observation in the Discussion section.

2.4. *Correlations between WMC and feature-based attention*

To test for a relationship between WMC and feature-based attention we calculated the correlations between, on the one hand, performance on each of the three WMC measures, and on the other hand, the effect of feature-based attention on N2pc amplitudes, P_D amplitudes, and for completeness, RTs observed during the Visual Search task. The results of

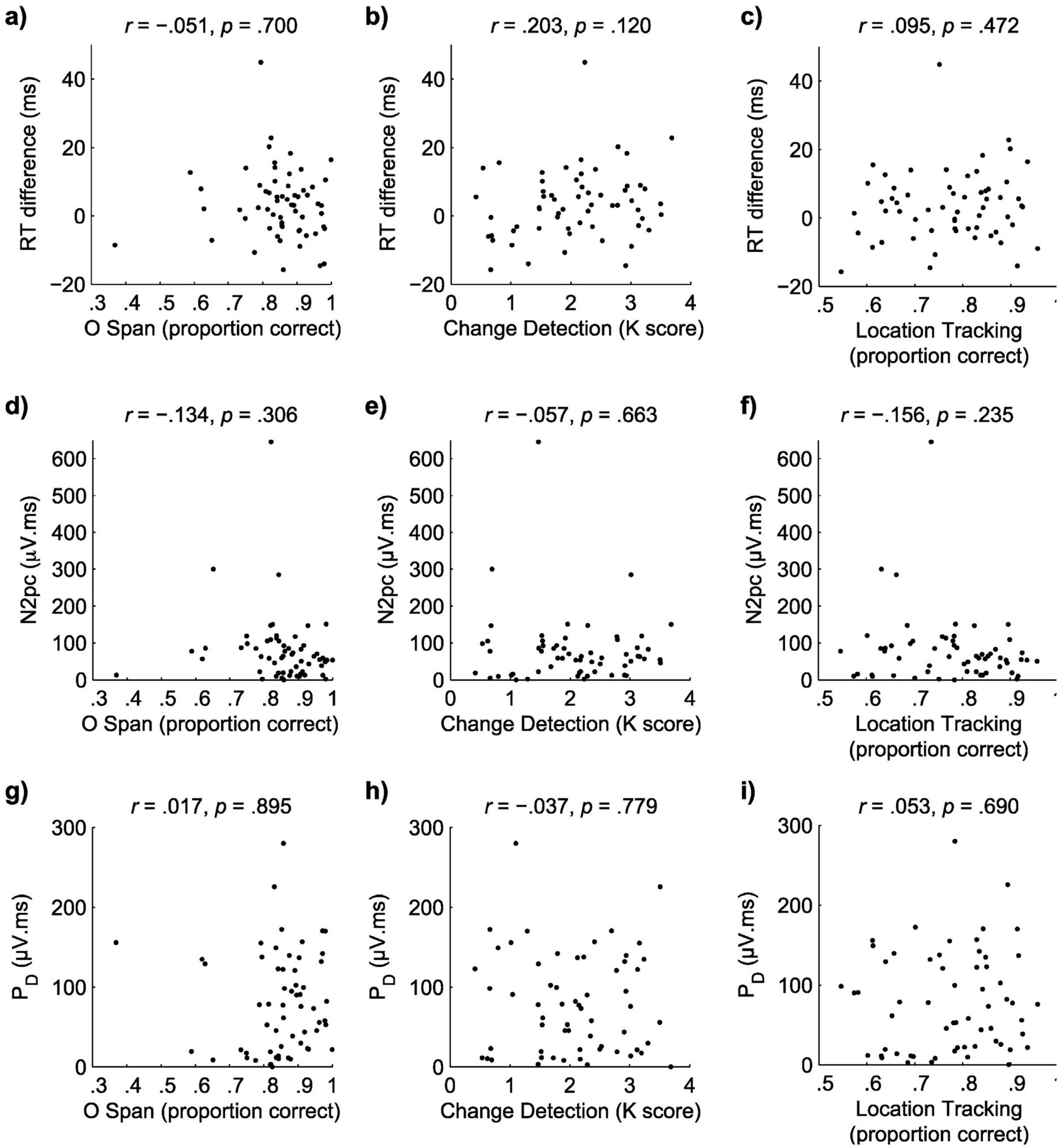

Fig. 6 – Correlations between the three WMC measures and the three measures of feature-based attention (RT, N2pc and P_D).

