PROCESSING OF
CONTEXTUAL CUES

EARLY PROCESSING
OF
CONTEXT IN A STROOP TASK:
EVIDENCE FROM EVENT RELATED POTENTIALS

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Abstract

The Stroop effect is considered a reliable measure of the contributions of word reading and colour naming processes. Changes in the size of the Stroop effect suggest modulations in the relative contributions of the two processes. Furthermore, item specific proportion congruent (ISPC) differences in the Stroop effect suggests that these modulations are rapid and stimulus driven. Recent behavioural and event-related potential (ERP) findings in a global/local task support the hypothesis that modulations in control can occur very early in visual processing. The present study extended the application of ERP methods to examine item-specific proportion congruency effects in the Stroop task. Findings from the present study are consistent with previous studies and observable ERP differences were recorded at the N1 component as early as 140 ms at site O1. These findings suggest that modulations in control can occur rapidly upon stimulus onset. However a surprising finding at site Oz suggests that item-frequency also plays a role in affecting response selection. The latency and location of this effect are similar to those reported by Shedden et al. (2009) suggesting that item specific effects occur as early as 100 ms. As well, this is the first study to report a combined influence of a simple associative learning mechanism and rapid, contextually driven control processes.

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Cognitive control processes ensure that behaviour is guided by task-relevant information rather than task-irrelevant information (Fernandez-Duque & Knight, 2007). Prior experiences for example can be a source of irrelevant and conflicting information and can interfere with a current task goal (Logan, 1979). This rapid influence of a prior experience on present performance is sometimes referred to as an 'automatic' influence. Overriding or inhibiting these automatic influences then requires increased cognitive control to ensure that behaviour is determined by the task goals at hand. In this light, an issue of importance for researchers of cognitive control is the interplay between controlled and automatic processes (Tzelgov, Henik & Berger, 1992).

Cognitive control is typically associated with voluntary shifts in processing that are slow to initiate, but highly flexible (Neely, 1977). This voluntary control ensures that behaviour is in agreement with specific task goals. Thus, although cognitive control has the advantage that it affords flexible processing in accord with task goals, it has the disadvantage of being slow and resource-demanding (Posner & Snyder, 1975). In contrast, automatic processes are typically associated with unconscious shifts in processing that are relatively rapid and inflexible. In effect, automatic processes somewhat autonomously implement well-learned procedures that can be independent of task goals. Therefore, although automatic processes have the advantage of being rapid, they have the disadvantage of being inflexible, hard to control, and can even oppose task goals (Tzelgov, Henik, & Berger, 1992).

Historically, attentional control and automaticity have been associated with distinct processing pathways, governed by a limited-capacity gating mechanism that selects one pathway and inhibits the other (Posner & Snyder, 1975; Shiffrin & Schneider, 1977). Accordingly, a central executive selects appropriate processing pathways through goal weighting, but is susceptible to failure as automatic processes can unwittingly intrude upon a task (Duncan, 1990). Indeed, there is a great deal of research to support this framework (Duncan, 1990; Cohen, Dunbar, & McClelland, 1990; Allport, 1980). At the same time, this dichotomy between controlled and automatic processes, often referred to as the dual-process model, has recently been called into question, requiring a re-assessment of the mechanisms of controlled and automatic processing (Logan, 1979; Tzlegov et al. 1992; Besner & Stolz, 1999; Jacoby & Lindsay, 2003; Crump, Gong & Milliken, 2006).

The present study follows up on recent research that challenges the classic distinction between controlled and automatic processes. Jacoby, Lindsay and Hessels (2003) reported a finding that suggests a type of control process that has both the speed advantage associated with automatic processes and the flexibility typically associated with controlled attentional processes. The empirical method used by Jacoby et al. (2003), and in the current study, involves the Stroop task, and therefore a review of the Stroop effect as a measure of cognitive control follows.

The Stroop task is often used as a measure of both the success of controlled processes and the interference from an irrelevant dimension (Stroop, 1935). In a standard Stroop task, the goal is to name the ink colour of each word presented. The words are colour names (e.g., RED or BLUE) and their meaning can either match the actual colour of the ink (a congruent trial) or not match the colour of the ink (an incongruent trial). In a modified version of this task, participants are placed in front of a computer and told that words will appear on the screen one at a time. The participant is then asked to identify the font colour of the word through either a vocal response or a key press. Critically, congruent and incongruent trials are randomly intermixed and consequently participants cannot be sure of the trial type until it is presented. The typical finding is that response times are much faster for congruent trials than for incongruent trials. This difference between congruent and incongruent trials is often described as the consequence of competition between two processes, word reading and colour naming (see Macleod, 1991 for a full review).

According to this framework, word reading is the more automatic process because most participants have a great deal of experience in generating the names of colours in response to words, but relatively less experience in generating the names of colours in response to the colours themselves (Posner & Snyder, 1975; Besner, 2001). Surely, for skilled readers, word reading may be so highly practiced and automatic that it cannot be prevented (Macleod, 1991). On the other hand, colour naming is thought to require control, in that an explicit process is required to connect visual information with its correct label (Macleod, 1991). This distinction between automatic and controlled processes provides a reasonable explanation for the Stroop effect; interference from incongruent words occurs because they are processed without intention, and consequently incorrect responses are activated that conflict with the task requirement of colour naming.

Although this distinction between automatic and controlled processes has traditionally been used to explain the Stroop effect, it relies on a strict application of automaticity towards word reading. This definitive automaticity of word reading becomes suspect however, when word reading is shown to be subject to cognitive control. In other words, a process like word reading cannot be completely automatic if it can be prevented to some extent (Yantis & Jonides, 1990; Kahneman & Treisman, 1984). To this end, Logan (1979) proposed that participants could instead formulate expectations based on past experiences, and use these expectations to strategically adjust the relative contributions of particular processes. Consequently within a Stroop experiment, participants could rely on knowledge gained from previous trials to predict whether word reading or colour naming is more appropriate for the next trial.

Two opposing strategies in a Stroop task are to rely on a colour naming process, or to rely on a word reading process. Strategic reliance on colour naming slows performance on congruent trials (reduced benefit of word reading would occur), but speeds performance on incongruent trials (reduced interference from word reading would occur), thus decreasing the size of the Stroop effect. In contrast, strategic reliance on word reading speeds performance for congruent trials, but slows performance for incongruent trials, thus increasing the overall size of the Stroop effect. When the expectation of congruency is high, it would be reasonable for participants to employ a word reading strategy, which would produce a relatively large Stroop effect. If instead the expectation of congruency is low, it would be more appropriate for participants to employ a colour naming strategy, which would produce a relatively small Stroop effect.

Numerous studies have reported precisely this result (Logan, 1979; Lowe & Mitterer, 1982; Cheesman & Merikle, 1986; Eglin & Hunter, 1990; Logan & Zbrodoff, 1998). When the experimental session includes a high proportion of congruent trials, the Stroop effect tends to be large. Such a result implies that participants apply word reading as a strategy for all trials, producing large processing benefits for congruent trials but also large costs for incongruent trials. Conversely, when the experimental session includes a low proportion of congruent trials, the Stroop effect tends to be relatively small. This result implies that participants selectively ignore the word for all trials, producing little in the way of processing benefits for congruent trials but also little cost for incongruent trials.

These and other studies contradict the definitive automaticity or ballistic nature of word reading (Besner, 2001). Certainly, if the relative contribution of the word reading process can be adjusted within a given context, then the distinction between automatic and controlled processes becomes somewhat blurred. Indeed, researchers have long acknowledged that so-called automatic processes can often be subject to flexible top-down control. Perhaps a more interesting and controversial question concerns a different form of blurring of the automatic/controlled distinction; that is, can controlled processes be selected automatically rather than voluntarily? Recent evidence suggests that 'automatic control", or control that is both rapid and flexible, may be possible.

Jacoby et al. (2003) tested the 'automatic control' hypothesis by presenting participants with randomly ordered Stroop words drawn from two discrete classes of items: Mostly Congruent and Mostly Incongruent. Mostly Congruent items were created using a specific subset of the colours in the experiment (e.g., blue, green, red) and appeared as congruent 75% of the time and incongruent only 25% of the time. Mostly Incongruent items were created using a different subset of the colours in the experiment (e.g., black, yellow, purple) and appeared as congruent only 25% of the time and incongruent 75% of the time.

