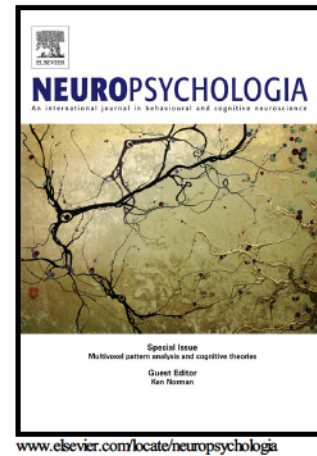


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# **View-sensitive ERP repetition effects indicate automatic holistic processing of spatially unattended objects**

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**Abstract**

This study examined the properties of ERP effects elicited by unattended (spatially uncued) objects using a short-lag repetition-priming paradigm. Same or different common objects were presented in a yoked prime-probe trial either as intact images or slightly scrambled (half-split) versions. Behaviourally, only objects in a familiar (intact) view showed priming. An enhanced negativity was observed at parietal and occipito-parietal electrode sites within the time window of the posterior N250 after the repetition of intact, but not split, images. An additional post-hoc N2pc analysis of the prime display supported that this result could not be attributed to differences in salience between familiar intact and split views. These results demonstrate that spatially unattended objects undergo visual processing but only if shown in familiar views, indicating a role of holistic processing of objects that is independent of attention.

**Keywords**

Event-related Potentials (ERP); Object Recognition; Repetition priming, Spatially unattended objects; N250

## Introduction

Are we able to visually recognise an object without paying attention to it? In reviewing 25 years of visual attention research, Carrasco (2011) noted that the processing fate of unattended objects has not been resolved. However, the answer to this question has implications for research in many applied and basic areas of cognition, particularly in visual attention (Kanwisher & Wojciulik, 2000) and object recognition (Hummel, 2013). The emphasis of the present study was to examine the processing of unattended objects in order to elucidate the nature of mental object representations.

Behavioural priming is one way that has been used to investigate how objects are processed: Objects are generally recognised faster and to a higher degree of accuracy when they are presented a second time (probe stimulus) after a previous viewing (prime stimulus) (Bartram, 1976; see Thoma, Hummel & Davidoff, 2004, for a brief review). Behavioural priming has also been observed in the absence of awareness of the prime stimulus (Henson et al., 2004; Warrington & Weiskrantz, 1974). It has been suggested that such priming is short-lived (Henson, 2003; Stankiewicz, Hummel & Cooper, 1998). Much of the empirical work investigating the nature of object representation has also relied on priming paradigms. Although a number of studies have previously investigated the nature of object representation using behavioural or fMRI measures, only few studies have used EEG to investigate the role of attention in object recognition. The use of scalp recorded event-related potentials (ERP, see Grill-Spector, Henson & Martin, 2006) allows the investigation of the changes in deflections of the EEG components after repeated presentations of the same (or similar) object. Importantly, EEG measures of object repetition permit the disentanglement of early (stimulus-driven) from late processing components, enabling

conclusions about the locus of priming and the nature of underlying object representations.

Thus far ERP studies on object recognition have concentrated on the properties of the representation of attended objects (for example the work of Schendan and colleagues, 2003; 2007; 2010). One example of an ERP study on unattended objects is that of Eddy et al. (2006), who used visual masking to render objects invisible to be processed without attention. They observed more negative amplitude deflections at occipital (O1/2) scalp locations for repeated objects within the time windows of N/P190 (100-250 ms), N300 (250-350 ms) and N400 (350-650 ms), indicating visual processing of unattended objects. However, there is some debate as to what degree visual masking renders a stimulus ‘unattended’ (Henson, 2003) rather than just harder to see. In addition, the study of Eddy et al (2006) presented prime and probe stimulus (even if temporally separated) in the same location and this type of manipulation may not fully prevent the prime from being attended as the task does not involve the necessity for an attentional shift (cf. Wolfe, 2000; Experiment 1 of Lachter et al., 2004). A more effective manipulation of visual attention is to spatially separate the attended target image from the unattended image (Thoma et al., 2004; Yantis, 2008). In the current study we both spatially separated and masked our stimuli, and used spatial cuing to control attention in order to investigate whether ERP repetition effects would still be elicited from spatially unattended objects. Our specific theoretical aim was to investigate whether the observed repetition effects indicate view-based object representations. Some theories posit that object recognition is mediated by view-specific representations (see e.g. Schendan & Kutas, 2003), possibly by some type of interpolation across several 2D views of an object (Bülthoff & Edelman, 1992; Logothetis, 1994; Poggio & Edelman, 1990; Tarr et al., 1998; Ullman, 1989; Ullman

& Basri, 1991) or via a distributed neural representation across view-tuned neurons (Perrett, Oram & Ashbridge, 1998).

A somewhat different role for view-specific representations is assumed in Hummel's (2001) hybrid model of object recognition, which predicts that attended objects prime themselves regardless of the viewpoint they are shown in. This is because priming from attended objects involves part-based representations of objects (Biederman, 1987; Biederman & Gerhardstein, 1993). However, unattended objects in this model are solely represented by view-based representations, as there is no attentional mechanism available to bind parts into structural descriptions (Hummel & Biederman, 1992).

In the previous tests of the hybrid model, the basic trial-paradigm was usually as follows: a prime display with two objects – left and right of fixation – was presented, with one of the objects being precued by a square surrounding the object, which had to be named. This brief (< 200ms) prime-display was followed after 2 to 3 seconds by a single object, the 'probe', which was either the same as the attended prime, the unattended prime, or a novel object. The probe object also had to be named (aloud, or covertly as in Thoma & Henson, 2011). The probe object was always shown in the identical familiar view whereas the prime objects were shown in either the same view or a novel view. The findings were consistent across a range of view manipulations: Attended prime objects elicited repetition priming in familiar and changed views, whereas unattended (uncued) prime objects only elicited priming effects when repeated in the same view. The hybrid model directly predicts view-specific repetition effects from unattended objects in familiar views. These predictions have been confirmed in behavioural (Stankiewicz et al., 1998; Stankiewicz & Hummel, 2002; Thoma, Davidoff & Hummel, 2007; Thoma, Hummel & Davidoff, 2004) and fMRI

(Thoma & Henson, 2011) experiments: Priming from unattended objects was only observed when they were presented in the identical view across the prime and probe displays, indicating that the object representation mediating priming was view-sensitive.