these correlation analyses are presented in Fig. 6. In each of the plots in these figures, the measure of WMC is plotted on the x-axis, and the measure of feature-based attention is plotted on the y-axis. None of these correlations was statistically significant, even at an uncorrected alpha level of .05, all $r \leq .203$ all $P \geq .120$. To test whether the lack of relationships between the variables might have been driven by outliers, we re-analyzed the data in two ways. First, we performed a median-split based on scores for one variable (the measure of feature-based attention), and then performed between-subjects t-tests based on scores on the other variable (the measure of WMC). This should have reduced any effect of outliers on the comparison. As with the correlation analyses, however, none of these t-tests revealed statistically significant effects of one variable on the other (all $t(58) \leq 1.70$, all $P \geq .094$), even at an uncorrected alpha level of .05. Second, we reduced the influence of outliers on the correlations by performing *skipped correlations*, as implemented in the Robust Correlation Toolbox (Pernet, Wilcox, & Rousselet, 2013; we thank an anonymous reviewer for the suggestion of the skipped correlation method). Consistent with the previous analyses, none of the skipped correlations revealed statistically significant results (all $t(58) \leq 1.76$, all $P \geq .084$), even at an uncorrected alpha level of .05.

To directly test for the strength of evidence in favour of the null hypothesis of no relationship between WMC and feature-based attention, we used Bayes factor analyses (Jeffreys, 1939/1961; Kass & Raftery, 1995; for recent discussions of the advantages of Bayes factor analyses, see Dienes, 2014; Rouder, Speckman, Sun, Morey, & Iverson, 2009; Wagenmakers et al., 2018; Wetzels & Wagenmakers, 2012). We first calculated the Bayes factors for each of the nine correlations in Fig. 6 using the default Bayesian hypothesis test for correlations put forward by Wetzels and Wagenmakers (2012). The Bayes factors (BF_{10}) for the correlations are plotted in Fig. 7a. Six of the nine Bayes factors fell below the 1/3 cut-off value used to indicate substantial evidence in support of H_0 (in this case, that there is no relationship between WMC and feature-based attention), and the remaining three fell in the anecdotal evidence for H_0 range (between 1/3 and 1). We also calculated the Bayes factors for each of the nine t-tests described in the previous paragraph using the Bayesian t-test put forward by Rouder et al. (2009), and for the nine skipped correlations described previously using the above-mentioned Bayesian hypothesis test for correlations (Wetzels & Wagenmakers, 2012). The Bayes factors (BF_{10}) for the t-tests are plotted in Fig. 7b. Here, five of the nine Bayes factors fell below the 1/3 cut-off value used to indicate substantial evidence for H_0, and the