Collapsed across both Mostly Congruent and Mostly Incongruent items, there were equal proportions of congruent and incongruent trials, and therefore one might not expect participants to favor either a word-reading or color-naming strategy. Furthermore, as participants could not possibly predict which discrete class of item (i.e. Mostly Congruent or Mostly Incongruent) would appear until its onset, they could not possibly rely on preparatory strategies that require explicit knowledge of whether an item will be from the Mostly Congruent or the Mostly Incongruent condition. The critical finding was that the size of the Stroop effect was dependent on the proportion context. That is, there was a larger Stroop effect for Mostly Congruent items than for Mostly Incongruent items. Jacoby et al. (2003) labeled this effect the item-specific proportion congruent (ISPC) effect, and they forwarded two very different potential explanations for why it occurs.

One explanation for the ISPC effect focuses on rapid and flexible modulation of attentional control processes. According to this view, attention processes can be recruited rapidly and flexibly from item to item, and in accord with the relevant context (Logan & Zbrodoff, 1979; Lowe & Mitterer, 1982; Lindsay and Jacoby, 1994). In turn, performance is then affected by the appropriateness of the recruited attention processes. Thus, if the word RED is usually displayed in the color red, then the word RED is likely to cue the retrieval of processes that allow word reading to occur, as word reading usually facilitates performance in this context. However, on the few occasions that the word RED is displayed in the color green, then retrieval of processes that allow word reading to occur will be in some sense 'inappropriate' for efficient performance, as word reading leads the participant toward the incorrect response in this case.

An alternative explanation of the ISPC effect focuses on an associative learning process involving particular items and responses, with the idea that frequently presented word-response pairs will produce fast RTs and infrequently presented word-response pairs will produce slow RTs. According to this item-frequency view, performance is affected by the appropriateness of the retrieved item-response association rather than the appropriateness of a particular way of controlling response selection (i.e., allow word reading to occur vs. focus on color naming). All things equal, one might well prefer the item-frequency hypothesis, as it suggests that a simple contingency learning process involving items and responses is sufficient to explain the ISPC effect without challenging the classic distinction between fast automatic and slow controlled processes (Schmidt & Besner, 2008).

If the word can be shown to cue retrieval of a particular proportion congruent context, then the online hypothesis can best explain the ISPC effect. However, if the word can be shown to cue different responses based on item-frequency, then the item-frequency hypothesis can best explain the ISPC effect. To address the relationship between the cue and the response, Crump, Gong and Milliken (2006) designed a Stroop-like experiment that relied on location to cue a particular proportion congruent context.

Crump et al. (2006) presented a brief colour word prime at fixation, and asked participants to name the colour of a subsequent coloured rectangle displayed above or below fixation. Congruent trials involved a match between the word and the colour of the rectangle. Conversely, incongruent trials involved a mismatch between the word and the colour of the rectangle. Each location (i.e., above or below fixation) was associated with a particular proportion of congruency, such that rectangles presented at the Mostly Congruent location were congruent with the preceding prime 75% of the time. On the other hand, rectangles presented at the Mostly Incongruent location were congruent with the preceding prime only 25% of the time. As the probe was equally likely to appear at either location following a prime, participants could not rely on the word to provide any predictive information about whether the following colored rectangle was likely to be congruent or likely to be incongruent. The results were similar to those of Jacoby et al. (2003), with a larger Stroop effect for trials at the Mostly Congruent location than for trials at the Mostly Incongruent location. With this design, where location acts as a contextual cue, the different sizes of Stroop effect for the two location contexts cannot be attributed to associative learning of frequent word-response combinations.

Yet it may still be argued that some word-location-response combinations were more frequent than others, and if responses are fastest for those combinations that are most frequent, then it would produce precisely the pattern of results reported by Crump et al. (2006) (Schmidt & Besner, 2008). In other words, although the results of Crump et al. (2006) cannot be explained by a simple word-response associative process, a slightly more complex word-location-response associative process would be sufficient to explain the results.

Given that the results of these ISPC experiments can be explained either by reference to flexible online control or by reference to item-frequency, alternative methods are needed to distinguish between these hypotheses. One candidate alternative method is to examine electrophysiological correlates of the behavioural ISPC effect. The flexible online control hypothesis assumes that there is a process that happens very quickly after stimulus onset that is sensitive to whether an item belongs to the Mostly Congruent or Mostly Incongruent context. If such a process occurs, then there should be a relatively early brain response that is sensitive to the distinction between Mostly Congruent and Mostly Incongruent items, regardless of congruency or item frequency. This issue was first addressed by Shedden, Milliken, Watter, and Garcia (2009) using a global-local variant of the ISPC method.

Shedden et al. (2009) asked participants to complete a letter identification task. The stimuli used were hierarchical Navon (1977) letters (e.g., large letter J's made up of smaller letter S's) and participants were instructed to identify the letters that appeared at the local level of these stimuli. As in the Stroop task, each stimulus could be congruent (i.e., large J made up of small J's) or incongruent (i.e., large J made up of smaller S's). Four letters were used in the experiment, and two letters were assigned to each of two stimulus sets. Similar to the design used by Jacoby et al. (2003) and Crump et al. (2006), one set was designated Mostly Congruent and items from this set were congruent 80% of the time. The other set was designated Mostly Incongruent and items from this set were congruent only 20% of the time. During the course of the experiment, stimulus locked ERP waveforms were recorded. (See Figure 1.0 for a depiction of the proportion manipulation and stimulus set used in Shedden et al., 2009).

The behavioural results were consistent with previous studies of the ISPC effect, with a smaller Stroop effect for the Mostly Incongruent items than for the Mostly Congruent items. However, the critical finding was in the physiological data. Located at Oz and a latency of just over 100 ms, the amplitude of the P1 response was larger for the Mostly Congruent items than for the Mostly Incongruent items, while there was no effect at all of item congruency. Shedden et al. (2009) concluded that these results constitute strong evidence that items from the two sets are processed differently very early in visual processing. (See Figure 2.0 for an image of the grand average waveform at Oz reproduced from Shedden et al., 2009).

The Present Study

The present follow-up to Shedden et al. (2009) examines ERP correlates of the Stroop ISPC effect. If the P1 modulation in the prior global-local ISPC study reflects a process that is generally responsible for rapid online shifts in cognitive control, then it should be present in a Stroop task as well. Using an experiment design identical to Shedden et al. (2009), but with Stroop stimuli, we examined ERP correlates of the Stroop ISPC effect. Of course, we predicted that the behavioural Stroop effect would be smaller for Mostly Incongruent items than for Mostly Congruent items. However, the more important issues were whether we would find an ERP correlate of this effect at a relatively early latency following stimulus onset, whether this ERP correlate would be sensitive to the distinction between Mostly Congruent and Mostly Incongruent items rather than to item-frequency or congruency, and whether this ERP correlate would overlap spatially and temporally with that found in the earlier global-local study.

Methods

Participants

42 undergraduate students (35 females) with a mean age of 19 years were recruited from McMaster University to participate in this experiment. All participants received course credit for their participation as partial fulfillment of a course requirement. All participants reported normal or corrected to normal vision and were fluent in English. As well, participants who required corrective eyewear for reading were encouraged to wear eye glasses as opposed to contacts to reduce eye strain and irritation. However, immediately following recording, one participant was excluded for squinting during the session, another was excluded for admitting that she was not fluent enough in English to understand the debriefing, and a third was excluded from further analysis due to a response mapping error. Individual averaged files that exceeded an acceptable level of noise upon visual inspection were excluded from the final Grand Average Process.

Apparatus and Stimuli

Stimulus presentation. Stimuli were presented on a 17-inch colour CRT monitor with resolution of 1024 x 768 pixels at a frame rate of 75 Hz using Presentation experimental software (www.neurobs.com). Participants conducted the experiment on a Pentium 4 computer using a Windows 2000 operating system. A viewing distance of 80 cm was maintained with the use of a chin rest. Stimuli were colour words presented in colour, using capital letters in Arial font. The font size of each stimulus was 24. Individual letters measured 1 cm in height and subtended a visual angle of 0.44°. The word RED subtended a visual angle of 1.6°; the word BLUE subtended a visual angle of 2.0°; the word GREEN subtended a visual angle of 2.9°; and the word BLACK subtended a visual angle of 2.6°.

There were two distinct sets of colour words; the words RED and BLUE composed one set and these items could only appear in the colours red and blue. The words BLACK and GREEN composed the other set and these items could only appear in the colours black and green. Within each set, items could appear as congruent (i.e. the colour matched the word meaning) or incongruent (i.e. the colour did not match the word meaning), but the proportion in which they were presented varied. One set was designated high proportion congruent and items from this set were 80% congruent and only 20% incongruent. The other set was designated low proportion congruent and items from this set were 20% congruent and 80% incongruent. Individual items were presented at random throughout the experiment. (See Figure 3.0 for a depiction of the proportion manipulation and stimulus set used in the present study).