Although the results of these studies support the conclusion that priming for unattended objects is view-dependent, it is less clear whether this unambiguously supports the notion of a holistic and automatic (attention-independent) representation. First, it is in principle possible that in a prime display with a familiar view and an unfamiliar view of objects, that the familiar one may simply attract more attention – independently of whether it was cued or not. This may have biased previous results finding priming only for common views of objects. Although the spatial cuing paradigm has been used in a number of studies to control the allocation of spatial attention, the possibility that salient images may themselves draw attention (e.g. from familiarity or uniqueness in the visual array; Yantis, 2000, Forster & Lavie, 2008, Folk & Remington, 1998) must be acknowledged. In the current study we therefore investigate possible differences in the allocation of spatial attention to the uncued image by examining ERP components related to the prime objects, that is, the magnitude of the prime-locked N2pc. This ERP component, observed between 200-300 ms at posterior electrode sites, is considered to be an indicator of attentional allocation (Astone, Nobre & Scerif, 2010; Eimer, 1996; Luck & Hillyard, 1994) to either side of the visual field, and allows (albeit here in a post-hoc manner) to detect possible differential influence of familiar versus unfamiliar views.

Secondly, and more importantly, it could be argued that the lack of priming effects from unattended objects after view-change may have been simply due to low-level differences in matching the 2D input. In other words, because the probe was always

shown in a familiar view, the usually observed view-specific priming may be simply due to picture-to-picture priming; there was a low-level match of the 2D input for the identical prime-probe images that was not present for those for which there was a view-change between and probe display<sup>1</sup>. In an early attempt to address this issue, Thoma et al., (2004; Experiment 3) ran an additional experiment in which primes were also presented either in a familiar (intact image) or unfamiliar (split-image, transformed by vertically splitting the image and swapping the location of each side) view. Crucially however, unlike previous studies, the prime and probe views were matched – such that the probe object could be the repeated prime object in an unfamiliar view. This distinguished the contributions of the familiarity of the (canonical) view of the object prior to the experiment from that of low-level matching within the experiment to the resultant priming. Thoma et al. (2004) observed that unattended objects showed priming effects in familiar views, but not when prime and probe were shown in unfamiliar views ('split-images') of objects. This result confirmed that priming from unattended objects relies on the access to a 'pre-existing representation' (cf. Cooper, Biederman & Hummel, 1992; Biederman & Cooper, 1991; Fiser & Biederman 2001). However, these behavioural results could still be a result of possible confounds as described above (e.g., attentional slippage to more

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<sup>1</sup> Even though in previous behavioural work prime and probe stimuli were shown at different locations, low-level matching of stimulus properties may still occur: In the Olshausen et al. (1993) model outputs of retinotopic visual neurons (as found in V1 and V2) are mapped to neurons whose receptive fields are invariant with translation and scale. This model would either predict no priming at all for ignored objects (because such object models are not stored in IT, as e.g. split versions) or priming solely for identical images when unattended (both split and intact pairs).



familiar views), and behavioural priming is simply not always sensitive enough to detect repetition effects for unfamiliar views (Guillaume et al., 2009 have argued that ERP repetition effects have consistently been observed in studies in which behavioural priming was not).

Depending on the time windows in which they were observed, ERP correlates of object repetition have been associated with view-dependent representations at low-level processing (e.g., N1/P150), post-perceptual (e.g. N250) or conceptual representations (e.g. N400), as discussed in Schendan et al., (2010). In combination with the prediction from the attentional cueing paradigm (as described above), the use of ERP correlates of object recognition in this study will therefore help to determine the nature of shape representations underlying object recognition.

Schendan and Kutas (2003) observed repetition effects as early as the vertex P150 component (140-250 ms) up to 700 ms post-probe onset, and these were view-dependent: Objects repeated in the same view elicited enhanced amplitudes compared to new objects or objects repeated in a different view. Schendan et al. (2010) distinguished processing before and after 200 ms post-probe onset as perceptual or post-perceptual, respectively.

The N1 (160-190 ms) component also lies within this early perceptual time frame, and Henson et al. (2004) observed ERP repetition effects manifested as a more positive deflection at frontal sites accompanied by an enhanced deflection at occipito-temporal sites for repeated non-face objects. Doniger et al. (2001) have suggested that the repetition effects that they observed in their N1 window (155-185 ms) were associated with structural analysis of the image. They also suggest that such analysis occurs in 'perceptual mode' and that the object recognition that it leads to is automatic

(in the sense that it is "rapid and effortless"). Similarly, the N170 has been found to be sensitive to configural processing, even for non-faces (Roission et al, 2002, but see Bentin et al. 2002). The enhanced amplitude negativity for repeated objects continues into the subsequent time window (200-300 ms) of the Henson et al study, and it is within this post-perceptual time window  $\geq 200$  ms post-probe onset (Schendan et al., 2010) that ERP repetition effects from attended objects have been more consistently reported (e.g. Doniger et al., 2000 (230-330 ms); Zhang et al., 1997 (220-260ms)).

The N250 is the negative-going wave in the time window of 180-290 ms at inferior temporal electrode locations (Luck, 2005). Schweinberger, Pickering, Burton and Kaufmann (2002) found the N250r (for repeated faces) to be maximal at around 220-290 ms at inferior temporal electrode locations. Martín-Loeches et al. (2005) observed enhanced negative occipito-temporal (200-300 ms) deflections upon the repetition of both attended face and object images, which the authors associated with stored structural representations. The N250r has also been observed to be sensitive to the view of the repeated image (e.g. Bindemann, Burton, Leuthold & Schweinberger, 2008).

Finally, the N400 is a negative-going wave reported as peaking at around 400 ms post-stimulus onset at anterior electrode sites. These repetition effects post-400 ms are qualitatively different to the N1 and N250, and have been associated with conceptual processing for example by Henson et al. (2004) who observed repetition effects between (400-500 ms) elicited by attended objects, and Eddy et al. (2006) who observed repetition effects between (350-650 ms) elicited by masked primes.

The present experiment tested whether ERP repetition effects can be elicited by spatially unattended intact or configurally changed (i.e. 'split') images. Key to the

configural change in these images is that the two halves of the image are swapped in location (as illustrated in Figure 1). This manipulation disrupts the 2D view of a familiar object while leaving the part-based description largely intact, and has been shown to distinguish between part-based and view-based representations (Hayward et al., 2010; Thoma et al., 2004). Splitting an image arguably presents an object in an unfamiliar view, but also crucially disrupts its holistic properties: In Biederman's (1987) Recognition-By-Components theory and Hummel's (2001) hybrid model, an object seen as a split 2D image is only recognisable from its component parts. Both theories predict that no part-based priming occurs for unattended objects. In the present study only priming from the uncued objects was examined<sup>2</sup>.

