An Event-Related Potential Study of Onset Primacy in Visual Change Detection

Jennifer Van Pelt[1], Maria J. Donaldson[2], Patrick Johnston[1,3], and Naohide Yamamoto[1,3,*]

[1]School of Psychology and Counselling, Queensland University of Technology, Brisbane, Queensland, Australia

[2]Department of Psychology, Cleveland State University, Cleveland, Ohio, USA

[3]Institute of Health and Biomedical Innovation, Queensland University of Technology, Brisbane, Queensland, Australia

[*]Corresponding author (naohide.yamamoto@qut.edu.au)

Abstract

Onset primacy is a robust behavioural phenomenon whereby humans identify the sudden appearance of an object in the environment (onset) with greater speed and accuracy than other types of visual change, such as the sudden disappearance of an object from the environment (offset). The default mode hypothesis explains this phenomenon by postulating that onset detection is the default processing mode of the attentional system. The present study aimed to test this by investigating whether onset primacy is also reflected on a neural level, as indicated by the comparative efficiency of neural processing for onsets, using electroencephalography. It was hypothesised that this relative efficiency would be reflected in the P300 event-related potential as a greater mean amplitude with an earlier peak across temporal, parietal, and occipital regions during onset detection, compared to offset detection. This prediction was tested through a change detection task in which participants were required to identify the location of onset or offset between paired images of naturalistic scenes. Results showed that P300 amplitude and latency differed between onset and offset conditions in the anticipated directions, supporting the default mode hypothesis. These results suggest that the P300 is a neural marker of onset primacy in visual change detection.

Keywords: attention, attentional capture, EEG, P300, P3b, N200

Acknowledgments

The authors thank Yasmin Allen-Davidian for cooperation in participant recruitment and Jonathan Robinson for assistance with electroencephalography data collection and analysis.

An Event-Related Potential Study of Onset Primacy in Visual Change Detection

The ability to direct attention within an environment provides an adaptive mechanism that is particularly useful for the detection of change. In the absence of effective visual change detection, it would be difficult to successfully navigate everyday life. Driving a car or crossing the road, for example, requires the ability to detect new obstacles as they appear in the visual field. Research involving visual search paradigms has indicated that humans are particularly adept at noticing new or novel objects that abruptly enter their environment (Cole & Liversedge, 2006; Jonides & Yantis, 1988; Yantis & Jonides, 1984). Under certain conditions, however, even significant changes in visual scenes go unnoticed, through a phenomenon known as change blindness (Simons & Rensik, 2005). Behavioural studies have demonstrated that the sudden appearance of an object (object onset) is relatively robust to change blindness, while other types of change, such as the sudden disappearance of an object (object offset), are more likely to remain unnoticed (Cole & Kuhn, 2010; Yantis & Jonides, 1984). The comparative efficiency of onset over offset detection has been referred to in the literature as onset primacy (Cole, Kentridge, & Heywood, 2004).

The persistence of onset primacy across experimental paradigms led Donaldson and Yamamoto (2016) to propose that onset detection is the default processing mode of the attentional system. To process other kinds of change, a shift is required from this default mode, resulting in a delayed attentional response. While the robust nature of onset primacy may be functionally adaptive, given that onset detection is advantageous in most situations, there are other situations in which offset detection may be more beneficial. For example, a life guard monitoring a crowded beach needs to notice the disappearing swimmer; a parent watching over a group of children in the playground needs to notice if one goes missing. As such, it is important to understand how and why onset primacy occurs by investigating the processes that underlie onset and offset detection.

In pursuing this endeavour, the present study tested the validity of the default mode hypothesis (Donaldson & Yamamoto, 2016) by examining differences in neural activation across change detection tasks. If onset and offset detection do indeed recruit different neural mechanisms, in a manner in which onsets are processed with greater neural efficiency than offsets, it would lend support to the default mode hypothesis and offer a deeper insight into the operation of visual attention mechanisms. In particular, this study considered the P300 event-related potential (ERP) as a potential marker of the neural processes that underlie behavioural findings of onset primacy. Using electroencephalography (EEG) techniques, an experiment was conducted to investigate whether the amplitude and latency of the P300 would reflect more efficient processing of onsets than offsets in the brain.

The P300 is a positive deflection that typically occurs between 300–400 ms after the onset of sensory stimuli, though it has been reported to range more widely, from 250 ms up to 900 ms (Polich, 2007). It is generally implicated in selective attention and information processing and may be evoked after exposure to auditory or visual stimuli. Given that the P300 varies in topographical distribution, it is often conceptualised as two separate subcomponents, the P3a, a frontal distribution associated with stimulus novelty, and the P3b, a temporal-parietal distribution associated with attention and memory processing (Polich, 2007). The latter component has also been observed across the occipital lobe in studies of selective attention (Koivisto & Revonsuo, 2007), presumably appearing as a marker of visual awareness (Singh-Curry & Husain, 2009). While the P3a novelty component may instinctively be of interest in a change detection paradigm, it is likely that novelty effects would quickly be habituated across the repetitive presentation of visual stimuli, making meaningful P3a components difficult to observe across averaged trials. The P3b component, however, remains of particular interest. As such, consequent discussion of the P300 is

focused on the P3b in this paper. For simplicity, the P3b component is referred to as P300 hereafter.