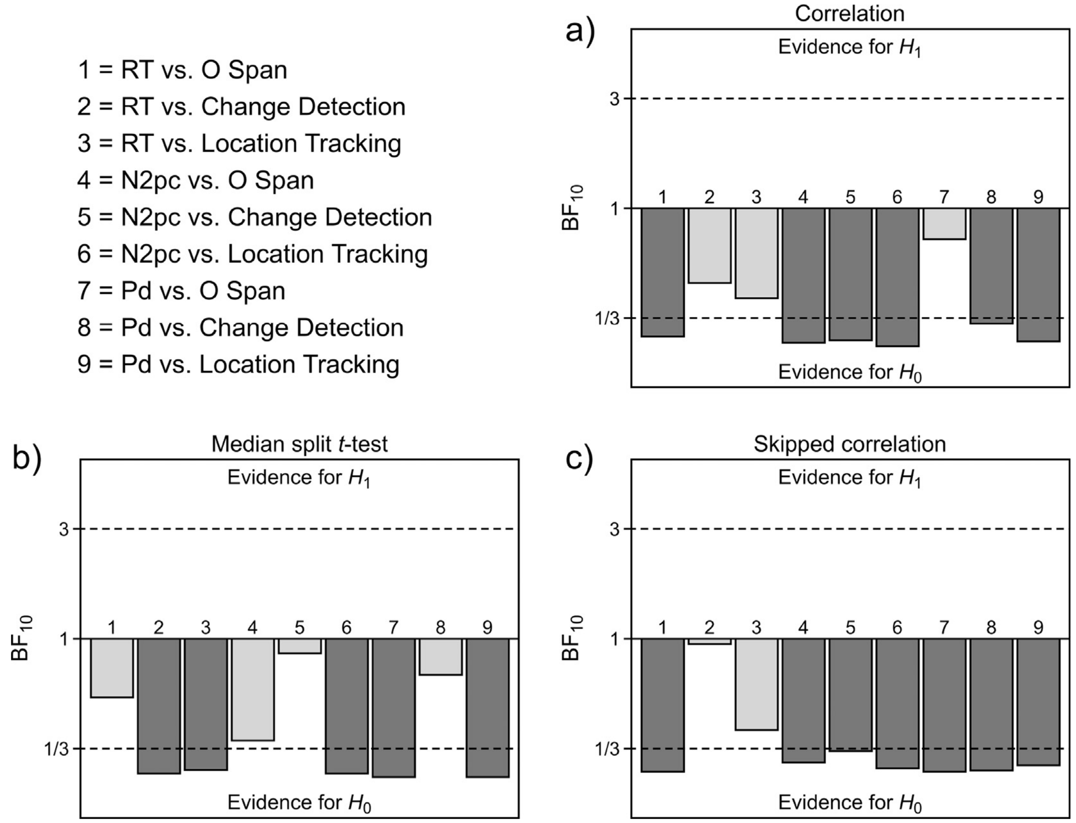

Fig. 7 – Bayes factors for the relationships between WMC and feature-based attention. Bayes factors below 1/3 indicate substantial evidence for H_0 (dark gray bars); those between 1/3 and 1 indicate anecdotal evidence for H_0 (light gray bars); those between 1 and 3 indicate anecdotal evidence for H_1; and those above 3 indicate substantial evidence for H_1. The y-axis is presented on a log scale to appropriately show equivalent levels of evidence for H_1 and H_0. (a) Bayes factors when the relationship was calculated as a correlation. (b) Bayes factors when the relationship was calculated as a median-split *t*-test. (c) Bayes factors when the relationship was calculated as a skipped correlation.

remaining four fell in the anecdotal evidence for H_0 range. The Bayes factors (BF_{10}) for the skipped correlations are plotted in Fig. 7c, and show seven of nine Bayes factors fell below the 1/3 cut-off for substantial evidence for H_0, and the remaining two fell in the anecdotal evidence for H_0 range. The similarity in the overall pattern of results between the correlation Bayes factors, the median-split *t*-test Bayes factor analyses, and the skipped correlation Bayes factors indicates that the lack of relationship between WMC and feature-based attention is not likely to be due to the presence of outliers. Overall the results suggest there is no correlation between WMC and feature-based attention as indexed via the N2pc or P_D components.

3. Discussion

Numerous theories of attentional control assert that maintaining effective attentional settings involves similar neural resources to other cognitive control functions, such as working memory (e.g., Lavie et al., 2004). One testable prediction that arises from this assertion is that individuals' capacity to temporarily store and manipulate information in working memory should be associated with their ability to implement an attentional set for objects with task-relevant features. We tested this prediction in the present study. We obtained three separate measures of each participant's WMC using well-known and reliable tasks. We then measured the extent to which each participant's feature-based attentional set influenced stimulus processing. Participants searched for target objects of a specific color while distractors that either possessed or did not possess the target color were presented at irrelevant, lateralized locations. We obtained electrophysiological measures of attentional signal enhancement using EEG and focused on two key evoked responses: the N2pc component, a measure of attentional capture, and the P_D component, a putative measure of attentional suppression or disengagement (Lien et al., 2008; Hickey et al., 2009; Luck, 2012; but see Livingstone, Christie, Wright, & McDonald, 2017, discussed below).