Because to our knowledge the current ERP study is the first examining view-sensitivity of repetition effects from spatially unattended objects, the predictions for the current study were based on previously observed repetition effects on ERP amplitude for attended and masked objects, and also upon the assumptions of the hybrid model. Therefore, our directional hypothesis was that ERP repetition effects would be manifested as an enhanced negativity for repeated compared to unrepeated objects at parietal or occipito-parietal scalp locations (P7/8, or PO7/8 respectively,

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<sup>2</sup> Because of these theoretical considerations, we correctly use the term 'view-specific' and 'holistic' here interchangeably: Intact and split images of an object (see Figure 1) refer to different holistic representations (different features are bound to different locations in the image, see Hummel, 2001), but retain an almost equivalent structural representation (the same parts are depicted). Splitting an image is therefore a true test of holistic (view-based) representations – conventional view manipulations such as scaling or depth rotations are not (Thoma et al., 2004; Thoma & Davidoff, 2007), as they may map on identical structural representations.

following Martín-Loeches et al., 2005; Zhang, et al., 1997) within the time windows of the N1 or N250r. (For the behavioural measure we expected that repeated objects would be named faster than unrepeated objects). From the assumptions of the hybrid model that pertain to the representation of unattended objects, it was expected that such repetition effects would only be elicited by intact, and not split, object images.

## Materials and Methods

### Participants:

Eighteen right-handed Native English speakers all reporting normal or normal-to-corrected vision gave written informed consent to participate in the experiment. Ethics were approved by the University of East London Research Ethics Committee. All participants received either course credits or high street vouchers for their time. Due to insufficient numbers of artefact-free trials (less than 60%) four participants' data were excluded from further analysis. The remaining fourteen participants (eight female) were aged between 19-26 years ( $M = 20.8$  years,  $SD = 2.39$ ).

### Materials:

The stimuli consisted of 400 black and white line drawings of familiar everyday objects from the picture sets of Snodgrass and Vanderwart (1980), Rossion and Pourtois (2004), and Cycowicz, Friedman and Rothstein (1997). The experiment was of a 2 x 2 within-participants design, with the independent variable probe presentation condition: (1) intact repeated (2) intact unrepeated (3) split repeated (4) split unrepeated, with 40 trials in each condition, giving a total of 160 trials. Examples of stimuli in each presentation condition are shown in Figure 1. Note that split images are not only split, but the locations of the halves themselves are also swapped (left to

right and vice versa). Each trial included a prime display (comprised of two images: one cued and thus attended and the other uncued and so unattended), and a probe display (comprised of one image). For the repeated conditions the probe image was the same object as the unattended prime image. For the unrepeated conditions the probe image was a completely different object to both the unattended and attended images in the prime display. The prime objects (and corresponding probe) were shown either as an intact image or a split image. The cued (attended) image was always shown as an intact image. All objects were only seen once for each participant.

Each of the object stimuli was allocated to one of seven subsets (A, B, C, D, E, F and G). Subset A contained 160 objects that were presented to all participants as cued (attended) images, i.e. all attended images were the same for all participants, and these were randomly paired with unattended images. To ensure that all objects only appeared once for each participant and that all unattended objects appeared equally often as prime and probe in all conditions across participants, the subsets B, C, D, E, F and G were used in different conditions counterbalanced across participants.

Subsets B, C and D each contained 40 objects that for the first participant appeared as intact images in random order as repeated primes and probes (B), unrepeated primes (C) and unrepeated probes (D). The same logic was applied to the subsets E, F and G, also each containing 40 objects, but that appeared as split images. The subsets were counterbalanced across participants. All images within each subset were presented in random order.

Stimuli were presented on a 17" CRT monitor with a refresh rate of 60 Hz. Each object image was standardised to subtend a visual angle of  $4.5^\circ \times 4.5^\circ$ . Stimulus presentation was controlled using a Pentium PC running E-prime v.1. (Psychology

Software Tools, Pittsburgh, P.A.). The number of responses, reaction times and EEG were recorded for each participant for both prime and probe displays.

#### **Procedure:**

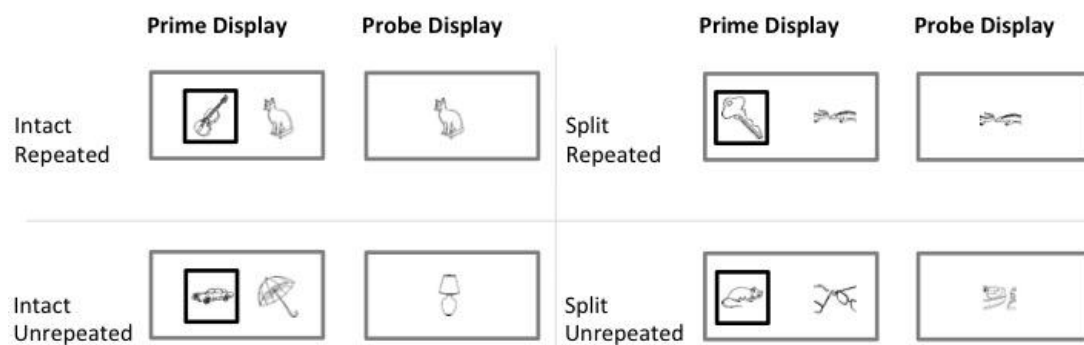
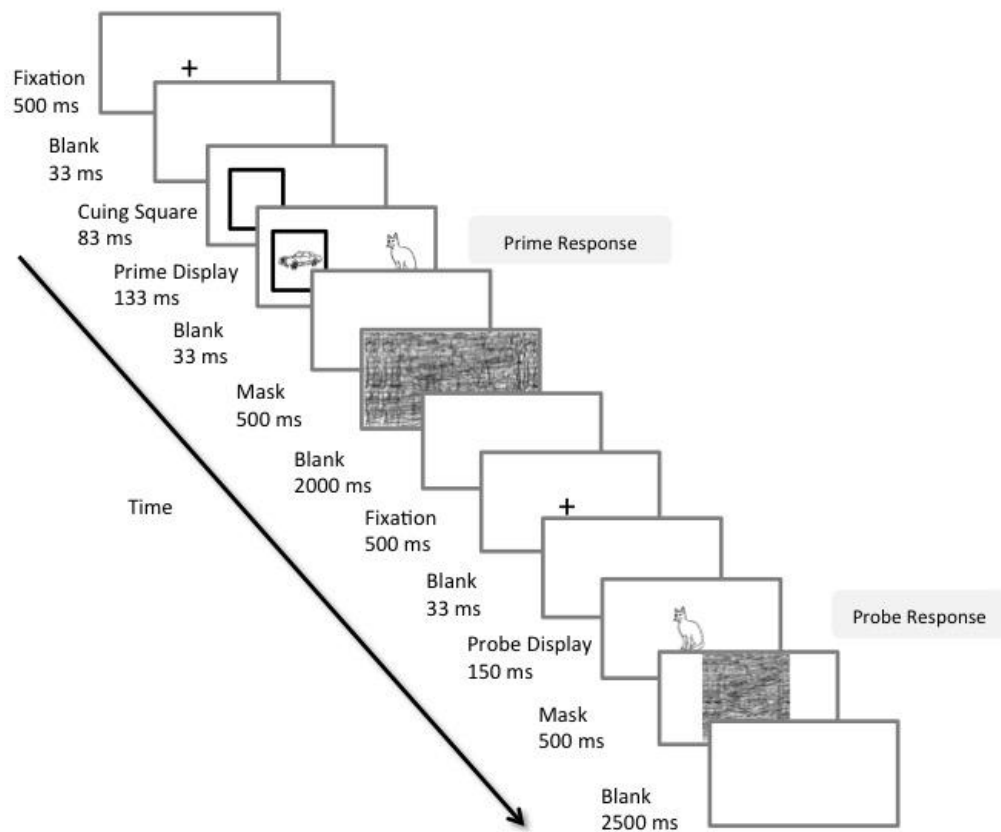
The experimental procedure was adapted from the short-lag repetition-priming paradigm used for behavioural tests by Thoma et al. (2004), and is shown in Figure 1. Each trial began with a central fixation cross (500 ms), which was followed by a blank screen (33 ms). Then the cuing square ( $4.57^\circ \times 4.57^\circ$ ) was shown (83 ms) at a distance of  $4.0^\circ$  either to the left or right of the centre of the screen. The cuing square remained on the screen during the prime display that was presented for 133 ms. The prime display consisted of two object images: The cued ‘attended’ object within the square and the uncued ‘unattended’ object equidistant to the other side of the screen. The cued object was always presented as an intact image, whereas the uncued object was presented for half the number of trials as an intact image and for the other half as a split image in randomised order. The prime display was first followed by a blank screen (33 ms) and then by a random-line mask ( $500 \text{ ms}$ ), which covered the display area ( $15.6^\circ \times 15.6^\circ$ ). After this, a blank screen was presented (2000 ms), allowing time for the participant to respond. Participants were required to sub-vocally name the cued object and simultaneously respond with a button-press. They were asked to withhold from pressing the button if they were unable to name the object. Sub-vocal naming was used in order to avoid contamination of the EEG signal with muscular artefacts, following the rationale of previous work such as Cheng, Schafer and Akyürek, 2010 (see also Ganushchak, Christoffels & Schiller, 2011, and Porcaro, Medaglia & Krott, 2015, for further discussion). Importantly, overt and covert ERPs to picture naming have been observed not to differ up to 400 ms post-stimulus onset

