

**Title page****Title:**

Event-related potential N270 delayed and enhanced by the conjunction of relevant and irrelevant perceptual mismatch

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**Running head:**

Event-related potentials of perceptual mismatch

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## **Abstract**

Event-Related Potential (ERP) studies using delayed match-to-sample tasks have demonstrated the presence of two components, N270 and N400, possibly reflecting the sequential processing of multiple sources of endogenous mismatch. To date, studies have only investigated secondary sources of mismatch between a single cue and target. In this study, we used distractor stimuli to investigate the effect of a secondary source of mismatch distinct from the task relevant stimulus. Subjects performed such a task in two paradigms in which the cue and target could match or mismatch – producing a source of task-relevant endogenous mismatch. In the second paradigm, task-irrelevant distractors were added - producing an additional, distinct source of irrelevant perceptual mismatch. A mismatch-triggered negativity was elicited in both paradigms, but was delayed and enhanced in magnitude in the distractors present paradigm. It is suggested that the distractors may differentially affect mismatch responses through the generation of an automatic but task-irrelevant mismatch response.

**Descriptors:** Event-related potential, Selective attention, Serial processing, N270, N400, Mismatch, Conflict negativity

## **Introduction**

Event-related potential (ERP) studies have shown that mismatch trials in delayed match-to-sample tasks elicit a 'mismatch-triggered negativity', typically peaking at around 270 ms (henceforth 'N270') (for a review, see Folstein & Van Petten, 2008). The N270 can be elicited by mismatches in various feature dimensions including shape (Cui, Wang, Wang, Tian, & Kong, 2000; Zhang, Wang, Li, Wang & Tian, 2005, Zhang, Wang, Wang, Cui, Tian & Wang, 2001), faces (Zhang et al., 2001) colour (Mao, Wang & Wang, 2005), spatial position (Yang & Wang, 2002), supramodal mismatch (Wang, Wang, Cui, Tian, & Zhang, 2002) and also when incorrect answers are presented for simple arithmetical operations (Wang, Kong, Tang, Zhang & Li, 2000). The N270 is also elicited for mismatches in task-irrelevant features, but is much reduced in magnitude (Mao & Wang 2007; Wang, Wang, Kong, Cui & Tian, 2001; Wang, Cui, Wang, Tian & Zhang, 2003). Katayama and Murohashi (2006) found that the N270 magnitude increased with the magnitude of task-irrelevant changes in the spatial frequency of gratings.

Collectively, these results suggest that the N270 is a robust effect which seems to represent the endogenous mismatch between a working memory representation of an initial stimulus and the perception of a second (mismatching) stimulus. There is some evidence (reviewed below) that if the target stimulus mismatches on multiple dimensions (e.g. mismatch in shape and colour) a second mismatch-triggered negativity is produced, peaking at around 400 ms (henceforth 'N400'). The 'sequential processing hypothesis', tentatively put forth by Wang, Tian, Wang, Cui, Zhang and Zhang (2003), states that these sequential negativities represent the sequential stages of processing associated with each mismatch. However, studies of the N400 have focused on mismatch between a single cue and a single target that differ on two or more feature

dimensions. It is the purpose of this paper to investigate the effect of adding a secondary source of mismatch, separate from the target stimulus, in the form of distractor stimuli. Of interest is whether the distractors differentially affect match vs. mismatch trials. In this paper, both the N270 and N400 component may both be referred to as ‘mismatch-triggered negativity’.

Several studies have found evidence to suggest the existence of an N400 component, though its significance is not yet clear. Zhang et al. (2001) found that, in comparison to an identical task using simple shapes, mismatching human faces elicited a prolonged N270 and there were hints of a second negative component, the N400, at left parieto-occipital regions (possibly reflecting activity from the fusiform gyrus, known to specialise in face processing). This may reflect a different kind of processing - since multiple features must be attended and integrated during facial recognition.

To date, studies investigating the significance of the N400 have tended to have participants compare two individual stimuli, separated in time, according to two or more feature dimensions. Wang et al. (2003) conducted a study of this sort in which participants had to evaluate either the colour or both the colour and shape of a pair of sequentially presented stimuli. When participants had to evaluate two feature mismatches, a fronto-central N270 was elicited, but was followed by an N400. When participants attended to a single feature dimension using identical stimuli, only the fronto-central N270 resulted. Mao and Wang (2007) likewise found that only when participants evaluated two mismatches did a significant secondary N400 component appear (this pattern was observed at anterior and posterior regions). A study by Wang, Cui, Wang, Tian and Zhang (2004) used three time windows for analysis; 230-324 ms (N270), 326-360 ms (interval lasting 34 ms) and 362-540 (N400). A significant N270 and secondary N400 was observed at

fronto-central and parieto-occipital regions. Importantly, there was no significant mismatch-triggered negativity during the 34 ms interval, providing positive evidence for the N270 and N400 being separate components. This study represents the most compelling case for the sequential processing hypothesis. However, the length and latency of the time windows seem tailored to neatly encompass each mismatch-triggered negativity, making it hard to evaluate the generality of the time course of ERP modulations described.