There are several factors that have been reported to influence the amplitude of the P300 (for a review, see Patel & Azzam, 2005), though one of the most relevant factors to a change detection paradigm is discrimination difficulty. Many studies investigating P300 components have used variations of the oddball task, where participants are required to respond when they perceive an infrequent or deviant stimulus that is randomly presented among a series of standard stimuli (Donchin, Ritter, & McCallum, 1978). The P300 is modulated in these tasks when it is more difficult to distinguish between the standard stimuli and deviant stimuli. This increased difficulty is reflected in the P300 as a decreased amplitude and delayed latency, relative to easy discrimination trials (Kramer, Wickens, & Donchin, 1985; Polich, 2007). These findings have been replicated across other studies that manipulate task difficulty, suggesting that observed differences in P300 amplitude and latency reflect neural processing, most notably relating to attention and working memory, that is required for successful task performance (Kok, 2001; Polich, 2007). Although the direction of this relationship may seem counter-intuitive, given that more difficult discrimination tasks may be thought to evoke a larger amplitude, the earlier occurrence and higher amplitude of the evoked potential found in easier discrimination tasks can be taken as an indicator of greater neural efficiency that allows observers to perform the tasks with relative ease. When applied to onset primacy, this framework leads to a prediction that the P300 would show a greater amplitude and earlier peak during detection of onset than offset, as behavioural studies indicate that onsets are detected with greater speed and accuracy than offsets (Donaldson & Yamamoto, 2012, 2016).

The P300 has also been subject to some investigation within a change detection paradigm. Rather than explaining differences in P300 amplitude through task difficulty, many

of these studies infer that amplitude differences between conditions are the result of detected versus undetected change (Koivisto & Revonsuo, 2003; Niedeggen, Wichmann, & Stoerig, 2001; Turatto, Angrillia, Mazza, Umilta, & Driver, 2002) and further, participants' confidence in their report of a detected change (Eimer & Mazza, 2005). Because it is possible that these factors interact, where more difficult tasks cause change to remain undetected and lower ratings of confidence in the participants' change response, it is not clear whether successful detection or participants' confidence itself has unique effects on the P300. Nevertheless, the fact that successfully and more confidently detected changes resulted in larger P300 amplitudes in these studies suggests that the P300 amplitude would be greater during onset detection than offset detection, as behavioural measures of onset primacy (i.e., quicker and more accurate detection of onsets than offsets) indicate that onsets are more prone to successful and confident detection than offsets.

In summary, in order to seek neural evidence for more efficient processing of onsets than offsets, the current study measured P300 amplitude and latency while participants attempted to detect onsets and offsets. Given the behavioural findings of onset primacy, indicating that onsets are detected with greater speed and accuracy than offsets, onsets should be easier to discriminate in a visual scene than offsets. It then follows that the P300 should appear in a larger amplitude and shorter latency for onset than offset conditions in temporal, parietal, and occipital regions of the brain. This pattern of the P300, if actually observed, would provide new evidence for the default mode hypothesis of onset primacy.

Method

Participants

Twenty-five undergraduate students (19 female, 6 male) aged 17–29 years (M = 20.88, SD = 3.25) participated in return for partial credit toward their course. Written informed consent was obtained prior to their participation. All were right-handed with no

known history of neurological disorder, and had normal to correct-to-normal vision, as confirmed by a Snellen eye-chart. The experiment was approved by the Human Research Ethics Committee of the Queensland University of Technology.

Materials

This experiment used Donaldson and Yamamoto's (2012) change detection task, who modelled it from the earlier paradigm developed by Cole, Kentridge, Gellatly, and Heywood (2003). Stimuli depicted visual scenes, each of which included a small circular table-top (30 cm diameter) with a single supporting leg (38 cm height). A range of objects of approximately equal size (4 cm width, 3 cm height, 2 cm depth) were placed onto the table in sixteen different arrangements. The number of objects on the table was varied, ranging from six to nine, to minimise the potential to predict patterns of change. Images were presented at a central fixation point, with visual angle subtending approximately 7° horizontally and 4° vertically. Participants viewed the stimuli from an approximate distance of 60 cm on a monitor with a screen resolution of 1920 × 1080 pixels, via PsychoPy software (version 1.86; Peirce, 2007).

Design and Procedure

Participants were informed that they were going to view a series of paired photographs, and that a change would be identifiable on the appearance of the second image. They were instructed to indicate whether they observed the change on the left or right side of the stimulus by pressing either F or J on their keyboard, respectively. Participants were asked to keep their index fingers resting on the response keys throughout the experiment and to respond as quickly and accurately as possible. Participants were not informed of the nature of change (onset or offset) across trials and received no performance feedback throughout. The experiment was conducted in a darkened room and external sensory disturbances were minimised as much as possible.

The paired photographs were presented across a single block of trials. In onset trials, the second image contained one additional object on the tabletop; in offset trials, the second image removed one object from the tabletop (see Figure 1 for an example). The change occurred on each side of the table (left and right) an equal number of times and was counter-balanced across onset and offset conditions. To control for the potential influence of object properties, such as colour, location, or semantic salience, the same paired photographs were used for both onset and offset trails, in reversed order. Each photograph in the pair had either seven or eight objects on the tabletop, with each object acting as the change target an equal number of times. There were 64 trials for each change type, making a total of 128 experimental trials.