(Eulitz, Hauk & Cohen, 2000). Of particular relevance here, Thoma and Henson (2011) also used sub-vocal naming in their fMRI study that also used a short-lag repetition-priming paradigm similar to that of the present study. Thoma and Henson (2011) replicated the behavioural priming patterns of overt naming observed previously in the studies of Thoma, Hummel and colleagues.

Following this prime sequence, another central fixation cross was presented (500 ms), followed by a blank screen (33 ms). The probe display was then presented (150 ms), and this consisted of a single object image that was either the same as the uncued image in the prime display (repeated) or a previously unseen image (unrepeated). The view of the probe image was always matched to that of the corresponding uncued prime image. Therefore, the four probe display conditions were intact-repeated, intact-unrepeated, split-repeated and split-unrepeated. The probe display was followed by another random-line mask (500 ms), which covered the area of the probe image ( $4.57^\circ \times 4.57^\circ$ ). The mask was followed by a blank screen (2500 ms), allowing time for participants to respond to the probe display. Participants were asked to sub-vocally name the probe image and simultaneously make a button-press. The subsequent trial was delayed with a random jitter of inter-stimulus-interval of 190, 390, 590 or 790 ms.

There were 160 experimental trials in total, with 40 trials in each experimental condition. Prior to the experimental trials, participants completed a short practice session of 16 trials, using different images to those in the experimental block. Three of the trials in the practice block, presented at random, were catch-trials in which participants were asked to name out aloud the cued object and probe images. This was done to ensure participants' understanding of the task. Although participants were told that such overt naming might be required at any time during the experimental

block, actually only one catch-trial was included, and this was always the last trial of the block.





*Figure 1.* Top panel: Example trial sequence in which the uncued object was shown in an intact configuration. Bottom panel: Examples of prime and probe displays for each experimental condition.

### EEG Recording

EEG was recorded using an EGI Hydrocel Geodesic Sensor Net (HGSN) with dense array of 128 Ag/AgCl sensors. The impedance of each electrode was maintained at below 50 k $\Omega$  during the testing session. The data were sampled at 500 Hz and filtered on-line to accept frequencies within the band of 0.1-200 Hz.

Off-line, data were processed using Netstation (NS) v.4.2.4 (EGI, Eugene) software. A low-pass filter of 30 Hz was applied and then data segmented from 200 ms prior to and up to 800 ms following each prime or probe onset. Only those trials where a response was given to both prime and probe display were included in further analysis. Artefact detection was performed on a trial by trial basis and an automated procedure (NS) applied to detect all trials containing eye-movements (amplitude difference of 55  $\mu$ V, for a moving average window of 80 ms), blinks (amplitude difference of 140  $\mu$ V for a moving average window of 80 ms) and where 20% of channels were deemed 'bad' (i.e. with an amplitude difference of 200  $\mu$ V). The NS algorithm 'bad channel replacement' was used to replace the signal from the remaining 'bad' channels. Trials contaminated by such artefacts were excluded from further analysis. The remaining trials were averaged across each condition for each participant, re-referenced to an

average reference<sup>3</sup> (following e.g. Gruber et al., 2004; Engst et al., 2006; Schweinberger et al., 2002) and then baseline-corrected to 100 ms prior to event-onset. After artefact detection, the average number of artefact-free trials left in each condition across participants were: Intact-repeated  $M = 31.4$ ,  $SD = 4.60$ ; Intact-unrepeated  $M = 31.6$ ,  $SD = 5.75$ ; Split-repeated  $M = 27.6$ ,  $SD = 6.48$ ; Split unrepeated  $M = 28.9$ ,  $SD = 4.77$ . Where appropriate the Greenhouse-Geisser corrected values are reported to address possible non-sphericity.

Statistical analyses were focused on the electrode sites corresponding to the 10-20 sites: P7, P8, PO7, PO8, as these were the sites previously linked with ERP repetition effects at both the time windows of the N1 (100-200 ms) and N250r (220-290 ms) components. Planned comparisons were run on the predicted interaction of View x Repetition, derived from the hybrid model, with the alpha level (one-tailed) set at .05 for statistical significance, following Howell (2009). Otherwise follow-up analyses employed Bonferroni corrections accordingly.

A peak-picking algorithm (EGI adaptive mean) was used to calculate the latencies at the peak and mean amplitudes  $\pm 20$  ms around the peaks within the N1 time windows for each participant. All participants' data showed negative peaks within 130-190 ms (N1), confirmed by visual inspection. The mean amplitude over the time window of 230-310 ms (consistent with the N250r) was also calculated for each participant.

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<sup>3</sup> Problems with using an average reference have been raised (e.g. Luck, 2005), however, it has also been suggested that the high numbers of electrodes such as in our 128-channel array may improve the accuracy of voltage measurement and alleviate problems with reference biases (Dien, 1998).