The fact that semantically incongruous information also elicits negativity at around 400 ms (for a review on the semantic N400, see Kutas & Federmeier, 2011) requires care in the interpretation of the perceptual mismatch-triggered N400 under discussion here. For instance, Chen, Li, Qui and Luo (2006) required participants to evaluate a stimulus according to one, two or three feature dimensions. Two sources of mismatch were present in each condition. When two or more features were attended a large mismatch-triggered negativity was observed starting at around 270 ms and lasting until around 500 ms. This mismatch-triggered negativity displayed two peaks; one at around 280 ms and another at around 400 ms and it is tempting to interpret this as reflecting the N270 and N400 components. This pattern of results was observed all over the scalp, but was more pronounced at fronto-central regions. However, given the complexity of the task used, participants required relatively long stimulus presentations (1500-2000 ms compared to 200-300 ms typical of the other paradigms) and may have used semantic memory strategies (e.g. verbal rehearsal) which could be expected to elicit an N400 (Kutas & Federmeier, 2011). Szucs, Soltesz, Czigler and Csepe (2007) highlight the need to minimise the potential use of semantic strategies when attempting to claim an N400 is due to a secondary perceptual mismatch. Participants performed a delayed match-to-sample task in which the task-relevant stimulus dimension could be colour or category (i.e. 'letter' vs. 'number'). Mismatch trials in the category

task (an overtly semantic task) elicited an N270 and an N400, whilst only an N270 resulted in the colour task.

In summary, mismatch-triggered negativity seems to represent the detection of perceptual mismatch. The N400 seems to follow the N270 when participants are required to process multiple sources of mismatch. The significance of the N270 has been investigated quite thoroughly. However, the significance of the N400, which usually follows the N270 but is not theoretically contingent upon its occurrence, is still uncertain. It is conceivable that the N400 may not even be truly distinct from the N270 – instead representing an especially prolonged N270. If it is a distinct component, it could represent several things: 1) a simple re-occurrence of the N270 mismatch-triggered negativity due to the detection of a secondary source of perceptual mismatch (i.e. the sequential processing hypothesis), or 2) a qualitatively different component requiring a more complex mismatch situation, or 3) merely the use of semantic strategies. It will obviously take several investigations to fully characterise the relation between the N270 and N400 mismatch-triggered negativities. A start can be made by determining whether it is possible to delay the mismatch-triggered negativity with the addition of task irrelevant distractors - a purely attentional manipulation. It is known that a single source of task relevant mismatch elicits a mismatch-triggered negativity at 270 ms. By forcing participants to first process the distractors, the mismatch-triggered negativity may be delayed to a time consistent with the N400. This would provide evidence that the N400 can be viewed as a simple re-occurrence of the N270. If the distractors then go on to differentially affect match vs. mismatch trials, it could be argued that the N400 mismatch-triggered negativity is somewhat sensitive to complex mismatch situations. This aspect of mismatch-triggered negativity in delayed match-to-sample tasks has not been directly investigated to our knowledge.

In this study, the addition of distractor stimuli necessitated placing the target at peripheral locations. We decided to take this opportunity to see whether the relative location of the cue in relation to the target would affect match/mismatch discrimination processes through an alteration of the prior distribution of attention over the visual field. In order to maximise any such prior alteration of attention, the cue was made to immediately move (and ‘grab’ more attention) from one of the four periphery locations to the central fixation position in 80% of trials (this also helped to return participants gaze to the correct fixation position prior to target onset). In the remaining 20% of trials the cue appeared stationary at the central fixation to act as a control comparison.

Therefore, in the current paper, one group of participants performed a delayed match-to-sample task in which the cue and target stimuli were presented in four locations in the periphery of the visual field. In order to ensure that the distractors had a significant impact on task difficulty, the locations of the cue and target in each trial were not correlated, therefore no strategy of prediction was possible since target location was not predicted by cue location. A second group of participants performed an identical task but without the presence of distractor stimuli.

## **Method**

### Participants

All participants were students at the University of Leicester with normal or corrected vision. All gave written informed consent and received course credit for participating. Participants were randomly assigned to one of two experimental paradigms: the distractors absent paradigm or the

distractors present paradigm. In the distractors absent paradigm, of an initial 17 participants, one was excluded due to excessive eye-movement artifacts. Therefore, data from 16 participants were analysed (15 right-handed, 10 females, mean age = 20, range = 18-33 years). In the distractors present paradigm, of an initial 15 participants, one was excluded due to excessive eye-movement artifacts. Therefore, data from 14 participants were analysed (all right-handed, 9 females, mean age = 19, range = 18-22 years).

### Stimuli and Procedure

Stimuli were presented on a 21" monitor (ViewSonic G810) (40cm horizontal x 30cm vertical) with a refresh rate of 100 Hz and a resolution of 1024x768 pixels. The monitor was located in a black viewing tunnel so that only the display was visible. The participants' head was stabilised in a head and chin rest. Viewing distance was 57cm. The monitor displayed a white 0.4° fixation spot in the centre of a grey 26° diameter circle, shown against a black background. Participants were instructed to maintain fixation on the fixation spot throughout the experiment. A trial consisted of the following sequence of events, shown in figure 1: A) fixation (490 ms) B) cue onset, C) cue offset, D) delay (400, 600 or 800 ms), E) target onset (150 ms).

After the fixation phase (A), a cue was presented (B). The cue was either a 2° hexagon or diamond and either red or green. The cue was either 'dynamic' or 'static'. In dynamic conditions, the cue appeared (B) at 10° in the periphery at one of four locations: either the top-left or right or bottom-left or right quadrant. The cue immediately moved to the centre of the screen and disappeared (C) – cue offset. The duration of the phase B-C was 600 ms. In static conditions, the cue was presented at the centre of the screen for 600 ms. After a delay (D) following cue offset, the target was presented for 150 ms (E). The target was either a hexagon or diamond and always



the same colour as the cue in that trial. The target was presented at one of the four 10° peripheral locations described above. In the distractors absent paradigm, only the target was present during E, as shown in the left-hand panel of figure 1. In the distractors present paradigm, 15 homogeneous distractors – 2° circles - were equally spaced around the perimeter of a 10° radius circle as shown in the right-hand panel of figure 1. The distractors were a different colour from the target and all either red or green.