Electroencephalography. A continuous electroencephalographic (EEG) file was recorded from 128 Ag/AgCl scalp electrodes using the ActiveTwo Biosemi electrode system. In addition there were 4 electrodes placed around the eyes to record eye muscle activity and help correct for eye blinks. Continuous EEG was sampled at 512 Hz. A left hemisphere parietal common mode sense (CMS) active electrode and an additional driven right leg (DRL) passive electrode replaced the traditional "ground" electrodes used in standard systems (http://www.biosemi.com/faq/cms&drl.htm). The BioSemi system is an active electrode system and there is no conventional reference electrode; a monopolar signal is stored for each active electrode and all re-referencing is done in software after acquisition. The EEG file was digitized and filtered offline with a 0.03 to 30 Hz bandpass filter to enhance the signal. Further processing of the signal was performed using EEProbe software (www.ant-software.nl), including eye-blink corrections, artifact rejection, re-referencing to a common average electrode, and averaging according to experimental conditions. Individual trials were coded using triggers sent online through the stimulus presentation software. Trials were coded for characteristics such as stimulus type, proportion congruent, trial congruency and response mapping.

The continuous EEG was segmented into epochs of 1000 ms including 100 ms pre-stimulus to 900 ms post-stimulus and correct trials were selected for ERP averaging. Movement and eye blink artifacts were identified and subjectively assessed. Based on these exemplars, a regression correction process was applied to individual trial data when possible. Trials with large uncorrectable artifacts were rejected from the averaging process. An average of 2% of trials was rejected for each participant. Average ERP waveforms for each participant were calculated using EEG time-locked to the onset of each Stroop stimulus.

Procedure

Each experimental session was conducted in a dimly lit, quiet room to minimize distractions. The entire procedure lasted approximately two hours including equipment set-up, data collection and clean up. Each participant was properly briefed regarding the procedure for ERP experiments and the importance of staying focused and still during the experiment. Once participants were comfortable with the EEG setup, they were instructed to remain with their head resting on a chin rest for the duration of the experiment and to refrain from eye blinks during trials. In total, there was one practice block and 20 experimental blocks consisting of 40 trials each. Individual block length was short in order to reduce eye strain and the number of eye blinks.

The task goal was to identify the colour of each word presented using one of four keys on a keyboard placed directly in front of the participant. Participants were instructed to familiarize themselves with the correct response mapping prior to starting the experiment in order to reduce response mapping errors. Responses for one colour set (e.g., red and blue) were mapped to the "z" and "x" keys. The "." and "/" keys corresponded to responses for the other colour set. Combining response mapping with proportion congruent produced four combinations which were counterbalanced across participants. The task goal instructions and the appropriate response mapping were displayed at the beginning of the experiment and again at the beginning of each new block. Participants initiated the beginning of each block by pressing the space bar key. Each trial was presented centrally following a randomly selected inter-trial interval that ranged from 400 ms to 800 ms. Stimuli remained on screen until response and participants were instructed to be fast and accurate in responding. At the end of each block participants were allowed a break and were presented with feedback regarding their accuracy for that block. (See Figure 4.0 for a depiction of trial sequence).

Results

Behavioural Data

The factors of interest in this experiment were proportion congruent (high and low) and item congruency (congruent and incongruent). This design creates four trial types of interest: Congruent trials from the high proportion congruent set (hi-con); incongruent trials from the high proportion congruent set (hi-inc); congruent trials from the low proportion congruent set (lo-con) and incongruent trials from the low proportion congruent set (lo-inc).

The data from three participants were excluded from analysis for excessively high error rates. These participants were identified by applying a recursive outlier identification procedure with a criterion of 2.5 standard deviations. This criterion was first computed after temporarily excluding the participant with the highest error rate. If the temporarily excluded participant had an error rate that fell within 2.5 standard deviations of the mean, then that participant was re-included and the outlier procedure stopped. If the temporarily excluded participant had an error rate that fell beyond 2.5 standard deviations of the mean, then that participant was rejected and the process was repeated with temporary exclusion of the participant with the next highest error rate. All three participants who were excluded had error rates greater than 15%. This left 36 participants to contribute to the analysis of the behavioural data.

An outlier analysis procedure that corrects for the tendency to reject different numbers of observations from cells of different size (Van Selst & Jolicoeur, 1994) was then applied to each participant's reaction times (RTs) separately for each of the four trial types, which eliminated 2% of the observations from further analysis. Mean RTs were computed from the remaining observations, and these mean RTs and error rates were submitted to a repeated measures analysis of variance (ANOVA) that treated proportion congruent and congruency as within-subject factors. Mean RTs and error rates for each condition, collapsed across participants, are reported in Table 1.0. Unless otherwise noted, an alpha level of .05 was used for all statistical comparisons.

In the analysis of RTs, there was a significant effect of congruency. Responses were faster for congruent trials (668 ms) than for incongruent trials (740 ms), F (1, 35) = 97.49, MSE = 1902.63. Critically, there was also a significant interaction between proportion congruent and congruency, F (1, 35) = 40.78, MSE = 1620.60. To examine this interaction further, separate analyses were conducted for the two proportion congruent conditions. For the high proportion congruent condition, responses were 115 ms faster for congruent trials than for incongruent trials, F (1, 35) = 107.81, MSE = 236498.89. For the low proportion congruent condition, responses were 29 ms faster for congruent trials than for incongruent trials, F (1, 35) = 11.34, MSE = 15070.51. Clearly, the Stroop effect was considerably smaller in the low proportion congruent condition than in the high proportion congruent condition.

In the analysis of error rates, there was a significant effect of congruency. Participants had a greater percentage of errors on incongruent trials (5.7%) compared to congruent trials (3.0 %), F (1, 35) = 29.36, MSE = 8.62. There was also a significant effect of proportion congruent as participants had a slightly larger percentage of errors in the high proportion congruent condition (4.9%) than the low proportion congruent condition (3.9%), F(1,35) = 4.08, MSE = 8.80. Finally, there was also a significant interaction between the main factors of proportion congruent and congruency, F (1, 35) = 9.23, MSE = 9.86. The error rates reflected the ISPC effect noted in the RT data as there was a smaller difference in error rates (1.1%) between congruent and incongruent trials in the Mostly Incongruent condition, F (1,35) = 4.13, MSE = 20.27 than between congruent and incongruent trials in the Mostly Congruent condition (4.3%), F (1,35) = 23.87, MSE = 323.85.

Electrophysiological Data

Individual average files were inspected for excessive noise levels, and a further six participants were excluded for uncorrectable levels of noise in their waveforms, leaving data from 30 participants for subsequent analyses. For the purposes of this study, all subsequent analyses were also restricted to the four waveforms for each participant that corresponded to the four trial types defined by the factorial combination of the proportion congruent and congruency variables (i.e., hi-con, hi-inc, lo-con and lo-inc). We also used a consistent series of steps to create a focused analysis. The first step was visual inspection of grand average waveforms at individual electrode sites. When an interesting effect or interaction was visually apparent, a peak analysis was conducted using automatically or manually retrieved peak values. Finally, a mean analysis was carried out to confirm the duration of the effect or interaction. Unless otherwise specified, all peak or mean amplitude values for each area of interest were submitted to a 2 x 2 repeated measures ANOVA, with the factorial combination of two levels of proportion congruent (high and low) and two levels of congruency (congruent and incongruent).

P1 interaction at site Oz. Based on previous findings from Shedden et al. (2009), we first examined whether the main effect of proportion congruent would appear in an early positive component at site Oz, as was the case in that study. We conducted a focused search for evidence of any of the three possible outcomes: an effect related to congruency; an effect related to item-frequency or an effect related to proportion congruent. Visual inspection of the Grand Average at electrode site Oz, restricted to latencies less than 200 ms, suggested that there might be an effect related to item-frequency. (See Figure 5.0 for an image of the grand average waveforms at electrode site Oz, in the present study). Consequently, we conducted a maximum peak analysis for electrode site Oz, a critical electrode reported in Shedden et al. (2009). An automated process failed to retrieve a sufficient amount of peak values due to the variance in latency for the P1 between participants. Therefore, individual average files were inspected manually in order to retrieve P1 peak values for each condition and for each participant. (See Table 2.0 for the mean amplitude (in microvolts) and standard deviation for each condition at the central electrode at site Oz).