An additional 32 photograph pairs were created as filler trials to make trial type unpredictable. Across 16 onset trials, an eight-object display was followed by a nine-object display. Across 16 offset trails, a seven-object display was followed by a six-object display. Filler trials were randomly intermixed with experimental trials, creating a total of 80 onset and 80 offset trials. Each participant performed all of these trials (i.e., a within-participant design). Data from filler trials were not included in the analysis. Participants also completed 16 practice trials (8 onset and 8 offset, randomised) to familiarise themselves with the task. Practice trials consisted of new photograph pairs that were not used in the filler or experimental trials.

The sequence of each trial is demonstrated in Figure 1. First, participants viewed a central fixation cross for 1000 ms. The first image then appeared for 1200 ms, followed by blank grey screen for 100 ms. The second image, depicting the change (change stimulus), then appeared for 1200 ms, before a final grey screen lasting 2000 ms. Participants were able to provide a response any time after the appearance of the second image. When a response

was provided, or when the final grey screen timed out, the fixation cross would reappear to indicate the start of the next trial.

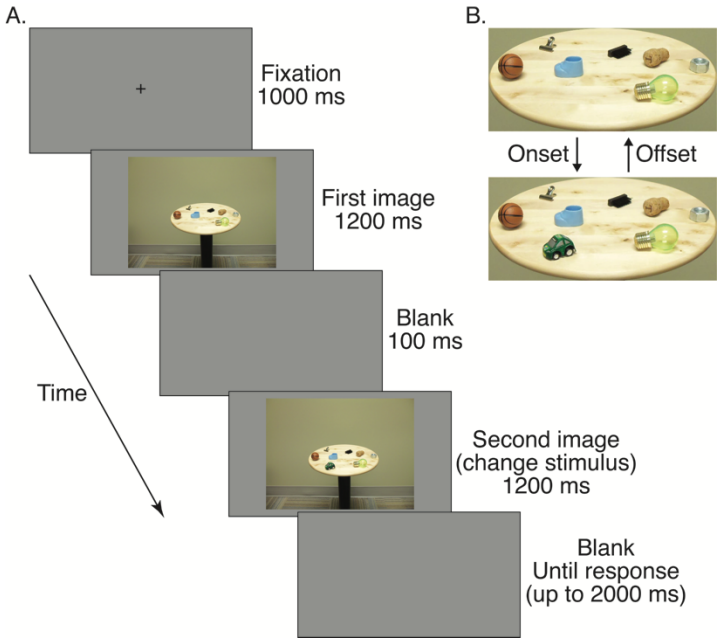

Figure 1. Experimental stimuli (adapted from Donaldson & Yamamoto, 2012). (A) Sequence of trials. (B) A closer view, demonstrating how the paired images changed between onset and offset trials. Here, the green car is the object of change.

EEG Data Acquisition and Analysis

Electrical activity was recorded across 64 channels, aligning with the International 10–20 system of electrode placement. Data were collected using a sampling rate of 1024 Hz. Impedance values were kept below 25 Ω, with a notch filter set to 50 Hz as per Australia mains frequency. EEG data were recorded using a BioSemi 64-channel amplifier, displayed on the acquisition program Actiview. Pre-processing was completed using Brain Vision Analyzer 2 software. Amplitude and latency data were analysed using MATLAB software and the statistical program SPSS.

During pre-processing, data were re-referenced to a common average based on all electrodes. A bandpass filter was then applied with a high pass filter of 0.3 Hz and a low pass

filter of 30 Hz. An ocular correction was applied using independent component analysis, with electrode Fp1 as the reference point. Visual inspection of the data revealed channels with excessive noise, which were then removed and re-estimated based on the mean of neighbouring electrodes. Data were then epoched into segments spanning from 100 ms before the change stimulus to 1000 ms after. Average ERPs were computed during the time-window for onset and offset conditions separately. Activity during the inter-stimulus interval (the grey screen before the change stimulus) was used as the baseline for comparison.

Outcome Measures

Behavioural. Reaction time was measured as the time that elapsed between the appearance of the change stimulus and the participant's response. Accuracy of the change location judgement, as indicated by the keyboard button press, was also measured. Trials where participants failed to provide a response before the end of the final grey screen were considered incorrect. When incorrect responses were made, associated reaction time data were excluded from analysis.

P300. The region of interest (ROI) for the P300 included the cortical surface of the temporal, parietal, and occipital lobes. Electrodes in these regions were grouped into clusters corresponding to their topographical location: Left (CP1, CP3, CP5, TP7, P1, P3, P5, P7, PO3, PO7, O1), Centre (CPz, Pz, POz, Oz, Iz), and Right (CP2, CP4, CP6, TP8, P2, P4, P6, P8, PO4, PO8, O2). Mean amplitude was calculated across the time-window of interest, defined as 275–500 ms after the presentation of the change stimulus (Eilmer & Mazza, 2005; Turatto et al., 2002). Mean latency of the amplitude peak was also calculated, defined as the time that elapsed from the appearance of the change stimulus to the largest amplitude peak within the time-window (Polich, 2007). These EEG measures were calculated using correctly performed trials only.