< Figure 1 about here >

The participants' task was to indicate via a keypad whether the target shape was the same or different from the cued shape. The centre of the keypad was aligned with the participants' midline. The two types of response were made with the left and right index fingers. The mapping was counterbalanced across subjects. Speed and accuracy were encouraged. Reaction time and correct/incorrect response data were recorded. Participants were instructed to maintain central fixation and to blink only after a response had been made. Before the main experiment, participants completed a short practice session to adjust to these requirements. In this session, participants received auditory feedback following an incorrect response. This feedback was not present in the main experiment.

Participants completed 960 trials in six blocks of 160 trials. Participants were allowed to pause every 80 trials. Each block of 160 trials consisted of 80 pseudo-randomly distributed trials from each of the two experimental conditions (match vs. mismatch). The delay duration (400, 600, 800 ms) was held constant within blocks and the order of each block was counter-balanced across participants using a Latin Square procedure. Static and dynamic trials made up 20% and 80% of the total trials, respectively. Trials were pseudorandomly selected to maintain these

proportions within each block. Overall, the dynamic cue and the target appeared equally often in each quadrant therefore target location was not predicted by cue location. The experiment lasted for approximately 60 mins. Static cue and dynamic cue trials were analysed separately.

### EEG Recording

Continuous electroencephalograph (EEG) signals were recorded by a DC 32-channel amplifier (1-kHz sampling rate, 250 Hz high cut-off frequency; Brain Products Inc., Germany). The EEG activity was recorded via a Waveguard elastic cap, containing 64 unshielded and sintered Ag-AgCl electrodes (CAP-ANTWG64; ANT, Netherlands), with an electrode layout according to the international 10–5 electrode system. The right-earlobe electrode served as on-line reference. EEG waveforms were re-referenced off-line to the average of the right and left-earlobe electrodes. Two electrodes placed in a bipolar montage at approximately 1 cm from the outer canthi of both eyes served to record the horizontal electrooculogram (HEOG). The vertical electrooculogram (VEOG) and blinks were recorded from electrodes positioned below and above (prefrontal electrode Fp2) the right eye. Electrode impedance was kept below 5 K $\Omega$ . EEG was epoched from 200 ms prior to target singleton/search array onset to 600 ms after, giving a total epoch of 800 ms. Each EEG epoch was visually inspected off-line, and those with ocular artifacts (as indicated by HEOG activity exceeding  $\pm 40$   $\mu$ V and/or VEOG activity exceeding  $\pm 80$   $\mu$ V) or other artifacts (activity exceeding  $\pm 80$   $\mu$ V at any electrode) were rejected from the analysis.

For both paradigms, separate ERPs were computed for four regions of interest (ROI), each ROI being the average of three electrodes: O1, PO3 and PO7 = 'Left parieto-occipital region'; O2, PO4 and PO8 = 'Right parieto-occipital region'; F3, FC1 and FC5 = 'Left fronto-central region';

F4, FC2 and FC6 = 'Right fronto-central region'. ERPs were computed for trials relative to a 200 ms pre-stimulus baseline (static cue trials and dynamic cue trials were computed and analysed separately). ERPs were then filtered using 0.01-Hz high-pass, 45-Hz low-pass, and 50-Hz notch filters. The mean amplitudes during four non-overlapping time windows were used for the analysis: 250-299 ms; 300-349 ms; 350-399 ms; 400-449 ms.

### Data Analysis

For each participant, only data for trials with correct responses, reaction times (RT's) between absolute values of 150 ms and 2000 ms and also within three standard deviations of the individuals mean RT were analysed. RT and error rate data were analysed in a mixed ANOVA. In each ANOVA, the between-participant factor was 'Paradigm' (distractors absent vs. distractors present). There were three within-participant factors: 'Trial Type' (match vs. mismatch trials), 'Cue-Target Location' (same quadrant vs. adjacent quadrant above/below vs. adjacent quadrant left/right vs. opposite quadrant vs. static control trials) and 'Delay' (400 vs. 600 vs. 800 ms).

The duration of the grand average ERP mismatch-triggered negativities elicited in each paradigm were characterised by conducting a *t*-test (2-tailed), at each millisecond, comparing the divergence between match and mismatch trials. In addition, the onset latency was defined individually for each participant as the first time point in a series of 10 consecutive milliseconds all of which exceeded a threshold of 0.71  $\mu$ V. This threshold represented 50% of the peak amplitude of the distractors absent paradigm ERP difference wave (match – mismatch). Since the peak amplitude in the distractors absent paradigm was the smaller of the two paradigms, 50% of this provided a common threshold that was achievable by participants in both paradigms. Having individual onset times for all participants allowed the difference in onset times between the two

groups to be submitted to an independent samples *t*-test.

The ERP data was then analysed with an ANOVA conducted with the between-participant factor 'Paradigm' (distractors absent vs. distractors present). There were three within-participant factors: 'Trial Type' (match vs. mismatch trials), 'Hemisphere' (left vs. right ROI) and 'Time window' (250-299 ms; 300-349 ms; 350-399 ms; 400-449 ms). In all cases, Greenhouse-Geisser epsilon adjustments for nonsphericity were applied where appropriate. Post hoc paired *t*-tests were Bonferroni corrected for multiple comparisons. For all statistical tests,  $p < .05$  was considered significant.

## **Results**

### **Behavioural Data**

The relative locations of the cue and target in dynamic trials had no effect on either accuracy or RTs, therefore dynamic and static trials were pooled. Accuracy and RT data is displayed in figure 2.