There was a significant interaction between proportion congruent and congruency, F (1, 29) = 10.767, MSE = 6.933. The average amplitude for incongruent trials was significantly larger (2.83uV) than for congruent trials (2.67uV), in the high proportion congruent condition. In contrast, the average amplitude for congruent trials was significantly larger (3.24*u*V) than incongruent trials (2.72*u*V) in the low proportion condition. (See Figure 6.0 for a graph of the interaction between proportion congruent and congruency at electrode Oz).

The final step of analysis was on the mean amplitude of the P1 component at electrode Oz. The mean amplitude for each participant was retrieved automatically from a small time window between 100 ms and 150 ms. This time window was determined through inspection of the Grand Average waveforms for each participant. The values retrieved were submitted to a repeated measures ANOVA with two levels of proportion congruent (high and low) and two levels of congruency (congruent and incongruent). This analysis revealed no difference between any of the factors, therefore the interaction appears to be limited to the peak.

To address whether any of the possible effects might appear at other sites and latencies in the present task, visual inspection was conducted for each of the remaining 127 electrode sites restricted again to latencies less than 200 ms. A consistent interaction was present at P1 at electrodes Oz and Pz. P1 values for these electrodes were retrieved manually and averaged to create a cluster representing sites Oz and Pz. (See Figure 7.0 for a graph representing the clustered mean amplitude for these electrodes). These clustered values were submitted to a repeated measures ANOVA with the factorial combination of proportion and congruency. There was a significant interaction between proportion congruent and congruency, F (1, 29) = 9.07, MSE = 5.71. The effect of congruency approached significance for Mostly Incongruent items. That is the amplitude for congruent items was slightly larger (3.29 uV) than for incongruent items (2.88 uV). However, there was a significant congruency effect for items from the Mostly Congruent set. The amplitude for incongruent items was larger (3.45uV) than the amplitude for congruent items (2.98uV), F (1, 29) = 7.22, MSE = 3.21. (See Figure 8.0 for an image of the grand average waveforms of the each of the clustered electrodes).

N1 effect of proportion at site O1. We then turned our attention to other regions finding only one other site of interest. A clear and consistent difference between proportion congruent conditions was noted around the N1 component, at about 150 ms after stimulus onset, in 10 electrode sites: D23 through D32. Inspection of individual average files revealed that the effect was sustained over a small time window between 140 ms and 190 ms. (See Figure 9.0 for an image depicting the relative locations of Oz and O1).

Similarly to the steps described earlier for electrodes at site Oz, an automated procedure was first used to retrieve minimum peak values for all 10 electrodes from all participants' averaged files and for all four conditions of interest (i.e., hi-con, hi-inc, lo-con, lo-inc). This procedure failed to retrieve a substantial number of values due to the variance within each file. Specifically, many participants did not have a clearly delineated N1 peak and there was considerable variance in the latencies between individuals. This variance made it difficult to manually identify a clear N1 peak for many participants as well. Therefore, a small time window of 140 ms to 190 ms was identified across which the main effect of proportion was evident. An analysis of the mean value across this time window at electrode site D25 revealed a significant effect of proportion, F (1, 29) = 4.76, MSE = 3.3. Therefore a mean for the same 50ms time window was retrieved automatically using a custom configuration file and command script for each electrode from D23 through to D32, for each participant and for each of the four main conditions (i.e., hi-con, hi-inc, lo-con, lo-inc). These values were collapsed across electrodes to create a clustered mean representing the average brain activity at site O1.

High proportion congruent and incongruent trials produced smaller N1 peaks than low proportion congruent trials, revealing a main effect of proportion, F (1, 29) =5.28, MSE = 3.15. There was not a main effect of congruency and there was no interaction between the two main factors of proportion and congruency. The mean amplitude and standard deviation for each condition collapsed across all 10 electrodes, across a time window of 140 ms to 190 ms is presented in table 3.0. (See Figures 10.0 - 10.4 for an image of the grand average waveforms for each electrode at site O1. Also, see Figure 11.0 for a graph representing the mean amplitude across the cluster of electrodes).

Discussion

The present study provides a new understanding of attentional control and enlists a re-conceptualization of cognitive control processes. In the present study we were looking for very early ERP correlates of the ISPC Stroop effect. That is we wanted to know whether a dissociation between processing for Mostly Congruent items and Mostly Incongruent items occurs at a very early latency in a Stroop task. The discovery of an early dissociation between these sets of items suggests that it is possible for items to be categorized rapidly, well before visual processing is complete. We were also interested in confirming a behavioural effect (i.e., the ISPC Stroop effect). Our main behavioural result was a clear replication of the ISPC effect reported in several studies (Shedden et al., 2009; Crump et al., 2006; Jacoby et al., 2003). The Stroop effect was smaller for the Mostly Incongruent class of items than for the Mostly Congruent class of items. Therefore, our empirical method proved reliable. Critically, our findings of a difference between processing for Mostly Congruent items than for Mostly Incongruent items, regardless of the congruency of the item are consistent with Shedden et al. (2009) who reported a similar distinction in a Global/Local task. The present result in light of previous findings can be interpreted as evidence of a general mechanism sensitive to proportion congruent manipulations. More importantly, our results provide evidence that sensitivity to the category of a particular item is present within a very early time window immediately following stimulus onset.

Recent studies reporting the ISPC effect have suggested that proportion congruent effects are a result of modulations in control driven by contextual cuing. That is a cue, in this case provided by the word itself, can rapidly become associated with a particular likelihood of congruency, thereby causing the recruitment of the most appropriate control processes (Crump et al., 2006; Jacoby et al., 2003). This suggestion is incongruous to the historical framework of cognitive control, which conceptualizes control processes as slow and effortful. Within this framework, control processes are often contrasted against automatic processes, which are characterized as fast and autonomous. However, several studies reporting modulations in the Stroop effect, an effect accepted as representing the relative contributions of automatic and controlled processes, suggest that automatic processes can be controlled to some extent. That is, word reading can be controlled to a certain degree leading to adjustments in the size of the Stroop effect. These findings compel us to consider whether controlled processes on the other hand can be recruited automatically to some degree.

In reference to a Stroop task, the concept of ‘automatic control’ would suggest that not only can word reading be controlled, but that the contribution of colour naming can be adjusted rapidly upon stimulus onset (Jacoby et al. 2003). It has been noted that in order for such a mechanism to exist, the relative contribution of the more automatic process of word reading and the relative contribution of the more controlled process of colour naming would have to be assessed after the word is already processed (Schmidt & Besner, 2008). We would argue that an assessment of the appropriateness of either process can occur in parallel with visual processing. However, up to now behavioural methods alone have not been sufficient to discern this explanation from an item-frequency hypothesis. That is, based purely on behavioural data, it is difficult to conclude that the two potential explanations (i.e., rapid online shifts in control vs. associations of item-frequency) are exclusive or that one theory is more accurate than the other.

Shedden et al. (2009) report a finding that supports a distinction between processing of items from different proportion congruent contexts and does not support a distinction between items (i.e., word-response pairs) of different frequencies. The goal of the present study was to extend this finding to a Stroop task in order to find evidence of a generalized mechanism that is sensitive to proportion contexts. We believe we have found evidence of such a mechanism that produces a notable difference in processing in the N1 component at a very early latency, extended across a time window between 140 ms and 190 ms and consistently present at 10 electrode sites as a distinction between Mostly Congruent items and Mostly Incongruent items. The fact that the effect found in the current study is lateralized suggests that there are some key differences between a Stroop task and a Global/Local task that require further investigation. It is possible that the combination of colour and semantic information within a single stimulus recruits attentional control procedures unique to word and colour processing that are not required in a Global/Local variant of an ISPC experiment. Certainly an investigation of the N1 component within individual average files suggests that more than one process is being generated immediately following stimulus onset, resulting in variability around the peak of the N1. Understanding the origin of these generators is a goal for future research. The more interesting and more pertinent issue at present, however, is the possible relationship between the main effect of proportion located in several electrodes at O1 and the two-way interaction located at electrodes at Oz.

We will now consider the possible explanations for the presence of both the main effect of proportion and the interaction within 10 – 20 ms of each other and within neighbouring electrode sites. One relevant explanation involves a serious consideration of the hypothesis of the present study; that immediately following stimulus onset a mechanism that is sensitive to contextual information rapidly categorizes items in a way that leads to adjustments in processing and eventually adjustments in task oriented behaviour in a very generalized manner. This interpretation is supported by very recent evidence from an empirical method designed to assess whether control processes can be recruited and applied in a general sense to all items from a certain category.