There was no significant correlation between any of the three measures of WMC and either of the measures of feature-based attention's influence on distractor processing at irrelevant locations. Unsurprisingly, there was also no correlation between the behavioral attentional capture effect we observed and any measure of working memory. Importantly, Bayes factor analyses indicated that the majority (six) of these correlations represented substantial evidence in support of the null hypothesis that there is no relationship between WMC and the influence of feature-based attention on distractor processing. The Bayes factors for the remaining three correlations were found to represent substantial evidence in support of the null hypothesis when we attempted to reduce any influence of outliers by analysing the relationship as a median-split *t*-test rather than a correlation. These findings are broadly in line with those of previous studies that also found no relationship between WMC and the influence of feature-based attention on attentional capture (Burnham et al., 2011; Fukuda & Vogel, 2011). Our study represents a crucial extension of these previous studies in several respects, however. First, we used electrophysiological measures of the influence of feature-based attention on distractor processing. Second, we tested for a relationship using three separate measures of WMC, rather than relying upon a single index alone (Burnham et al., 2011; Fukuda & Vogel, 2009, 2011). Finally, rather than simply failing to find an association, our use of Bayes factor analyses allowed us to quantify the degree of evidence in support of the null hypothesis of no relationship between WMC and feature-based signal enhancement at irrelevant locations, as indexed via the N2pc and P_D ERP components.

It should be noted that without a distractor-absent condition, we can assess behavioral attentional capture only in a relative sense, that is, as a difference between reaction times on TC and NTC trials. We have no way of assessing the degree to which the presence of a TC or NTC distractor impacts behavior in the absolute sense. We note, however, that this limitation is also true of previous paradigms that included a no-distractor condition. As pointed out by Folk and Remington (1998), behavioral interference can occur for a number of reasons, not only because of capture of spatial attention away from the target location. In particular, competition in processing that occurs prior to the shift of attention can introduce a general, non-spatial slowing in the processing of all stimuli, including the target (Kahneman & Treisman, 1984). Such competition has been demonstrated to slow reaction times when responses to a target alone are compared with responses to the same target in the presence of a highly discriminable distractor (which should not be confused for the target; e.g.; Becker, 2007; Kahneman, Treisman, & Burkell, 1983; Treisman, Kahneman, & Burkell, 1983). Thus, the effects of attentional capture are resolvable only in comparison with another condition in which distractors do not capture attention, such as when distractors match a nontarget that requires a response to be withheld (Folk & Remington, 2008).

As noted earlier, Ruthruff and Gaspelin (2018) recently demonstrated that target-colored distractors appearing at locations that never contain a target do not capture attention when capture is assessed behaviorally. Our lateralised distractors never shared a location with the target and as such produced minimal behavioral interference, consistent with the results of Ruthruff and Gaspelin (2018). We did, however, observe a robust and reliable N2pc contralateral to lateralised target-colored distractors, indicating that they still benefitted from feature-based signal enhancement. This result is consistent with the known spatially-independent nature of feature-based attention (Maunsell & Treue, 2006). That target-colored distractors were subject to feature-based enhancement suggests that, although not immune to attentional capture (as indexed by the N2pc), they nevertheless do not elicit behavioral interference (Ruthruff & Gaspelin, 2018), perhaps due to inhibition at a later stage of processing, after the shift of spatial attention.

Our evidence in support of there being no correlation between the N2pc and any measure of working memory is in line with the suggestion of Fukuda and Vogel (2011) that working memory correlates with attentional disengagement rather than feature-based signal enhancement or attentional capture. Given this, one might have expected a correlation between working memory and the P_D component, which has been related to attentional disengagement (Sawaki et al., 2012;

Sawaki & Luck, 2013). Interestingly, we observed no such correlation. However, as only minimal behavioral interference was observed in this paradigm, it is difficult to know to what degree attentional disengagement needed to occur. Our N2pc results demonstrate feature-based enhancement at the location of target-colored distractors, and our P_D results imply the inhibition of that enhancement. From this view, the P_D we observed may then reflect inhibition of attentional engagement at the distractor location, rather than attentional disengagement (Eimer & Grubert, 2014), thus explaining why we observed very little behavioral interference from target colored distractors. That P_D amplitudes did not correlate with WMC suggests that it may be attentional disengagement in particular (Fukuda & Vogel, 2011; Gaspar, Christie, Prime, Jolicoeur, & McDonald, 2016), rather than inhibitory processes generally (Gaspelin & Luck, 2017), that is subject to limitations imposed by each individual's WMC.