< Figure 2 about here >

Accuracy data (% correct) showed a significant Paradigm x Trial Type interaction,  $F(1, 28) = 8.36$ ,  $p < .01$ ,  $\eta p^2 = .2.3$ . Post-hoc pairwise comparisons revealed that in the distractors present paradigm accuracy was lower for mismatch compared to match trials ( $p < 0.05$ ). Accuracy for mismatch trials in the distractors present paradigm was also lower than mismatch trials in the distractors absent paradigm ( $p < 0.05$ ).

RT data showed a significant Paradigm x Trial Type interaction,  $F(1, 28) = 14.55, p < .001, \eta p^2 = .34$ . Post-hoc pairwise comparisons revealed that RTs in both match and mismatch trials were slower in the distractors present paradigm ( $p < 0.01$  and  $p < 0.05$ , respectively). Also, only in the distractors present paradigm were RTs significantly slower for mismatch compared to match trials ( $p < 0.001$ ).

### ERP Data

In figure 3, topographic difference maps show the distribution of mismatch-triggered negativity in each paradigm. In order to compare these difference maps with each other (that is compare the topographic distribution of mismatch-triggered negativity *between* the two paradigms) we subtracted one set of maps from the other, essentially creating ‘difference of the difference’ maps. These latter maps showed that the most pronounced differences between paradigms in the distribution of mismatch-triggered negativity were at fronto-central regions (see figure 3) and we therefore confined our ERP analysis to the fronto-central electrodes.

< Figure 3 about here >

ERPs recorded at fronto-central regions for each paradigm is shown in figure 4. There was an enhanced negativity of the second negative peak at approximately 250-300 ms in the distractors present paradigm compared to the distractors absent paradigm. In addition, an enhanced negativity can be seen for mismatch trials at approximately 275-375 ms in the distractors absent paradigm and later with increased magnitude at approximately 300-450 ms in the distractors present paradigm. These observations were substantiated by statistical analyses (see table 1).

< Figure 4 about here >

In the distractors absent paradigm, the *t*-tests (2-tailed), conducted at each millisecond, comparing the divergence between match and mismatch trials were significant at every millisecond between 288ms – 342ms. In the distractors present paradigm, they were significant at every millisecond between 298ms – 438ms. Thus, the mismatch-triggered negativity was more prolonged in the distractors present paradigm. However, the difference in onset latencies was not significant when computed separately for each participant and submitted to a *t*-test (2-tailed),  $t(20.59) = .39, p > .05$ . There was a significant Paradigm x Time window x Trial Type interaction,  $F(1.79, 50.12) = 9.12, p < .01, \eta p^2 = .25$ . Post-hoc pairwise comparisons revealed the following time-course of ERP modulations (see table 1).

< Table 1 about here >

Between 250-299 ms, the distractor present paradigm was significantly more negative than the distractor absent paradigm for match and mismatch trials. Between 300-349 ms, distractor related negativity was no longer significant for either mismatch or match trials. In addition, trial type mismatch-triggered negativity was established in both the distractors absent (delayed N270 begins) and distractors present (N400 begins) paradigms. Between 350-399 ms, trial type mismatch-triggered negativity ended in the distractors absent paradigm (delayed N270 ends) but remained significant in the distractors present paradigm (N400). Interestingly, mismatch trials in the distractors present paradigm were significantly more negative than mismatch trials in the distractors absent paradigm (N400) – but the same was not true of match trials. Between 400-449 ms, trial type mismatch-triggered negativity remained significant in the distractors present paradigm (N400). Confidence in the generality of the time-course of these ERP modulations is boosted by the fact that four 50 ms windows were employed in a systematic back-to-back

fashion - leaving less freedom for fine tuning.

## **Discussion**

In both paradigms, mismatch-triggered negativity was observed at fronto-central regions (see figure 3). Given the lack of difference in RTs and error rates regarding the location of the cue in relation to the target, there was no evidence that the moving cue affected match/mismatch discrimination processes by changing the prior distribution of attention over the visual field. The distractors present paradigm produced a generally more negative ERP, especially from around 220 ms, peaking at 270 ms and ending after around 320 ms (i.e. centred on the second negative peak) – this may have been due to increased task difficulty or to the distractors mismatching with the cue. Task difficulty seems to have played at least a partial role because there is a clear modulation of the ERP beginning just prior to target onset and continuing at least until the N1 peak in the distractors present paradigm (see figure 4) – this probably represents contingent negative variation (CNV) in anticipation of the more difficult upcoming task.

More informative is the trial type mismatch-triggered negativity. In the distractors absent paradigm a mismatch-triggered negativity started at 288 ms and ended at 342 ms (delayed N270). The cause of the slight delay from the usual 270 ms peak is probably due to the need to orient to a peripheral target location (previous studies used foveally presented stimuli). In the distractors present paradigm, there was a similarly delayed mismatch-triggered negativity starting at 298 ms, peaking at 400 ms and ending at 438 ms (N400).

While the more negative N2 peak in the distractors present paradigm is likely due to the

increased difficulty of the task, it is possible that it actually represents an N270 in its own right due to the mismatch between the distractors and the simultaneously presented target and/or the sequentially presented cue. Zhang et al. (2005) presented two shapes simultaneously or in sequence while participants performed match/mismatch discrimination. The results were unambiguous; and N270 was seen all over the scalp for sequentially presented shapes but was absent for simultaneously presented shapes. However, in Zhang et al.'s (2005) study, participants did not need to use working memory in the simultaneous presentation paradigm - whereas the distractors present paradigm in this study retained the need for working memory. It could be that any source of interference whilst maintaining a representation in working memory can elicit mismatch-triggered negativity. This possibility ought to be tested in future studies which, unlike the present study, control for the difficulty between tasks.