Results

Behavioural

Accuracy. Accuracy scores were defined as outliers if they were greater than two standard deviations away from the mean of all participants, considering onset and offset conditions separately. This resulted in the exclusion of three participants from all further analyses (adjusted $N = 22$). The mean accuracy of excluded participants was 77.08% (onset) and 78.65% (offset). The mean accuracy of the remaining participants was 95.81% (SD = 0.04%, onset) and 94.39% (SD = 0.03%, offset). Although participants detected onsets with slightly greater accuracy, this difference was not statistically meaningful, $t(21) = 1.57$, $p = .133$, $d = 0.33$. This is not contrary to prediction, as previous studies demonstrated that accuracy is not as sensitive to onset primacy as reaction time (Donaldson & Yamamoto, 2012, 2016).

Reaction time. Reaction time data were defined as outliers if they were greater than two standard deviations away from the participant's individual mean, considering onsets and offsets separately. This resulted in 116 outlier trials, constituting 4.33% of the correctly performed trials. Outlier reaction times were not removed from accuracy calculations. The mean reaction time across remaining trials was 556 ms (SD = 132 ms, onset) and 609 ms (SD = 123 ms, offset). These data indicate that participants detected onsets faster than offsets, $t(21) = 6.31$, $p < .001$, $d = 1.35$. These data align with prediction and show that onset primacy was present.

EEG

P300. The mean amplitude and mean latency of the amplitude peak were first calculated across the P300 time-window (275–500 ms post change stimulus) for each participant, at each electrode in the ROI, for onset and offset trials separately. Outliers were defined as values with a z-score outside of the range −3 to 3. This resulted in the removal of

one participant from P300 analyses, who consistently contributed extreme amplitude scores (final $N = 21$). Additional seven mean amplitude scores (five in onset conditions and two in offset conditions, calculated at six electrodes in four participants) were removed as outliers by the same criteria, constituting 1.23% of the total amplitude data. Latency data that corresponded to these outliers were also removed. Mean amplitude and latency scores were then separately calculated for each participant across each electrode cluster, resulting in three averaged scores based on electrode location, for each change condition. The distribution of these averaged scores was accepted as normal for both amplitude and latency data, as skew remained within acceptable levels (between −3 and 3). Two separate 2 (onset, offset) × 3 (left, centre, right) repeated measures analyses of variance (ANOVAs) were used to test the effects of change type and electrode location on mean amplitude and mean latency of the amplitude peak within the P300 time-window. The Greenhouse-Geisser correction for non-sphericity was applied when appropriate.

Descriptive statistics for the mean amplitude and peak latency data are displayed in Table 1. Consistent with prediction, the mean P300 amplitude was higher and the mean peak latency was shorter in onset conditions than offset conditions. Mean amplitude values also suggest that amplitude varied with electrode location, with the highest mean amplitude occurring in the right electrode cluster. Figure 2 displays mean ERP waveforms from each cluster separately. Figure 2C, visualising the right cluster, demonstrates the expected pattern of the P300 most fittingly, where the amplitude was consistently higher and the peak earlier in onset trials than in offset trials.

Table 1

Mean Amplitude and Mean Peak Latency of the P300 as a Function of Change Type and Electrode Location

	Mean Amplitude (μV)			
	Onset		Offset	
Location	*M* (*SD*)	95% CI	*M* (*SD*)	95% CI
Left	2.85 (1.55)	[2.16, 3.46]	2.60 (1.11)	[2.14, 3.05]
Centre	3.20 (1.72)	[2.45, 3.96]	2.84 (1.30)	[2.27, 3.38]
Right	3.88 (1.56)	[3.23, 4.56]	3.27 (1.27)	[2.75, 3.87]
	Mean Peak Latency (ms)			
	Onset		Offset	
Location	*M* (*SD*)	95% CI	*M* (*SD*)	95% CI
Left	387.25 (44.46)	[367.56, 405.27]	396.48 (43.34)	[377.27, 414.62]
Centre	374.33 (32.26)	[360.07, 387.42]	391.30 (40.48)	[374.98, 408.94]
Right	384.17 (34.25)	[369.52, 397.94]	394.69 (45.23)	[375.53, 413.68]