In this study we have interpreted the P_D component as an index of attentional inhibition, in line with past research (Sawaki et al., 2012; Sawaki & Luck, 2013). An alternative explanation that is important to consider, however, is that what we are interpreting as a contralateral positivity is in fact an ipsilateral negativity that reflects attention switching to the distractor stimulus presented on the opposite side of the display (Woodman & Luck, 1999). To examine this possibility, we looked at the ERPs for the condition in which the TC distractor was presented with no stimulus on the opposing side. In this condition no shift of attention from the TC distractor to the opposite side should occur, so if a P_D component is still produced this would suggest that this component does in fact reflect inhibition of the location to which attention was captured. Indeed, this is exactly what we observed; distractors presented alone still produced both an N2pc and a P_D component, consistent with the attraction of attention to the distractor location, followed by the inhibition of this location. However, we also acknowledge that ERPs can be difficult to interpret when they are produced by imbalanced displays (hence our inclusion of the balanced conditions). Therefore, while we continue to interpret our P_D results as reflecting inhibition, as we feel this is the most parsimonious explanation of our results, we acknowledge that further work may be required for a definitive conclusion to be reached on this point.

Another alternative account of the P_D component has recently been suggested by Livingstone et al. (2017). They employed a contingent capture paradigm with three different SOAs and found that the P_D component from the cue was time-locked to the onset of the *target display*, overlapping in time with the target-evoked P1 component. The authors concluded that the cue-evoked P_D component and the target-evoked P1 component were one and the same. This result suggests the P_D component may actually reflect enhancement of subsequent stimuli at attended locations, rather than the disengagement of attention from these locations. This interpretation is clearly at odds with our result, as we observed only minimal behavioral interference from attentional capture in our paradigm. It is also at odds with P_D results observed in studies that did not employ rapidly presented sequential displays (e.g., Gaspar et al., 2016). Thus, as has been noted previously (Gaspelin & Luck, 2017), it may be that there is more than one positivity being labelled as the 'P_D component' in these studies (Kappenman & Luck, 2011; Luck, 2014).

The present findings stand in contrast to previous research that has linked WMC to other executive control functions, such as selectively attending to stimuli at a specific spatial location (e.g., Redick & Engle, 2006). A recent study by Robison and Unsworth (2017) might provide an explanation for these differences. They found that WMC did not correlate with attentional capture either when participants were in singleton-detection mode (Bacon & Egeth, 1994), or when they were in feature-search mode. By contrast, WMC did correlate with capture in situations in which participants had been trained to use feature search mode, and could now use feature search or singleton search to complete their task. Robison and Unsworth (2017) found that individuals with lower WMC were more likely to employ a singleton-detection strategy to undertake the search, suggesting that WMC is related to the executive control element of search involved in selecting or maintaining a target set, rather than the execution of search itself. These results are consistent with search being an automatic process following the implementation of a target set by executive control processes (Becker, Atalla, & Folk, 2020). To reiterate our earlier point, we are not suggesting that working memory is *never* associated with the feature-based capture of attention. Instead, we are arguing that the target template implemented in typical attentional capture tasks (those that use a constant target setting; e.g., Folk & Remington, 1998) is not associated with WMC. It is likely that working memory will be involved in implementing a target set in tasks that require frequent updating of target template settings. Indeed, prior studies assessing the involvement of working memory in feature-based attention have shown significant attenuation in neural indices of working memory involvement (the CDA component) after one target repetition (Carlisle & Woodman, 2011; Gunseli, Meeter, & Olivers, 2014; Gunseli, Olivers, & Meeter, 2014; see also Gunseli, van Moorselaar, Meeter, & Olivers, 2015, for similar behavioral evidence). This might explain the lack of relationship we observed between WMC and indices of attentional capture.

Other studies have also found relationships between some aspects of selective attention and the level of concurrent working memory *load* an observer is under. For example, Lavie et al. (2004) found participants were more susceptible to flanker interference in an irrelevant flanker task for stimuli presented during the retention interval of a concurrent high- relative to low-WM load task. Interestingly, however, in a series of three experiments Wang and Most (2008) failed to find any relationship between working memory load and the contingent capture effect, in line with our observation of no relationship between WMC and the effects of feature-based signal enhancement. These results are supported by recent EEG studies that have shown a dissociation between neural indices of spatial attention and working memory maintenance (Günseli et al., 2019; Hakim, Adam, Gunseli, Awh, & Vogel, 2019).