The different peak latencies of the two trial type mismatch negativities suggests that the traditional association of mismatch-triggered negativity with the second negative peak merely reflects the earliest time at which such processes can occur. It appears that the appropriate task manipulations (such as displaying the targets peripherally and adding distractor stimuli) can delay these processes arbitrarily. In other words, the mismatch negativities should be interpreted as simply reflecting the time at which the properties of the target stimulus are compared with the working memory representation.

In previous studies, the fact that the second mismatch-triggered negativity peaks at a latency of 400 ms has led some to draw a connection with the 'semantic-N400' reliably elicited by manipulations related to the processing of semantically meaningful stimuli. It has been suggested by Wang and colleagues (Wang et al., 2003; Wang et al., 2004) that the two negativities may



form part of a larger family of such 'cognitive information mismatch' components, along with negativities arising from error detection/feedback, response conflict and novel/deviant stimuli. Zhang, Wang, Li and Wang (2003) go further and suggest that the N400s elicited by perceptual and semantic mismatch may be one and the same component - reflecting any mismatch of sufficient complexity per se. However, it seems rather audacious to assert that there is such a close link between the N400 elicited by perceptual mismatch and the N400 elicited by mismatch of a semantically meaningful nature - since this latter component has been heavily documented over the last 30 years (for a review, see Kutas & Federmeier, 2011) and it would be very surprising (though not impossible) if some entirely non-semantic aspect of the situation had been overlooked for so long.

Apart from the different latencies, the magnitude of the trial type mismatch-triggered negativity is smaller in the distractors absent paradigm than in the distractors present paradigm; the magnitude in the distractors absent paradigm reached 1.3  $\mu\text{V}$  (between 300-349 ms) and in the distractors present paradigm reached 2.9  $\mu\text{V}$  (between 350-449 ms). So the magnitude was 2.2 times larger in the distractors present paradigm. Importantly, mismatch trials were most affected by the presence of distractors – being significantly more negative than their counterpart mismatch trials in the distractors absent paradigm. RT data complement these observations, showing that the addition of distractors produced a dramatic RT increase which was especially pronounced for mismatch trials. This means that the increased difficulty of the task cannot fully account for the variation wrought by the addition of distractors – since this effect clearly interacted with the match/mismatch discrimination process itself, rather than merely delaying the orienting to the target. In retrospect, this makes sense since it has long been known that a target defined by a single feature (in this case colour) 'pops out' of the search array and is not

particularly demanding to orient to (Treisman & Gelade, 1980). That the presence of distractors interacted with trial type, affecting mismatch trials more heavily than match trials, may indicate that there is indeed something ‘special’ about the occurrence of ‘multiple mismatch signals’. Zhang et al.’s (2003) suggestion that the second peak at 400 ms has some special relationship with complex mismatch may have some merit, even if there is no link to the N400 driven by semantically meaningful mismatch.

The distractors may induce a kind of automatic, but task irrelevant, mismatch detection which must be ignored in order to focus on the evaluation of the cue-target itself. This might make the establishment of a genuine ‘cue-target mismatch’ response harder. Specifically, a ‘mismatch signal’ could stem from either the cue-target (relevant) or the cue-distractors (irrelevant) and this may require careful checking. Conversely, a ‘match signal’ is unlikely to stem from the distractors (irrelevant) and so such a signal can be taken to be genuine – resulting in faster RTs and an ERP similar to match trials in the distractors absent paradigm. This idea could be tested like so: if mismatch responses are differentially harder to make as task difficulty increases, then this should be true regardless of how difficulty is manipulated. However, if the distractors are inducing an automatic detection of task-irrelevant mismatch which obscures the detection of genuine cue-target mismatch, then this effect should require distractors – maybe even only one distractor.

Stimuli that give rise to perceptual mismatch or suggest mismatching responses (the latter is also termed ‘response conflict’) usually prompt tighter ‘cognitive control’ over subsequent responses from participants (Folstein & Van Petten, 2008). While the notion of response conflict is not required to understand the results of this study, it does have some interesting theoretical

connections to perceptual mismatch and the relation between the two deserves some consideration since understanding one may help to understand the other. For instance, perceptual mismatch and/or response conflict, and cognitive control, are associated with enhanced negativities elicited fronto-centrally at around the time of the second negative peak in the ERP wave (Folstein & Van Petten, 2008). Furthermore, functional magnetic resonance imaging (f-MRI) studies often observe activation of the anterior cingulate cortex during tasks that elicit these negativities in ERP studies, but whether anterior cingulate cortex activation reflects the neural source of one or all such negativities has been the subject of debate. The traditional view was that anterior cingulate cortex activation is related with cognitive control, but the bulk of f-MRI evidence now favours response conflict instead (van Veen and Carter, 2002; Weissman Giesbrecht, Song, Mangun, & Woldorff, 2003).

Whether perceptual mismatch alone can activate the anterior cingulate cortex is currently an open question. In an attempted synthesis of f-MRI and ERP data, van Veen and Carter (2002) propose response conflict as being more important on the basis that, while holding perceptual mismatch constant, anterior cingulate cortex activity co-varies with the degree of response conflict - which can be manipulated by mapping conflicting responses either onto separate hands, or onto separate fingers on the same hand. However, this only shows that response conflict results in increased activity above that which may have been created by perceptual mismatch alone. Weissman et al. (2003) addressed this question using Navon figures (i.e. arrays of small 'local' letters which 'globally' form a single letter). Four target letters were used: two letters requiring identical left hand responses and two requiring identical right hand responses - this design allowed for perceptual mismatch between local and global letter without any response conflict. Aside from finding that response conflict activated the anterior cingulate cortex, the key

result was that when participants were attending to the local letter, global mismatch alone activated the dorsal caudal anterior cingulate cortex (this did not occur when participants attended the global letter).