Following the analysis of ERP repetition effects, a post-hoc N2pc analysis was also performed using the same artefact-free trials. The prime-locked ERP mean amplitude between 230-280 ms at electrode locations contralateral and ipsilateral relative to the spatially cued side of the visual field for each participant were compared. The electrode sites for the N2pc analysis (P7, P8, PO7 and PO8) and time window were chosen based on previously observed effects for the N2pc by e.g. Astle et al. (2010). Planned comparisons were performed to test for a significant N2pc for intact and split primes.

## Results

### Behavioural

Only those trials with a response for both prime and probe and with probe RT between 250-2000 ms were included in this analysis. The data from one participant were excluded from the RT analysis as their RT in each condition was found to be above 2SD from the group mean. Out of the data from the remaining 13 participants, 92% of the total trials were used in the subsequent analyses (the excluded 8% were lost to missed responses or RT that were outside of the limits defined above).

For the prime display, the effect of the view of the uncued image on the number of responses and RT were examined. A paired t-test on the percentage number of prime responses revealed significantly more responses for intact ( $M = 78.2\%$ ,  $SD = 10.6$ ) compared to split ( $M = 68.2\%$ ,  $SD = 13.8$ ) images,  $t(12) = 4.24$ ,  $p = .001$ ,  $d = 1.22$ , but the paired t-test on the prime RT revealed no significant difference between intact

( $M = 555$  ms,  $SD = 240.1$ ) and split ( $M = 554$  ms,  $SD = 228.0$ ) image conditions,  $t(12) = .124$ ,  $p = .904$ ,  $d = 0.03$ .

For the probe display, the mean probe RT for each participant were submitted to a 2 x 2 within-participants Analysis of Variance (ANOVA), with factors view (intact, split) and repetition (repeated, unrepeated). This revealed a significant main effect of view  $F(1,12) = 10.34$ ,  $p = .007$ ,  $\eta_p^2 = .46$ . Naming intact images ( $M = 563$  ms,  $SD = 196.2$ ) was faster than naming for split-images ( $M = 648$  ms,  $SD = 262.1$ ). There was no significant main effect of repetition  $F(1,12) = 0.396$ ,  $p = .054$ ,  $\eta_p^2 = .032$ , and the interaction between View and Repetition in this experiment was not significant,  $F(1,12) = 3.67$ ,  $p = .079$ ,  $\eta_p^2 = .23$ . This trend did mirror the results of the higher-powered experiment by Thoma et al. (2004, Experiment 3), with significant priming in the present study also only evident for intact images which showed a just significant repetition advantage of 29 ms ( $t(12) = 1.79$ ,  $p = .0495$ ; one- tailed)  $d = 0.50$ , that was not observed for split images, which suffered a repetition cost of 10 ms that was not-significant ( $t(12) = .478$ ,  $p = .320$ ,  $d = -0.13$ ). The mean RTs across participants for each condition are given in Table 1.

Table 1 Mean probe RT in ms and SEM for Intact and Split image view

View	<u>Repeated</u>		<u>Unrepeated</u>	
	Mean	SEM	Mean	SEM
Intact	549	48.8	577	60.6
Split	653	72.9	643	73.9

*Probe-locked ERP*

The grand-averaged probe-locked waveforms for each experimental condition for the electrodes P7, P8, PO7 and PO8 are shown in Figure 2. The mean ERP amplitudes from each participant were submitted to separate  $2 \times 2 \times 2 \times 2$  ANOVAs for each time window, with factors view (intact, split)  $\times$  repetition (repeated, unrepeated)  $\times$  hemisphere (left, right)  $\times$  electrode site (parietal P7/8, occipito-parietal PO7/8).

In the time window of the N1 (130-190 ms post-probe onset), the analysis of the amplitude revealed no significant effects involving the repetition factor,  $ps > .16$ .

There was a significant main effect of view  $F(1,13) = 13.67, p = .003, \eta_p^2 = .51$ , such that split images elicited an enhanced negativity in amplitude ( $M = -4.81 \mu V, SD = 2.75$ ) compared to intact images ( $M = -3.63 \mu V, SD = 2.32$ ). The main effect of electrode site was near significant,  $F(1,13) = 4.40, p = .056, \eta_p^2 = .025$ , and there were no other significant main effects or interactions,  $ps > .12$ .

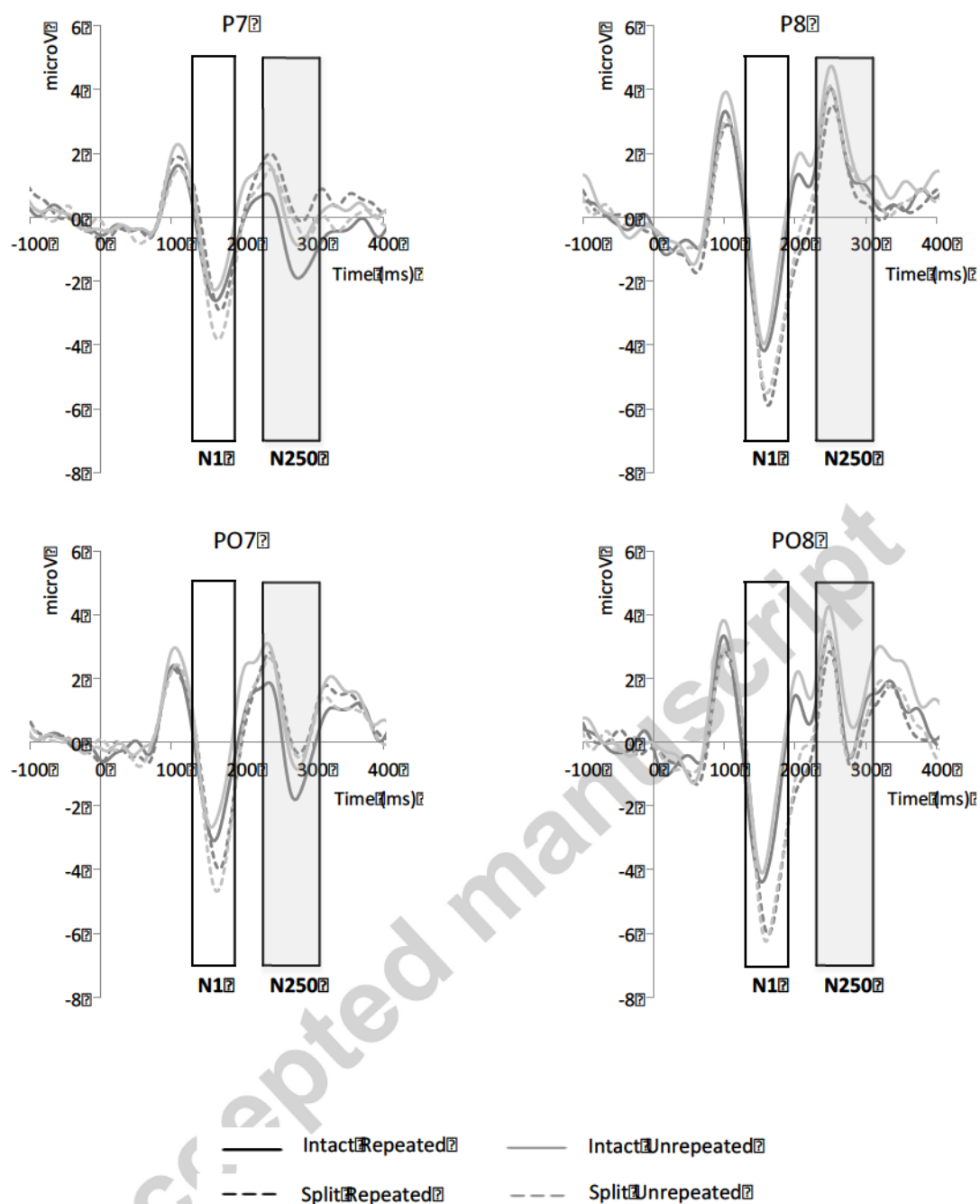
In the N250 time window (230-310 ms post-probe onset) a significant interaction between View and Repetition  $F(1,13) = 7.17, p = .019, \eta_p^2 = .36$  was observed. The interaction between View and Hemisphere was also significant,  $F(1,13) = 10.10, p = .007, \eta_p^2 = .44$ . No other main effects or interactions reached significance,  $ps > .069$ .