Theoretical accounts of attentional guidance propose that selective attention and working memory share a central pool of executive control resources (Anderson, Matessa, & Lebiere, 1997; Awh et al., 2006; Baddeley, 2003; Bundesen, 1990; Chun, 2011; Conway, Cowan, & Bunting, 2001; Cowan, 1988; Cowan et al., 2005; Desimone & Duncan, 1995; Duncan & Humphreys, 1989; Engle, 2002; Kiyonaga & Egner, 2013; Lavie et al., 2004; Logan & Gordon, 2001; Miller & Cohen, 2001; Nobre et al., 2004; Oberauer, 2009; Pashler & Shiu, 1999; Postle, 2006; Wolfe, 1994). Thus, it may seem surprising that there is no relationship between WMC and feature-based signal enhancement as measured by the N2pc. However, Olivers, Peters, Houtkamp, and Roelfsema (2011; see also van Moorselaar, Theeuwes, & Olivers, 2014) propose that working memory involves two distinct types of representations: *active* representations that are available to central executive processes, and *accessory* representations that are not. Olivers et al. (2011) discuss evidence that—although working memory as a whole can maintain multiple representations at once—the number of *active* representations that can be maintained at any one time is limited to one, regardless of an observer's overall WMC. These authors argue that visual search tasks (such as the one used to measure the effects of feature-based attention in the present study) rely solely on the active representation component of WM, which is used to store a template containing information about the search target. This account has mostly been tested in the context of memory-driven attentional capture (Olivers at al., 2006), which shows that attention can be captured by items in working memory. It remains to be seen, however, whether this is the same mechanism by which attentional templates for dedicated search targets are instantiated. This aspect of the theory has received less empirical investigation (but see Gunseli, Meeter, et al., 2014). If this account is correct, performance on visual search tasks should be influenced by the active component of an observer's WM, but not necessarily by an observer's overall WMC. This proposal may provide an explanation for why feature-based signal enhancement and attentional capture do not correlate with WMC, and suggests that a measure of the active component of an observer's working memory should correlate with attentional capture and the N2pc, if such a measure could be devised.

Another way in which WMC may in fact correlate with feature-based attention is if their relationship is moderated by other neural processes. For example, if the correlation between WMC and feature-based attention is moderated by measures such as the strength of functional connectivity between visual areas and attentional control regions. Recent work employing functional connectivity has shown that single-subject WMC measured via a change detection task is associated with the strength of functional connectivity between prefrontal and parietal brain areas (Duma et al., 2019). Functional connectivity analyses were outside the scope of the present study, and ideally require source reconstructed data from high-density EEG recordings, as well as anatomical MRI scans. Nevertheless, such an analysis would be an interesting avenue for future research.

In summary, although there are clearly relationships between some aspects of working memory and selective attention (e.g., Lavie et al., 2004; Redick & Engle, 2006), this may not generalize to all aspects of the two constructs. We found no relationship between participants' WMC and the extent to which their feature-based attentional set influenced stimulus processing, as reflected in the N2pc and P_D ERP components. We note, however, that there might be other ways in which feature-based attention is affected by WMC, beyond the specific conditions tested here. It is not yet clear whether this finding reflects a complete dissociation between WMC and feature-based attention, or was observed due to search being an automatic process that is not reliant on working memory once an attentional template is established, or alternatively arose because feature-based attention tasks only recruit the active subcomponent of working memory and thus do not reflect an individual's overall WMC. Nonetheless, it is clear from these results that the magnitude of typical electrophysiological measures of attentional allocation, the N2pc and P_D components, is not correlated with WMC.

Credit author statement

OJ, JB, RR, and SB conceived of the experiment. OJ collected the data. OJ and AH analysed the data. All authors contributed to interpreting the data. OJ and AH wrote the manuscript. All authors revised the manuscript.

Open practices

The study in this article earned an Open Materials badge for transparent practices. Materials and data for the study are available at https://osf.io/nehpf/.

Conflict of Interest

Authors report no conflict of interest.

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