Attending to a local element in the face of simultaneous global mismatch may be thought somewhat descriptive of requirements of the task in the distractors present paradigm of this paper and perhaps similar f-MRI results could be obtained with such a task. Zhang, Ma, Li, Wang, Weng and Wang (2008) report f-MRI results from a simple delayed matching-to-sample task in which mismatching geometric shapes (known to elicit an N270 component) were associated with increased activity in the right anterior cingulate cortex and also in the right dorsolateral prefrontal cortex.

If perceptual mismatch does reliably activate a particular part of the anterior cingulate cortex, then f-MRI studies may help to establish whether the N270 and N400 peaks in the fronto-central ERP waveform, observed in several studies, reflect a repetition of the same component or two different components. If the two peaks reflect the same component, then the same brain regions should be activated (i.e. anterior cingulate cortex and possibly the right dorsolateral prefrontal cortex), although the level of activity may be greater. If the second peak (400 ms) represents mismatch of high complexity (as per Zhang et al. 2003), then it might be possible to observe activation in additional brain regions.

## **Conclusion**

Perceptual mismatch elicits enhanced fronto-central negativity. The earliest onset of this

negativity seems to be associated with the second negative peak at around 270 ms. However, the mismatch detection process can be delayed and along with it comes a corresponding delay in the negativity, consistent with previous suggestions that the N400 is a simple re-occurrence of the N270 (reflecting sequential processing). The addition of distractors affects mismatch responses more than match responses. This may indicate that such responses are harder to make and increasing the overall difficulty of the task exaggerates this effect. Alternatively, this may be because the distractors induce an automatic but task-irrelevant mismatch detection which hinders the establishment of a genuine mismatch response, but does not hinder the establishment of a genuine match response. These possibilities should be investigated in future studies.

### **Acknowledgments**

Giorgio Fuggetta wishes to thank the University of Leicester for the support given in granting study leave for the 2<sup>nd</sup> semester of academic year 2012/2013. The authors would like to thank the anonymous reviewers for their valuable comments and suggestions to improve the quality of the paper.

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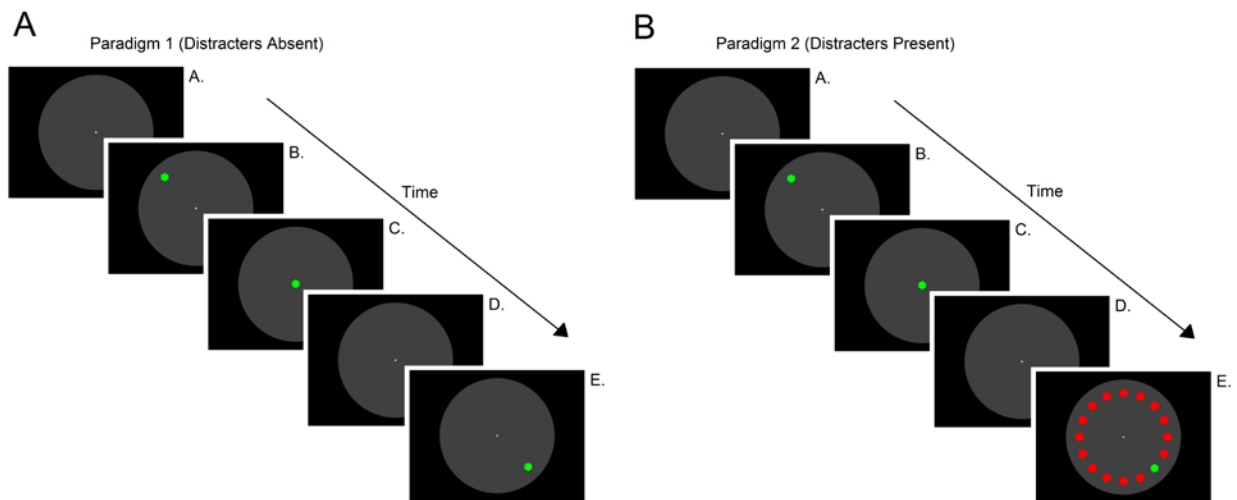
## Tables and Figures