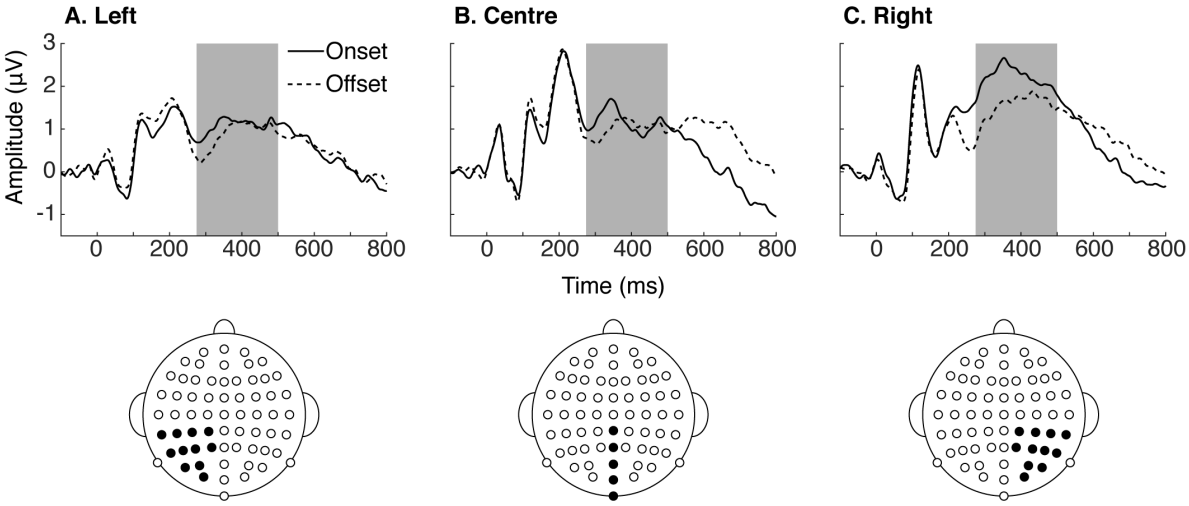

Figure 2. Mean P300 waveforms across participants (N = 21) by electrode cluster. Displaying (A) Left (CP1, CP3, CP5, TP7, P1, P3, P5, P7, PO3, PO7, O1), (B) Centre (CPz, Pz, POz, Oz, Iz), and (C) Right (CP2, CP4, CP6, TP8, P2, P4, P6, P8, PO4, PO8, O2) electrode clusters. Filled circles in schematic drawings below each panel indicate the electrodes included in each cluster. The zero point on a horizontal axis corresponds to the moment at which the change stimulus (the second image of a pair) appeared. Grey shading indicates the time-window across which amplitude was averaged for analyses (275–500 ms post change stimulus).

The ANOVA examining amplitude data revealed a significant main effect of change type, $F(1, 20) = 4.71$, $p = .042$, $\eta_p^2 = .19$, where onsets (M = 3.31 µV, SD = 1.37 µV) were greater than offsets (M = 2.90 µV, SD = 1.02 µV). There was also a significant main effect of electrode location, $F(2, 40) = 7.07$, $p = .004$, $\eta_p^2 = .26$. However, no significant interaction was found between change type and electrode location, $F(2, 40) = 0.56$, $p = .564$, $\eta_p^2 = .03$, indicating that the effect of change type on mean amplitude did not depend on the location of the electrode.

The main effect of electrode location was followed up by three pairwise comparisons (each with a Bonferroni-corrected α of .016). These tests revealed that mean amplitude was

significantly higher across the right electrode cluster than the left electrode cluster, $t(20) = 3.12$, $p = .005$, $d = 0.68$. There was no significant difference between the centre cluster and the left cluster, $t(20) = 1.58$, $p = .130$, $d = 0.35$, or the centre cluster and the right cluster, $t(20) = 2.52$, $p = .020$, $d = 0.55$.

The ANOVA examining the peak latency data revealed a main effect of change type, $F(1, 20) = 5.71$, $p = .027$, $\eta_p^2 = .22$, where onsets ($M = 381.92$ ms, $SD = 23.75$ ms) had a shorter latency than offsets ($M = 394.16$ ms, $SD = 32.29$ ms). There was no main effect of electrode location, $F(2, 40) = 0.54$, $p = .508$, $\eta_p^2 = .03$, and no significant interaction between change type and electrode location, $F(2, 40) = 0.24$, $p = .759$, $\eta_p^2 = .01$, suggesting that electrode location was not contributing to the observed variation in peak latency.

Post-hoc Analyses. Although the hypothesis of this study focused on the P300, ERP waveforms were visually inspected throughout the trial time-course and cortical regions. This observation alluded to the occurrence of additional, potentially meaningful, neural differences between onset and offset conditions. One of the most notable differences appeared as an early negativity, around 200 ms post change stimulus, in cortical regions across the frontal lobe (i.e., the N200 ERP; Patel & Azzam, 2005). Specifically, greater negativity was observed across onset trials compared to offset trials. A post-hoc analysis was conducted to investigate whether this difference was meaningful. Following the same procedure as P300 analyses, electrodes within the ROI (frontal lobe) were grouped into clusters corresponding to their topographical location. This resulted in three clusters: Left (Fp1, AF3, AF7, F1, F3, F5, F7, FC1, FC3, FC5, FT7), Centre (Fpz, AFz, Fz, FCz), and Right (Fp2, AF4, AF8, F2, F4, F6, F8, FC2, FC4, FC6, FT8).

A 2 (onset, offset) × 3 (left, centre, right) repeated measures ANOVA was conducted to examine the effect of change type and electrode location on mean amplitude within the relevant time-window (180–250 ms post change stimulus) and ROI. Given the post-hoc

nature of this analysis, *F*-test results were treated only as guides for relative magnitudes of the effects of each variable, instead of firmly determining their statistical significance. Sanity checks followed the same procedure as for P300 analyses, resulting in exclusion of the same participant and one additional amplitude score, constituting less than 0.01% of the total amplitude data (final $N = 21$).

Descriptive statistics of the N200 amplitude data are displayed in Table 2. Overall, onsets showed a greater negative mean amplitude than offsets, with maximal activation in the central electrode cluster. Figure 3 displays the averaged ERP values separately for each electrode cluster. The ANOVA revealed a trend that onsets ($M = -1.93$ μV, $SD = 2.01$ μV) had a greater negative amplitude than offsets ($M = -1.42$ μV, $SD = 1.6$ μV), as suggested by the main effect of change type, $F(1, 20) = 6.54$, $p = .019$, $\eta_p^2 = .25$. The main effect of electrode location, $F(2, 40) = 1.29$, $p = .061$, $\eta_p^2 = .06$, and the interaction between change type and electrode location, $F(2, 40) = 1.04$, $p = .363$, $\eta_p^2 = .05$, were weaker, suggesting that the location of electrodes was not contributing to the observed variance in mean amplitude.