Crump and Milliken (2008) presented participants with a word followed by a coloured target presented at a location either above or below fixation. The goal of the task was to name the colour of the target. The experiment design was similar to Crump et al. (2006) however targets presented at the Mostly Congruent location could either be from a word-target set that was 100% congruent or word-target set that was 50% congruent. Similarly, targets presented at the Mostly Incongruent location could either be from a word-target set that was 100% incongruent or a word-target set that was 50% congruent.

In a previous version of this experiment, Crump et al. (2006) reported an ISPC Stroop effect that varied according to the context of the location. In a more recent study, Crump and Milliken (2008) report a similar finding in that the size of the Stroop effect for the equal proportion class of items at the Mostly Congruent location was larger than the size of the Stroop effect for the equal proportion class of items at the Mostly Incongruent location. Therefore the expectation of congruency was learned through experience with the 100% congruent (or 100% incongruent) set of items and this learning generalized to the equal proportion items. The equal proportion items are presented equally often as congruent and incongruent and so cannot lead to associations based on item frequency. The authors concluded that this evidence supports a theory of rapid contextual cuing of processing that generalizes across all items presented within a given context.

If we hold true to this explanation, then it may be possible, in some sense, to ignore the interaction present at Oz and suggest that it is nothing more than an artifact. One reason to take this approach is that the strength of the interaction varies considerably across electrodes surrounding A15, A16 and A17 (the 3 electrodes reported in the analysis). Given this variability in surrounding electrodes it is possible that more than one process is occurring at this site and the interaction we find is not an accurate depiction of activity in the area.

Another possible explanation for the results of the present study is that the interaction present at Oz represents sensitivity to item frequency and it is this sensitivity that drives the later effect of proportion at the neighbouring O1 site. Within this framework, there are two possible interpretations of the interaction itself. One possible explanation is that highly frequent items (hi-con and lo-inc), which produced a smaller amplitude compared to infrequent items (lo-con and hi-inc) were expected and perhaps less surprising thereby requiring less cognitive effort to process. On the other hand, infrequent items are unexpected and perhaps more surprising, thereby requiring more cognitive effort to process. Therefore, this interaction at Oz could be nothing more than a measure of initial surprise, explaining why the interaction is limited to the peak of the P1 and also limited to a few electrodes in Oz.

It is also possible that item-frequency based associations between words and responses contribute strongly to response selection at a later stage in processing. From this perspective, the interaction present at Oz predicts the speed of response selection in relation to the overall frequency of the item. Therefore, we would predict a direct relationship between the mean amplitude of the ERP and the mean RT for each condition. In the present study such a relationship is not entirely supported by the data as the RT for the most frequent incongruent items is larger than the RT for the least frequent congruent items. In order to understand the relationship between these early effects and later response selection it is necessary to analyze data at later time points with a specific focus on the relationship between the four main conditions. It might also be helpful to conduct a partial least squares analysis of all ERP data in order to identify other regions of interest. In particular, it would be interesting to assess the role of frontal areas typically believed to be involved in conflict and error monitoring.

In conclusion then, we set out to investigate the possibility of a mechanism that allows the rapid categorization of items in a way that can help cue later processing. The assumption underlying this study challenges the historical framework of cognitive control which necessitates that shifts in processing occur prior to stimulus onset and in an effortful manner. We believe that our results provide good support for this assumption and consequently a re-evaluation of the traditional view of cognitive control. Future research will hinge upon the results of further analysis of later time points in the present data.

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Table Captions

Table 1.0 – Mean Correct Response Times (RT) in milliseconds and Error Rate (ER) for each condition with standard deviation in brackets. N = 36

Table 2.0 – Mean amplitude in microvolts and standard deviation for each condition at electrode site Oz, N = 30 (in the present study).

Table 3.0 – Mean amplitude in microvolts (uV) with standard deviation (in milliseconds) in brackets collapsed across electrodes D23 through D32, N= 30. The average amplitude for both lo-con and lo-inc are significantly larger than the average amplitude for hi-con and hi-inc.

Table 1.

Mean Correct Response Times (RT) in milliseconds and Error Rates (ER) by Condition

	Congruency					
	Congruent		Incongruent		Stroop Effect	ISPC Effect
Proportion Congruent	RT	ER	RT	ER		
	645.89	2.74	760.51	6.98	114.62	
High	(100.39)		(136.94)			
	690.26	3.33	719.19	4.39	28.93	85.69
Low	(98.72)		(115.84)			

Note: N = 36; standard deviation for RT in brackets.

Table 2.

Mean Amplitude in Microvolts (uV) for each condition.

Proportion Congruent	Congruency: Congruent	Congruency: Incongruent
High	3.55 (2.67)	3.99 (2.86)
Low	3.99 (3.25)	3.48 (2.75)

Note: Mean amplitude calculated for each condition averaged across cluster of electrodes at site Oz (Electrodes A15, A16 and A17); N = 30; standard deviation in brackets.

Table 3.

Mean Amplitude in Microvolts (uV) for each condition

	Congruency	
	Congruent	Incongruent
Proportion Congruent		
High	-1.92 (1.44)	-1.95 (1.69)
Low	-2.29 (1.82)	-2.22 (1.57)

Note: Mean amplitude calculated for each condition averaged across cluster of electrodes at site O1 (electrodes D23 – D32); N = 30; standard deviation in brackets.

Figure Captions

Figure 1.0 – A depiction of the proportion manipulation and stimulus set used in Shedden et al. (2009).

Figure 2.0 – The main finding in Shedden et al (2009). The Grand Average waveform at electrode A15, central electrode in Oz. The level of processing for high proportion items is represented by the two red lines, while low proportion items are represented by the two blue lines. There is a clear difference in processing for the two classes of items.

Figure 3.0 – A depiction of the proportion manipulation and stimulus set used in the present study.

Figure 4.0 - A depiction of stimulus presentation in the present study. Participants were instructed to name the colour of the word using the keys 'z', 'x', '.' and '/'. All items selected at random.

Figure 5.0 – Grand Average waveform at electrode site A15 in the present study. There is an interaction between proportion congruent and congruency at these electrodes in the P1 component.

Figure 6.0 – A graph of the interaction between proportion congruent and congruency at electrode site A15. There is a Stroop effect at each level of proportion congruent. The amplitude for congruent items is significantly different than the amplitude for incongruent items within each proportion of congruency (i.e., Mostly Congruent and Mostly Incongruent).

Figure 7.0 – A graph of the average peak amplitude across three clustered electrodes at site Oz. There is a clear interaction between proportion congruent (Mostly Congruent and Mostly Incongruent) and congruency (incongruent and congruent).

Figure 8.0 – 8.1 - Grand Average waveforms for 2 electrodes (A16 and A17). There is an interaction between proportion congruent and congruency at these electrodes in the P1 component.

Figure 9.0 - A drawing of the rear view of the head highlighting several sites, including O1, the location of the cluster of 10 electrodes showing a dissociation between items from the Mostly Congruent set and the Mostly Incongruent set.

Figure 10.0 – 10.4 - Grand Average waveforms for all 10 electrodes (D23 – D32) at site O1 that show a difference between high proportion and low proportion. Between 140 and 190 ms, the average amplitude for low

proportion trials (overlapping blue lines) is consistently lower than the average amplitude for high proportion trials (overlapping red lines).

Figure 11.0 – A graph of the mean amplitude across all electrodes within a time window of 140 ms to 190 ms. Mostly Congruent items are represented by the dashed line and Mostly Incongruent items are represented by the solid line. The mean amplitude across this time window is consistent with the prediction of online control of processing as congruent and incongruent items have similar values within each proportion context.

Figure 1.0 – A depiction of the proportion manipulation and stimulus set used in Shedden et al. (2009).

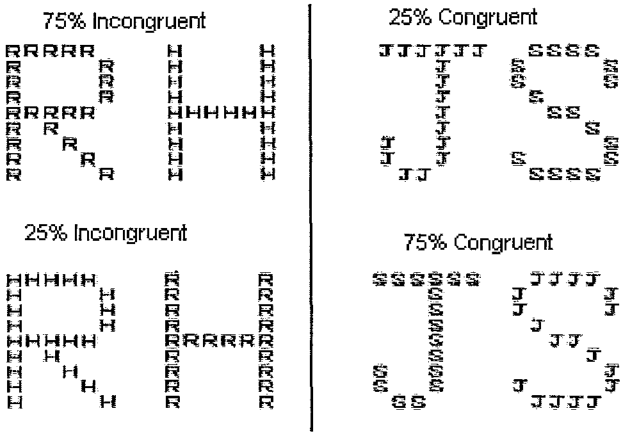


Figure 2.0 – The main finding in Shedden et al (2009). The Grand Average waveform at electrode A15, central electrode in Oz. The level of processing for high proportion items is represented by the two red lines, while low proportion items are represented by the two blue lines. There is a clear difference in processing for the two classes of items.