Table 1. Mean Amplitude Measures

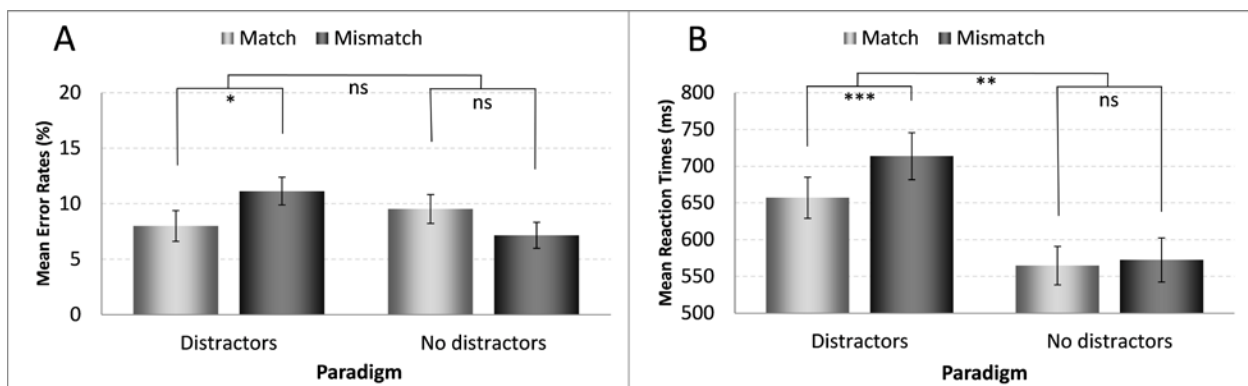
Comparison	Time Window (ms)			
	250-299 ( $\mu\text{V}$ )	300-349 ( $\mu\text{V}$ )	350-399 ( $\mu\text{V}$ )	400-450 ( $\mu\text{V}$ )
Distracters Absent vs. Present (Match Trials)	<b>2.4 vs. -0.8 *</b>	4.9 vs. 3.3	6.7 vs. 5.2	6.3 vs. 5.3
Distracters Absent vs. Present (Mismatch Trials)	<b>1.9 vs. -1.1 *</b>	3.6 vs. 2.0	<b>6.2 vs. 2.3 *</b>	6.2 vs. 3.4
Match vs. Mismatch (Distracters Absent)	2.4 vs. 1.9	<b>4.9 vs. 3.6 **</b>	6.7 vs. 6.2	6.3 vs. 6.2
Match vs. Mismatch (Distracters Present)	-0.8 vs. -1.1	<b>3.3 vs. 2.0 **</b>	<b>5.2 vs. 2.3 ***</b>	<b>5.3 vs. 3.4 ***</b>

\* $p < .05$ ; \*\* $p < .01$ ; \*\*\* $p < .001$

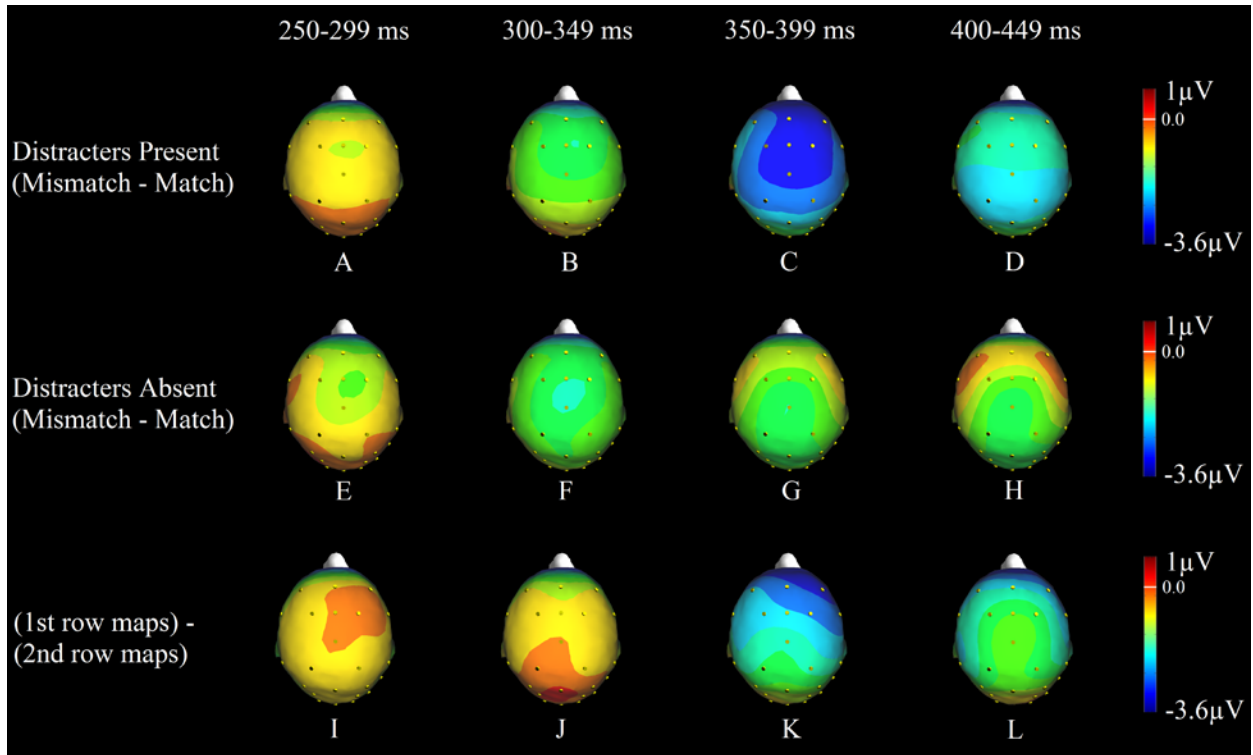
Table 1: Mean Amplitude Measures ( $\mu\text{V}$ )