Table 2

Mean N200 Amplitude (μV) as a Function of Change Type and Electrode Location

	Onset		Offset	
Location	*M* (*SD*)	95% CI	*M* (*SD*)	95% CI
Left	−1.83 (1.76)	[−2.53, −1.08]	−1.25 (1.73)	[−1.99, −0.52]
Centre	−2.00 (2.37)	[−2.95, −0.97]	−1.66 (2.23)	[−2.56, −0.69]
Right	−1.95 (2.06)	[−2.85, −1.07]	−1.35 (1.85)	[−2.14, −0.60]

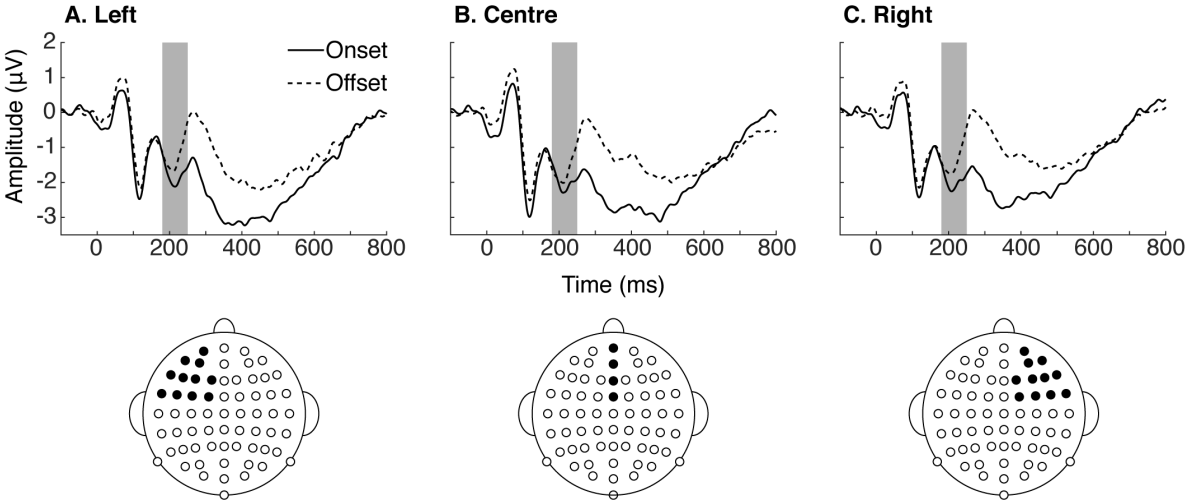

Figure 3. Mean N200 waveforms across participants ($N = 21$) by electrode cluster. Displaying (A) Left (Fp1, AF3, AF7, F1, F3, F5, F7, FC1, FC3, FC5, FT7), (B) Centre (Fpz, AFz, Fz, FCz), and (C) Right (Fp2, AF4, AF8, F2, F4, F6, F8, FC2, FC4, FC6, FT8) electrode clusters. Filled circles in schematic drawings below each panel indicate the electrodes included in each cluster. The zero point on a horizontal axis corresponds to the moment at which the change stimulus (the second image of a pair) appeared. Grey shading indicates the time-window across which amplitude was averaged for analyses (180–250 ms post change stimulus).

Discussion

Main Findings about the P300

The current study aimed to test the default mode hypothesis by examining whether behavioural findings of onset primacy were reflected on a neural level, as indicated by EEG recordings during a change detection task. If the default mode hypothesis is true, trials involving the detection of onsets should be processed with greater neural efficiency than trials involving the detection of offsets. That is, only detection of offsets should entail a shift of the mode of attention away from its default "onset detection" mode, and this shift should be reflected in neural activity that differentiates between onset and offset detection. On the

basis of previous studies on visual discrimination tasks (Kramer et al., 1985; Polich, 2007), the P300 ERP was hypothesised to be an index of this activity. Specifically, it was hypothesised that the P300 would have a higher mean amplitude and shorter latency across onset trials compared to offset trails, across the specified time-window (275–500 ms post change stimulus) and ROI (temporal, parietal, and occipital regions), reflecting the relative difficulty of discriminating offsets in change detection tasks.

The hypothesis was supported, as mean amplitude of the P300 component was larger and had an earlier peak in onset conditions than offset conditions. These findings are consistent with previous research, which has implicated the P300 in processes of visual awareness, attention, and memory (Polich, 2007). More specifically, the current findings provide further support for research suggesting that discrimination difficulty moderates P300 amplitude in change detection tasks (Kok, 2001; Patel & Azzam, 2005). These studies typically reported a larger amplitude with an earlier peak in response to visual stimuli that were easy to discriminate, compared to those that were more difficult. Reaction time and P300 data of the present study indicated the comparative efficiency of onset detection, supporting the default mode hypothesis on both behavioural and neural levels.

Although no predictions were formed about the effect of electrode location, differences in amplitude did emerge as a function of electrode location for the P300 component. Specifically, there was a main effect of electrode location on the mean amplitude of P300, suggesting that amplitude was higher across electrodes in the right hemisphere than the left hemisphere, regardless of change type. While this was the only pairwise comparison that reached significance, there was also a more general trend indicating that electrodes across the right had higher amplitudes than those across the centre, and that those across the centre had higher amplitudes than those across the left. It is perhaps most likely that this amplitude pattern across change conditions reflects the generally accepted view that the right

hemisphere is more specialised for the performance of visuospatial tasks (Corballis, 2003). This account is supported by EEG studies that examined performance across visuospatial tasks and identified similar P300 lateralisation (Makeig et al., 1999).