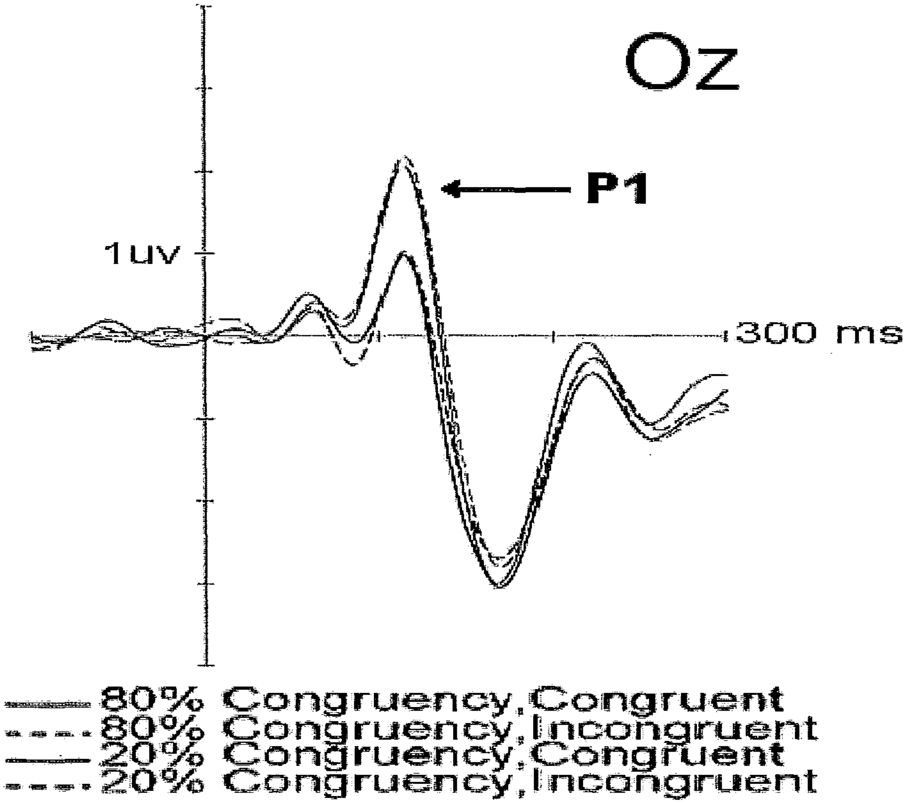


Figure 3.0 – A depiction of the proportion manipulation and stimulus set used in the present study.

75% Incongruent BLUE Presented in either Red or Blue	25% Congruent BLACK Presented in either Black or Green
25% Incongruent RED Presented in either Red or Blue	75% Congruent GREEN Presented in either Black or Green

Figure 4.0 : A depiction of stimulus presentation in the present study. Participants were instructed to name the colour of the word using the keys 'z', 'x', '.' and '/'. All items selected at random.

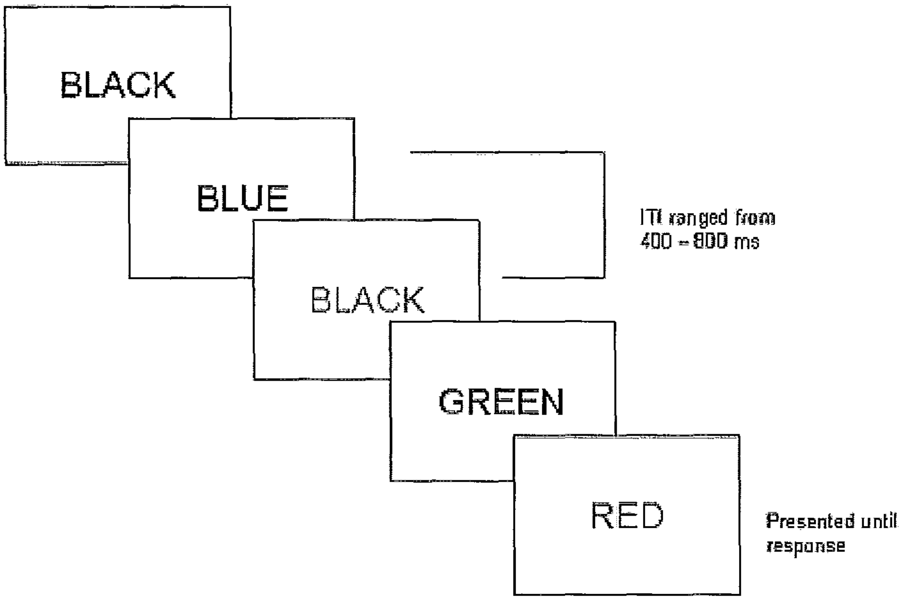


Figure 5.0 – Grand Average waveform at electrode site A15 in the present study. There is an interaction at this site (Oz).

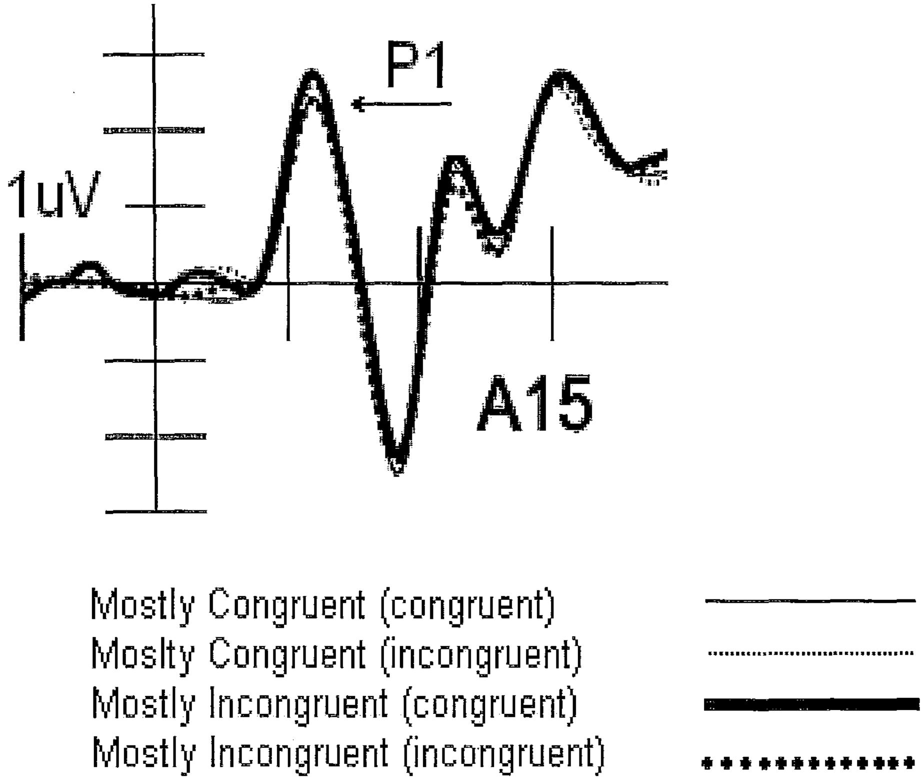


Figure 6.0 – A graph of the interaction between proportion congruent and congruency at electrode site A15. There is a Stroop effect at each level of proportion congruent. The amplitude for congruent items is significantly different than the amplitude for incongruent items within each proportion of congruency (i.e., Mostly Congruent and Mostly Incongruent).