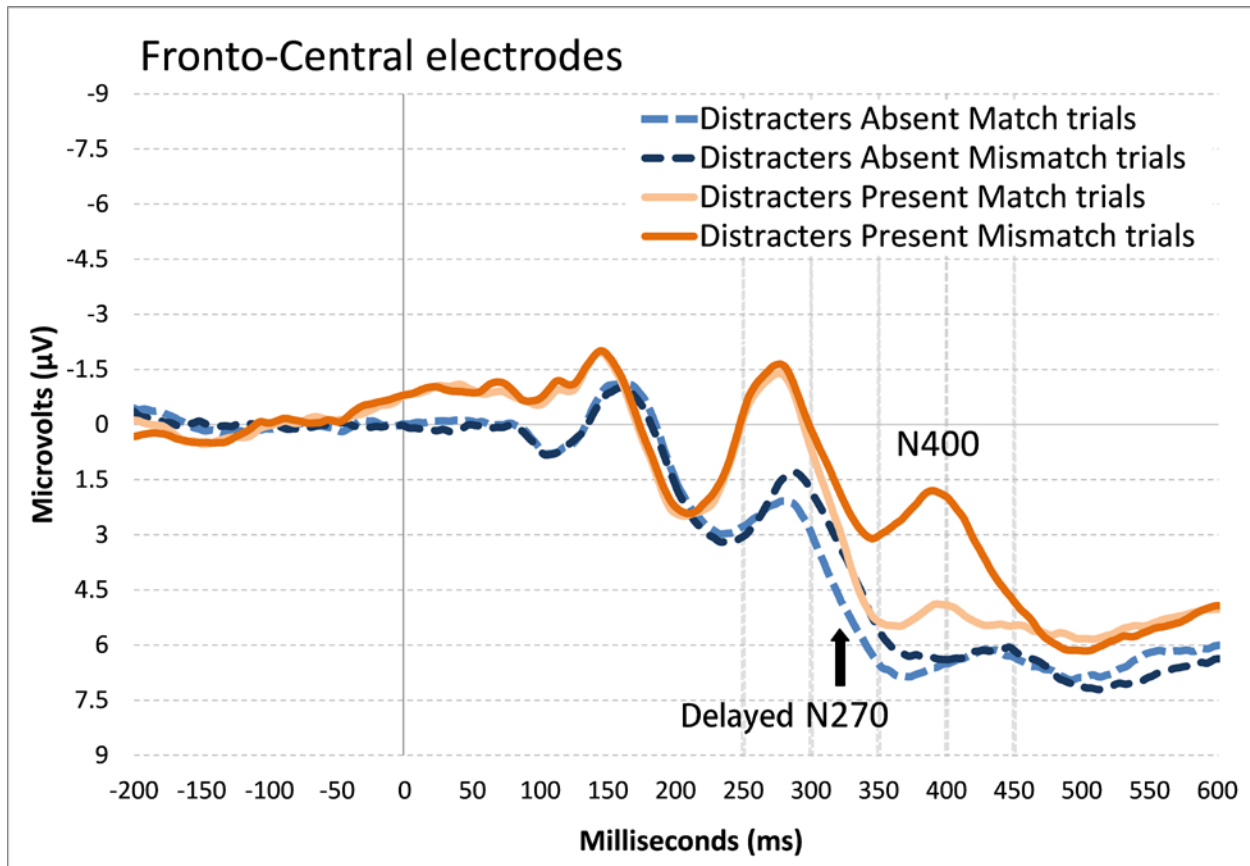
**Figure 1:** The temporal sequence of events for two analogous trials from each paradigm are shown. A fixation was shown for a brief period of time (A). A dynamic red or green cue (hexagon or diamond) moves within one quadrant from the periphery to the centre (B and C). A blank screen which lasted for either 400, 600 or 800 ms was displayed (D). A diamond or hexagon target briefly appeared (E); in the case of paradigm two, the target was embedded in a search array containing 15 homogeneous distractors (circles) arranged in a circle. The target singleton appeared in one of four fixed locations: top right quadrant, top left quadrant, bottom right quadrant or bottom left quadrant. In both paradigms, participants judged whether the shape of the target singleton matched or mismatched the cue.



**Figure 2:** Panel A shows mean error rates ( $\pm$  SE) for both paradigms. There was no significance between paradigms, although error rates were significantly higher for mismatch trials in the distractors present paradigm. Panel B shows mean reaction times ( $\pm$  SE) for the both paradigms. RTs were significantly increased in the distractors present paradigm. Moreover, only in the distractors present paradigm were RTs significantly different between mismatch and match trials. Asterisks denote significant differences between conditions (\*  $p < 0.05$ , \*\*  $p < 0.01$ , pair-wise post-hoc comparison, Bonferroni corrected).



**Figure 3:** Spline interpolated voltage difference maps for each analysis window (250-299; 300-349; 350-399; 400-450 ms). A-D) The mismatch-triggered negativity (mismatch – match trials) in the distractors present paradigm. A large negativity (N400) can be seen over fronto-central regions from 350-399 ms (C) and, to a lesser extent, from 400-449 ms (D). E-H) The mismatch-triggered negativity (mismatch – match trials) in the distractors absent paradigm. A slight negativity (delayed N270) can be seen, maximised centrally, from 300-349 ms (F). I-L) In order to compare the magnitude and topographic distribution of mismatch-triggered negativity between paradigms, we subtracted the second row (E-H) from the first row (A-D), essentially making ‘difference of the difference’ maps. There is virtually no difference from 250-349 ms (I and J). There is a difference in negativity from 350-449 ms (K and L). This difference is most pronounced at fronto-central regions and we therefore confined our ERP analysis to the fronto-central electrodes.



**Figure 4:** Grand average ERPs from bilateral frontal electrodes (average of: F3, FC1 FC5, F4, FC2 and FC6) for both paradigms. An enhanced negativity, peaking at 270 ms, stems from the presence of distractors. In the distractors absent paradigm, there is a slightly delayed negativity due to trial type mismatch (delayed N270). In the distractors present paradigm, there is a still further delayed negativity, also due to trial type mismatch (N400). The magnitude of the mismatch-triggered negativity in the distractors present paradigm is approximately 2.9 times greater than in the distractors absent paradigm. The time windows used for analysis are indicated by vertical lines.