Post-hoc Findings about the N200

In addition to the differences in P300 amplitude and latency, onset and offset trials might have differed in early negativity. Specifically, there was a trend that onset trials elicited greater negativity than offset trials across cortical regions of the frontal lobe between 180–250 ms after presentation of the change stimulus. Given the post-hoc nature of this observation, caution must be used when interpreting this pattern. Nevertheless, it may be worth considering this N200 component as a potential additional neural marker of onset primacy.

The N200, and more specifically the anterior N2a (Folstein & Van Petten, 2008), has been implicated in processes of mismatch detection and cognitive control. Studies involving sequential matching tasks, for example, have postulated that the N200 component may reflect a template matching process, whereby the observed stimulus is compared to a perceptual template containing expectations of the standard stimulus. During these tasks, the salience of template mismatch was found to be a driving factor in the generation of N200 amplitude, where a larger discrepancy between two sequentially presented stimuli resulted in greater negativity (Wang, Cui, Wang, Tian, & Zhang, 2004). Considering the current findings, the increased negativity of onset trials compared to offset trails could be an indication that the difference between the first and second photographs of a pair was processed as more salient when they presented object onset. This interpretation makes intuitive sense when considered beside the P300 data, as a more salient mismatch observed in early cognitive processing is likely to be easier to discriminate in later processing. Further research is needed to determine

whether the observed difference in the N200 reflects a true difference in neural processing during change detection tasks.

Implications for Current and Future Research on Onset Primacy

An important implication of the current experiment is the potential insight it provides into the debate within visual search literature as to the origin of onset primacy. As the visual properties of a stimulus, such as its luminance, shape, or motion compared to its surroundings, can influence attentional capture, it is often argued that the primacy of onset detection can be attributed to these sensory transients created by an appearing object, rather than the mere appearance of the object itself (Franconeri & Simons, 2003; Theeuwes, 1994). An alternative view is that object onset entails creation of a new mental representation of the object, and this cognitive operation is the source of onset primacy (Cole et al., 2004; Yantis, 1993). If the sensory account were true, then early sensory ERP components (e.g., those that occur within the first 100 ms) should reveal clear differences between onset and offset conditions. On the other hand, if the cognitive account were true, then onsets and offsets should evoke similar sensory responses in these early components, and begin to differ in later components that represent cognitive processes. The apparent alignment of early components between onset and offset conditions in temporal, parietal, and occipital regions shown in Figure 2, as well as the significant P300 differences reported above, suggest that onset primacy observed in this experiment primarily stemmed from cognitive as opposed to sensory processes, lending more support to the cognitive account than the sensory account. Although the present study was not designed to distinguish between the two accounts, these findings offer reason to pursue this line of enquiry in the future.

Given the current findings that the P300 amplitude and latency (and possibly the N200 amplitude as well) reflect neural processes underlying onset primacy, future research can utilise these ERP patterns as neural indices of how firmly observers' attentional priority

is set to the default onset-detection mode. For example, by measuring these ERP components while observers are being trained to prioritise detection of non-onset events (e.g., offsets), it may be possible to quantify the degree to which this training is effective (Donaldson & Yamamoto, 2016). Similarly, the same approach can be taken for exploring whether the default mode hypothesis persists in populations that may already be well practiced in alternate modes of change detection, such as lifeguards or child-care workers. A novel study by Laxton and Crundall (2017) suggests that lifeguards do indeed differ from the general population in their ability to detect change, as indicated by an experiment that required the detection of "drownings" in a crowded swimming pool. Measuring the P300 (and N200) while these experts detect offsets can be useful from both theoretical and practical points of view—it not only helps further examine whether the P300 works as a neural marker of onset primacy, but also has a potential for providing an objective measure of how well the experts adopt a non-default attentional mode for performing their professional duties.

Finally, future research could also explore other differences that were observed between onset and offset conditions, which were not investigated through the present hypothesis. Averaged ERP waveforms, visualised in Figures 2 and 3, revealed additional differences that may be of interest. Most notably, there appears to be a late enhanced negativity for onsets compared to offsets between 250–500 ms post change stimulus across the frontal lobe, as seen in Figure 3. A similar negativity was observed by Wang and colleagues (2004) in their sequential matching task, which was thought to represent the "classical N400" component, evoked in the processing of semantic information. If further differences were established between onset and offset conditions in these later ERPs, they would have the potential of providing corroborating evidence for the default mode hypothesis as an explanation of onset primacy.