The significant interaction between View and Repetition was followed up by paired  $t$ -tests that revealed that only intact images resulted in a significant repetition effect  $t(13) = 3.03, p = .005$  (one-tailed) such that repeated images elicited more negative amplitudes ( $M = -0.51 \mu V, SD = 3.22$ ) than unrepeated images ( $M = 0.50 \mu V, SD = 3.43$ ),  $d = 0.81$ . For split images, there was no significant difference in amplitude elicited by repeated ( $M = 0.19 \mu V, SD = 3.50$ ) and unrepeated conditions ( $M = 0.21$

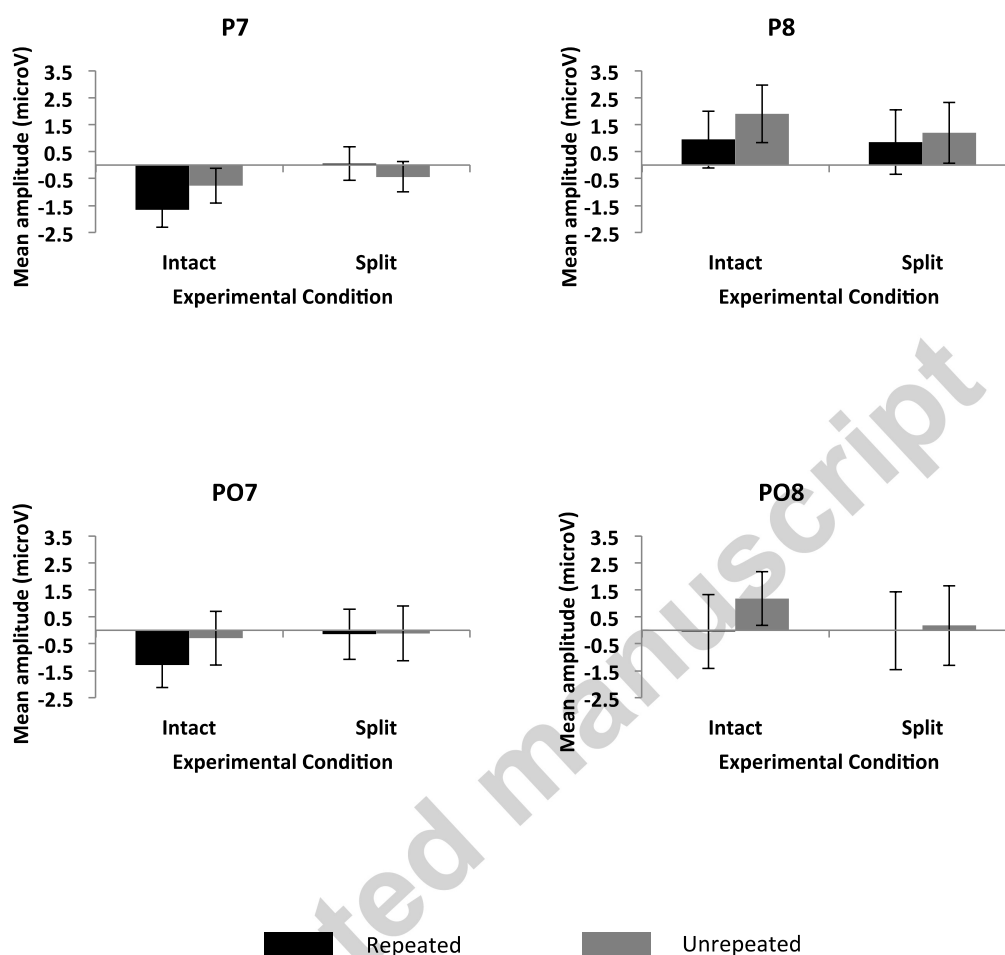
$\mu\text{V}$ ,  $SD = 3.62$ ),  $p = .47$  (one-tailed),  $d = 0.02$ . The mean amplitudes are shown in Figure 3.

In the N400 time window (400-500ms) a significant main effect for hemisphere,  $F(1,13) = 4.97$ ,  $p = .044$ ,  $\eta_p^2 = .276$ , was observed. No other main effects or interactions reached significance,  $p$ 's  $> .126$ .

Although only P7/8 and PO7/8 electrodes were analysed, the potentials at 128-channels were recorded, and the topographic difference (repeated – unrepeated) maps for intact and split conditions are shown in Figure 4.



*Figure 2.* Grand-averaged probe-locked ERP waveforms. The boxes show the time windows analysed for the N1 and N250; grey shading indicates where significant main effects or interactions with repetition were observed. Dark grey lines are used for repeated objects and light grey for unrepeated objects, solid lines for intact images, dashed lines for split images.



*Figure 3.* Probe-locked N250 mean amplitudes  $\pm 1$  SEM for parietal (P7/8) and occipito-parietal (PO7/8) electrode sites. Black shading is used for repeated objects and grey shading for unrepeated objects, solid shading for intact images, dashed lines for split images.