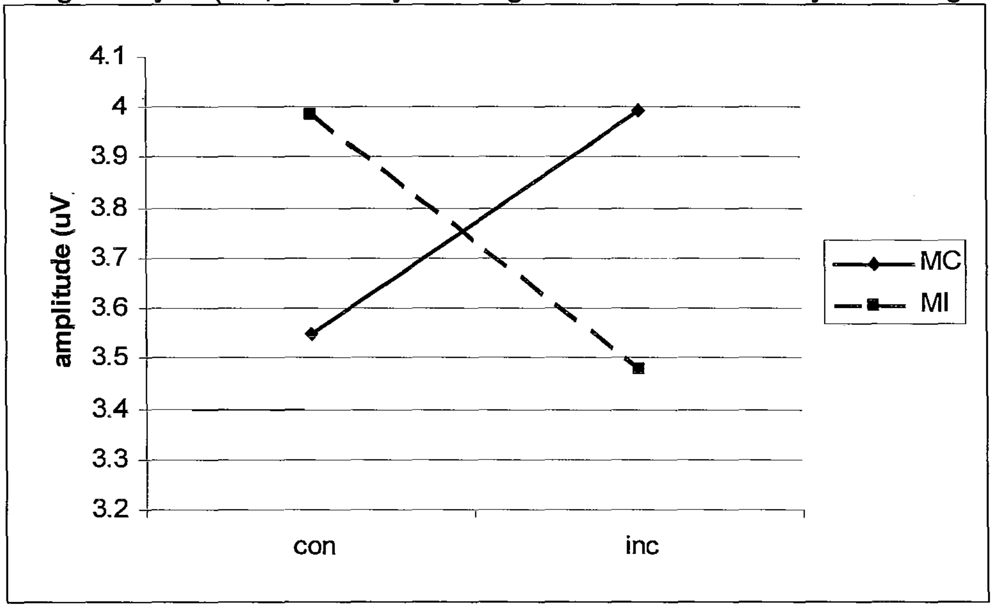


Figure 7.0 – A graph of the average peak amplitude across three clustered electrodes at site Oz. There is a clear interaction between proportion congruent (Mostly Congruent and Mostly Incongruent) and congruency (incongruent and congruent).

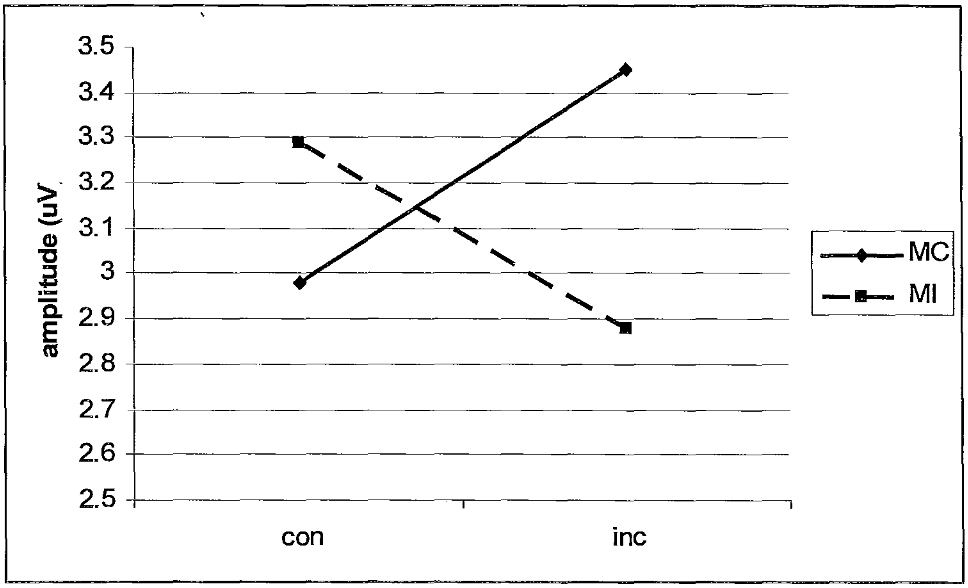
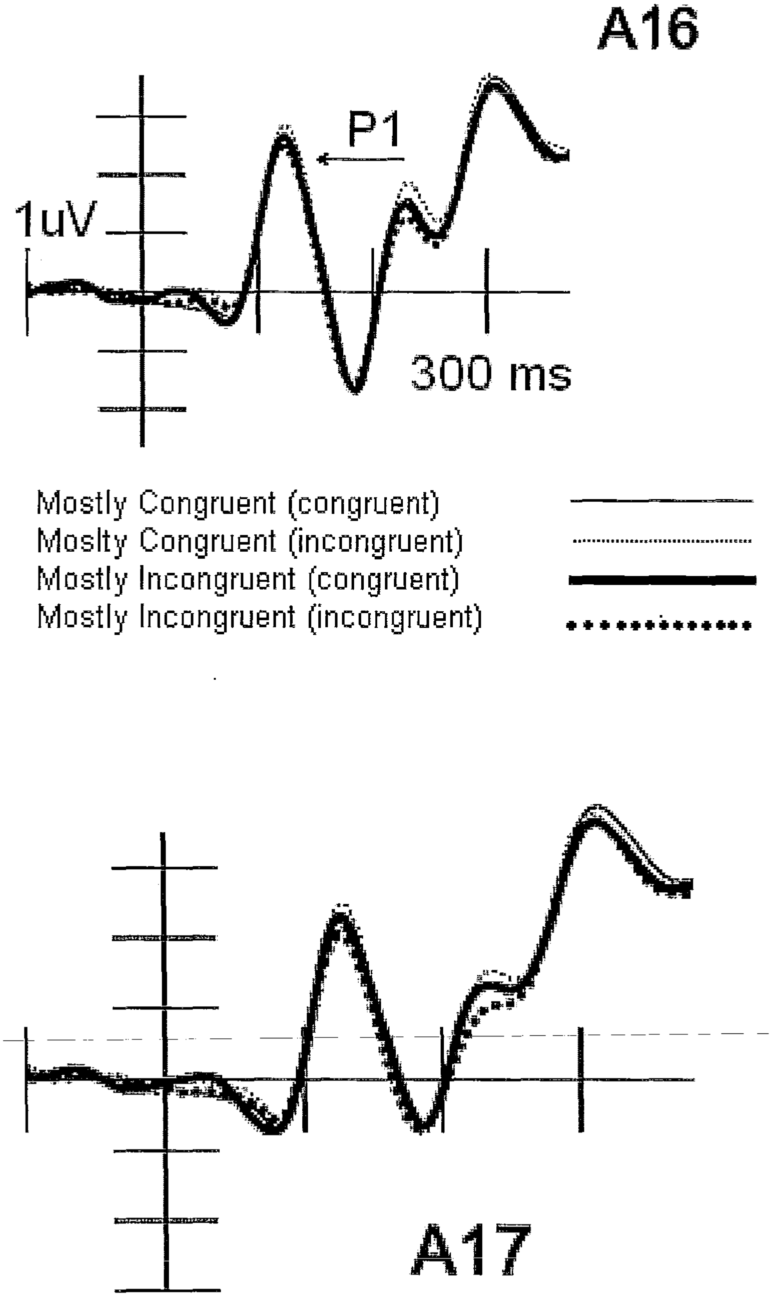


Figure 8.0 – 8.1 - Grand Average waveforms for 2 electrodes (A16 and A17). There is an interaction between proportion congruent and congruency at these electrodes in the P1 component.



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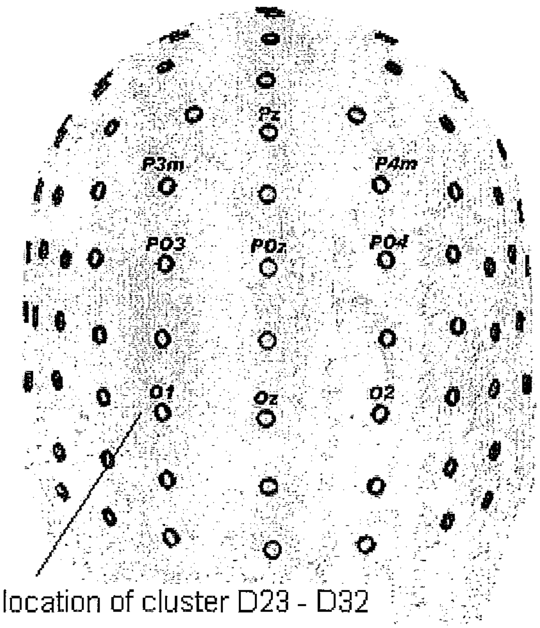


Figure 10.0 - Grand Average waveforms for all 10 electrodes (D23 – D32) at site O1 that show a difference between high proportion and low proportion. Between 140 and 190 ms, the average amplitude for low proportion trials (overlapping blue lines) is consistently lower than the average amplitude for high proportion trials (overlapping red lines).