References

Cole, G., Kentridge, R. W., Gellatly, A., & Heywood, C. A. (2003). Detectability of onsets versus offsets in the change detection paradigm. *Journal of Vision*, *3*(1), 22–31. doi:10.1167/3.1.3

Cole, G., Kentridge, R. W., & Heywood, C. A. (2004). Visual salience in the change detection paradigm: The special role of object onset. *Journal of Experimental Psychology: Human Perception and Performance*, *30*, 464–477. doi:10.1037/0096-1523.30.3.464

Cole, G., & Kuhn, G. (2010). Attentional capture by object appearance and disappearance. *Quarterly Journal of Experimental Psychology*, *63*, 147–159. doi:10.1080/17470210902853522

Cole, G., & Liversedge, S. (2006). Change blindness and the primacy of object appearance. *Psychonomic Bulletin & Review*, *13*, 588–593. doi:10.3758/BF03193967

Corballis, P. M. (2003). Visuospatial processing and the right-hemisphere interpreter. *Brain and Cognition*, *53*, 171–176. doi:10.1016/s0278-2626(03)00103-9

Donaldson, M. J., & Yamamoto, N. (2012). Detection of object onset and offset in naturalistic scenes. In C. Stachniss, K. Schill, & D. Uttal (Eds.), *Lecture Notes in Computer Science: Vol. 7463. Spatial Cognition VIII* (pp. 451–460). Berlin, Germany: Springer-Verlag. doi:10.1007/978-3-642-32732-2_29

Donaldson, M. J., & Yamamoto, N. (2016). Detection of object onsets and offsets: Does the primacy of onset persist even with bias for detecting offset? *Attention, Perception, & Psychophysics*, *78*, 1901–1915. doi:10.3758/s13414-016-1185-5

Donchin, E., Ritter, W., & McCallum, C. (1978). Cognitive psychophysiology: The endogenous components of the ERP. In E. Callaway, P. Tueting, & S. H.

Koslow (Eds.), *Event-related brain potentials in man* (pp. 349–411). New York, NY: Academic Press. doi:10.1016/B978-0-12-155150-6.50019-5

Eimer, M., & Mazza, V. (2005). Electrophysiological correlates of change detection. *Psychophysiology*, *42*, 328–342. doi:10.1111/j.1469-8986.2005.00285.x

Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology*, *45*, 152–170. doi:10.1111/j.1469-8986.2007.00602.x

Franconeri, S. L., & Simons, D. J. (2003). Moving and looming stimuli capture attention. *Perception & Psychophysics*, *65*, 999–1010. doi:10.3758/bf03194829

Jonides, J., & Yantis, S. (1988). Uniqueness of abrupt visual onset in capturing attention. *Perception & Psychophysics*, *43*, 346–354. doi:10.3758/bf03208805

Koivisto, M., & Revonsuo, A. (2003). An ERP study of change detection, change blindness, and visual awareness. *Psychophysiology*, *40*, 423–429. doi:10.1111/1469-8986.00044

Koivisto, M., & Revonsuo, A. (2007). Electrophysiological correlates of visual consciousness and selective attention. *NeuroReport*, *18*, 753–756. doi:10.1097/wnr.0b013e3280c143c8

Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology*, *38*, 557–577. doi:10.1017/s0048577201990559

Kramer, A. F., Wickens, C. D., & Donchin, E. (1985). Processing of stimulus properties: Evidence for dual-task integrality. *Journal of Experimental Psychology: Human Perception and Performance*, *11*, 393–408. doi:10.1037/0096-1523.11.4.393

Laxton, V., & Crundall, D. (2017). The effect of lifeguard experience upon the detection of drowning victims in a realistic dynamic visual search task. *Applied Cognitive Psychology*, *32*, 14–23. doi:10.1002/acp.3374

Makeig, S., Westerfield, M., Townsend, J., Jung, T., Courchesne, E., & Sejnowski, T. J. (1999). Functionally independent components of early event-related potentials in a visual spatial attention task. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *354*, 1135–1144. doi:10.1098/rstb.1999.0469

Niedeggen, M., Wichmann, P., & Stoerig, P. (2001). Change blindness and time to consciousness. *European Journal of Neuroscience*, *14*, 1719–1726. doi:10.1046/j.0953-816x.2001.01785.x

Patel, S. H., & Azzam, P. N. (2005). Characterization of N200 and P300: Selected studies of the event-related potential. *International Journal of Medical Sciences*, *2*, 147–154. doi:10.7150/ijms.2.147

Peirce, J. W. (2007). PsychoPy—psychophysics software in Python. *Journal of Neuroscience Methods*, *162*, 8–13. doi:10.1016/j.jneumeth.2006.11.017

Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology*, *118*, 2128–2148. doi:10.1016/j.clinph.2007.04.019

Singh-Curry, V., & Husain, M. (2009). The functional role of the inferior parietal lobe in the dorsal and ventral stream dichotomy. *Neuropsychologia*, *47*, 1434–1448. doi:10.1016/j.neuropsychologia.2008.11.033

Theeuwes, J. (1994). Stimulus-driven capture and attentional set: Selective search for color and visual abrupt onsets. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 799–806. doi:10.1037/0096-1523.20.4.799

Turatto, M., Angrillia, A., Mazza, V., Umilta, C., & Driver, J. (2002). Looking without seeing the background change: Electrophysiological correlates of change detection versus change blindness. *Cognition*, *84*, B1–B10. doi:10.1016/s0010-0277(02)00016-1

Wang, Y., Cui, L., Wang, H., Tian, S., & Zhang, X. (2004). The sequential processing of visual feature conjunction mismatches in the human brain. *Psychophysiology*, *41*, 21–29. doi:10.1111/j.1469-8986.2003.00134.x

Yantis, S. (1993). Stimulus-driven attentional capture. *Current Directions in Psychological Science*, *2*, 156–161. doi:10.1111/1467-8721.ep10768973

Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance*, *10*, 601–621. doi:10.1037/0096-1523.10.5.601