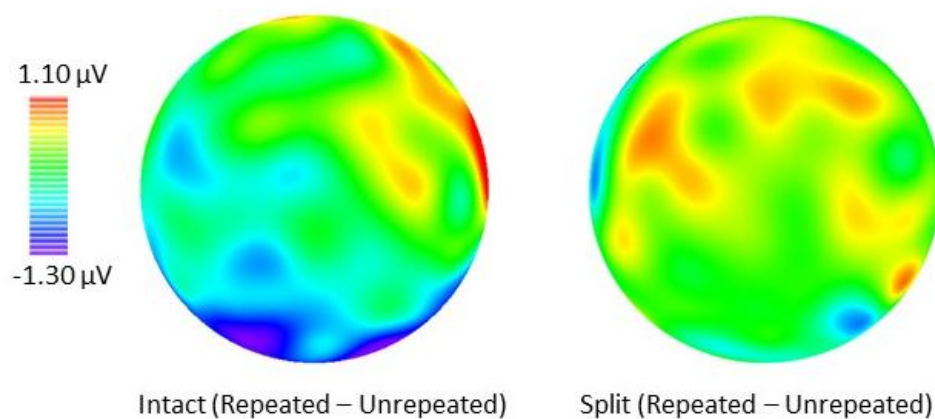


Figure 4. Topographic difference map (repeated – unrepeated) of potentials averaged over the time window of the N250 (230-310 ms).

#### ***Prime-locked ERP***

The ERP effects in the N250 time-window indicate priming only for objects in an intact (already familiar or learned) view, as observed in the behavioural results of Thoma et al (2004). However, one alternative interpretation of the presence of repetition effects elicited by intact and not split images in this experiment derives from the possibility that intact objects are more salient than their split counterparts (e.g. Yantis, 2000). Therefore, in order to argue that the observed repetition effects were elicited without attention, the possibility that the uncued intact images simply captured attention more than the split images was addressed through a post-hoc analysis of the effect of the view of the prime image upon the magnitude of the N2pc, an ERP component indexing the allocation of attention (Astle et al., 2010; Eimer,

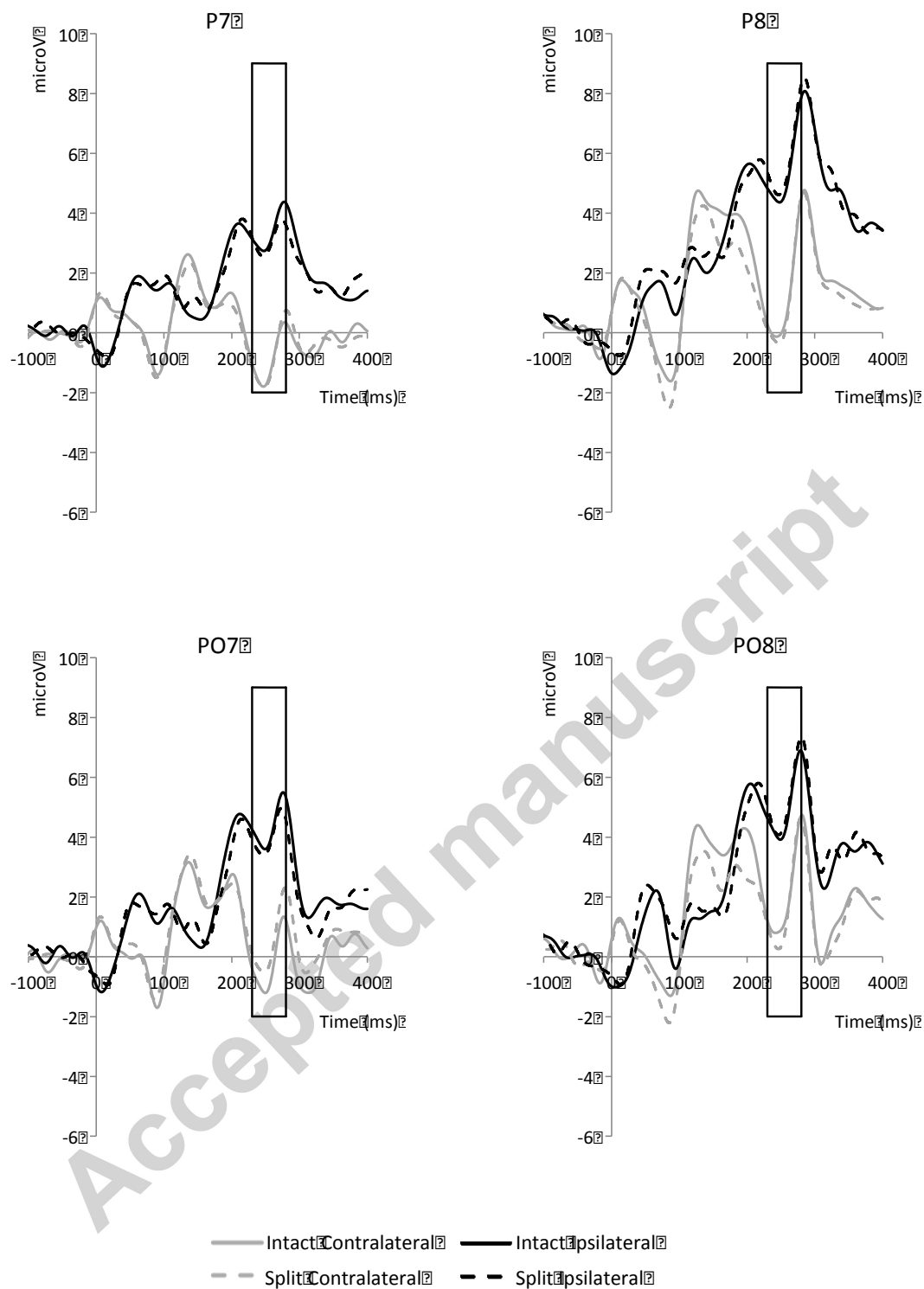
1996; Luck & Hillyard, 1994), was examined<sup>4</sup>. Specifically, an effect of view on the difference in amplitudes observed at electrode sites contralateral and ipsilateral electrode sites to the cued visual field would indicate that the initial prime presentation conditions were not equivalent for intact vs. split-images in terms of attentional allocation.

The grand-averaged prime-locked contralateral and ipsilateral waveforms relative to the cued visual field for each experimental condition for the electrodes P7, P8, PO7 and PO8 are shown in Figure 5. The mean amplitude for the time window 230-280 ms calculated for each participant were submitted to a 2 x 2 x 2 x 2 repeated-measures ANOVA with factors view (intact, split) x laterality (ipsilateral, contralateral to cued visual field) x hemisphere (left, right) x electrode site (parietal P7/8, occipito-parietal PO7/8). This revealed significant main effects of Laterality  $F(1,13) = 141.07, p < .001, \eta_p^2 = .92$ , and of Hemisphere  $F(1,13) = 8.70, p = .001, \eta_p^2 = .40$ , that were modified by a significant three-way interaction between Laterality x Hemisphere x Electrode Site  $F(1,13) = 8.47, p = .012, \eta_p^2 = .39$ . There were no other significant main effects or interactions,  $ps > .12$ . Importantly for this experiment, neither statistically significant effects involving main effect of, nor interaction with, view factor were revealed,  $ps > .18$ . In particular, although there was a significant N2pc (the difference between the contralateral and ipsilateral amplitudes) for both intact,  $t(13) = 9.51, p < .001, d = 2.54 (M = 3.99 \mu V, SD = 1.57)$ , and split,  $t(13) = 12.65, p < .001, d = 3.31 (M = 3.86 \mu V, SD = 1.14)$ , images, there was no significant

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<sup>4</sup> Although there is some debate as to whether the N2pc indexes target selection (e.g. Eimer, 1996) or distractor inhibition (e.g. Luck & Hillyard, 1994) processes, here the focus is only to use it to test for a difference between the view conditions at prime on attentional allocation.

interaction between View and Laterality,  $p = .706$ ,  $\eta_p^2 = .01$ . Note that caution is required in interpreting a null result and it must be acknowledged that the N2pc analysis usually relies on mastoid reference and greater trial numbers (Woodman, Arita, & Luck, 2009). Nevertheless, the N2pc analysis strengthens the conclusion that the difference in view (intact/split) of the uncued image did not result in a difference in attentional allocation at the target.



*Figure 5.* Grand-averaged prime-locked ERP waveforms for parietal and occipito-parietal electrode sites contralateral and ipsilateral to the spatially cued visual field.

Black lines are used for ipsilateral amplitudes and light grey for contralateral

amplitudes, solid lines for intact images, dashed lines for split images. The boxes indicate the time window analysed; no significant effects involving the view factor were observed.

## Discussion

This study is the first to demonstrate view-specific ERP repetition effects elicited by objects that were presented at a different spatial location to the attended object. Objects shown and repeated in familiar views revealed more negative amplitudes compared to unrepeated objects at parietal (P7/8) and occipito-parietal (PO7/8) sites in the time window of 230-310 ms. The important novel finding is that the current repetition effects for unattended objects were truly holistic<sup>5</sup> – as they are limited to situations in which observers were exposed to familiar intact 2D representations of objects: No repetition effects were found when both prime and probe were unfamiliar split versions of a common object.

These repetition effects confirm a key prediction of a hybrid model of object recognition (Hummel, 2001) proposing that both part-based and view-based shape representations mediate repetition effects. Whereas strictly part-based models of object recognition (e.g., Hummel & Biederman, 1992) predict priming (repetition)

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<sup>5</sup> Maurer, Le Grand & Mondloch (2002) have discussed the ambiguity in the definition of the term ‘configural’, particularly in face processing literature, and similarly here, ‘holistic’ is meant in the terms of the hybrid model to mean the way in which part and location information are bound in ‘one-shot’ in the representation. Such a representation is more than a low-level feature map (which would have resulted in repetition effects from split primes to split probes, and were not observed here).

effects only from attended objects, the hybrid model predicts object priming from unattended objects, as long as they are presented in a familiar view.

The current experiment specifically controlled spatial attention through a cuing paradigm (e.g., Thoma et al., 2004) that also enabled post-hoc checking –using the N2pc component– of potential attentional slippage as a possible confound (Lachter et al., 2004). It is worth noting that even if one assumed leakage or attentional slippage in the current paradigm, accepting the caveats associated with the N2pc results, part-based (structural) description models would have then predicted equal priming between split and intact prime-probe pairs, because an object's visible 3D parts are sufficient to encode the image (Biederman, 1987) – independent of whether these parts are coded from an intact image or a slightly scrambled (split) image of an object, e.g. of a car. Therefore, the present results provide a clear and strong indication that view-dependent but attention-independent representations mediate – at least to some degree - object shape processing.

Further, 'pure' view-based models can also not account for the current results: In order to account for previous findings on the hybrid model (e.g., Thoma and Henson, 2011; Thoma et al., 2007) these theories arguably would have predicted priming from unattended split objects to their split counterparts – so-called picture-to-picture priming. The fact that split images do not prime themselves specifically contradicts more recent view-based accounts (e.g. Edelman & Intrator, 2003) proposing 2D fragments rather than holistic views of objects as representational elements (for a discussion of this point see also Thoma & Henson, 2011). Thus, the current results confirm the prediction of the hybrid model that object recognition can rely on fast and automatic processing of view-based representations (potentially in combination with

part-based representations that depend on attention, Hummel, 2003; Thoma et al., 2004).

The current study is the first to report view-dependent ERP repetition effects for spatially unattended common objects that can be assumed to rely on stored mental representations of objects. But where is the locus of this view-specific automatic processing of shape? In terms of general view-specific repetition effects independent of attentional manipulations, the time window and scalp location of the repetition effects found here are consistent with the amplitude modulation of the N250r (Schweinberger et al., 2002; Engst et al., 2006; Martín-Loeches et al., 2005; Henson et al. 2004). At the same time the N250r has also been shown to be insensitive to scale (Bindemann et al., 2008; Zimmerman & Eimer, 2013). This pattern of view-sensitivity is resonant of that demonstrated by the present results. Only intact (and not split) prime images elicited ERP repetition effects, and this pattern was also found in the behavioural priming.

According to the two-stage model of recognition proposed by Schendan and Kutas (2007), pre-attentive low-level processes are reflected by effects prior to 200 ms of probe onset. Their observation that the repetition effects were only reliable when elicited by primes presented in canonical, rather than unusual, views is similar to the present findings as it suggests access to previously held (canonical) object representations, rather than a reliance on low-level feature matching. In the studies of Schendan and Kutas (2003; 2007) the prime objects were always attended, therefore it is possible that repetition effects reflected both pre-attentive processing and that occurring with attention.

To conclude, the view-sensitivity demonstrated by the present ERP repetition effects concurs with the previous neuroimaging and behavioural studies that have provided support for the hybrid model (Thoma & Henson, 2011; Thoma et al., 2004, 2007; Stankiewicz & Hummel, 1996, 2002). Importantly, in the present study split-images did not result in ERP repetition effects despite being repeated in an identical format (view) at the probe display. These observations are unlikely to be a result of attentional slippage to objects in familiar (intact) views in the prime display. This result thus strongly indicates that the repetition effects observed from intact objects cannot be attributed purely to low-level visual matching, but are mediated by holistic representations of the type described in Hummel's hybrid model of object recognition.

In summary, ERP repetition effects were elicited by spatially unattended familiar objects as long as they were presented as intact rather than split images. These effects were manifested as a negative deflection at posterior sites in the time windows of the N250. The view-sensitivity of these repetition effects was consistent with that predicted for automatic holistic shape representations as proposed by hybrid models.



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### Highlights

- Spatially unattended images of everyday objects elicited ERP repetition effects.
- Repetition effects were observed at posterior sites in the time window of the N250.
- Repeated objects elicited enhanced negativity to unrepeated in a covert naming task.
- Only familiar intact, but not part-scrambled, images elicited repetition effects.
- Holistic representations mediate repetition effects for spatially uncued objects.