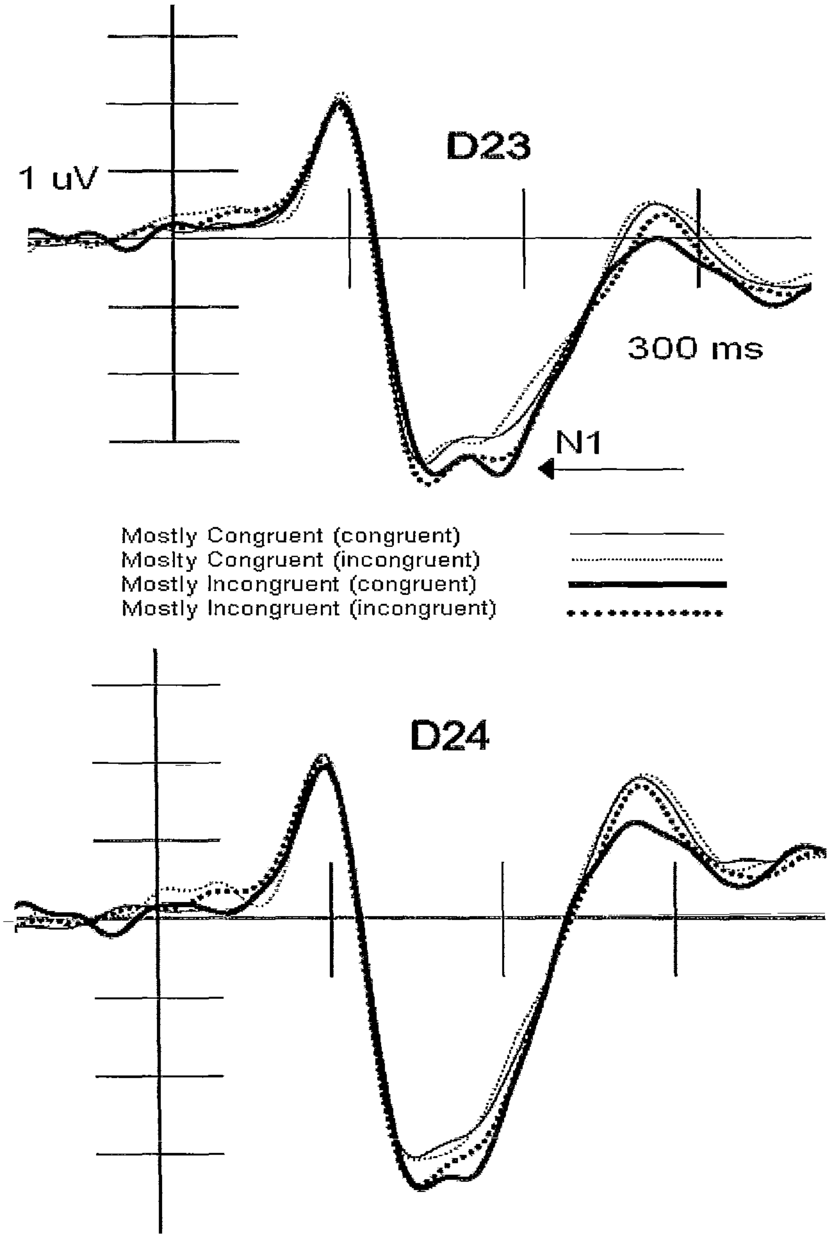


Figure 10.1 – Grand average waveforms for electrodes D25 and D26

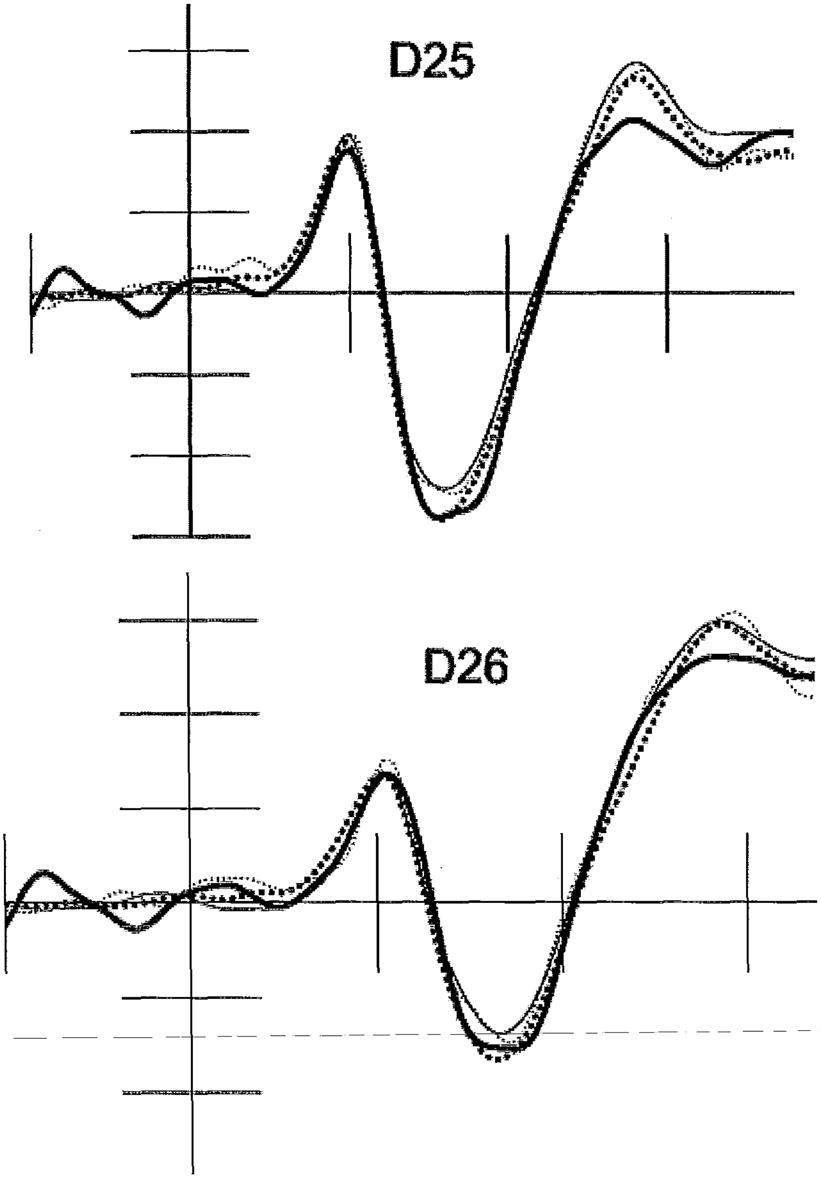


Figure 10.2 - Grand average waveforms for electrodes D27 and D28

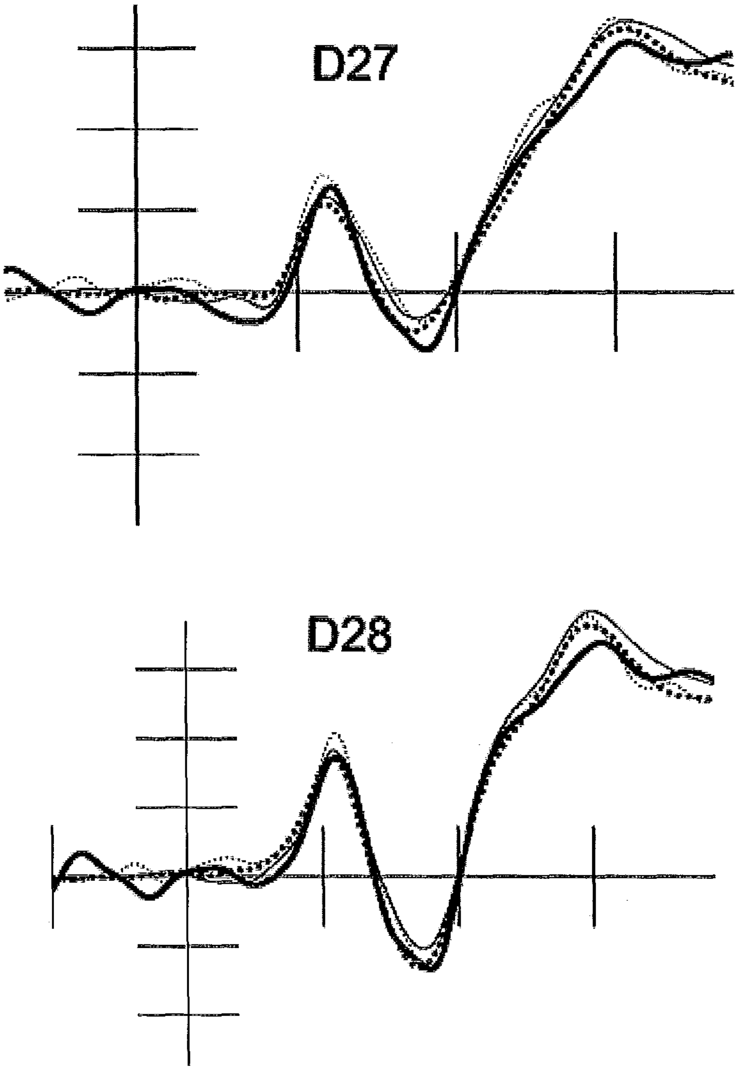
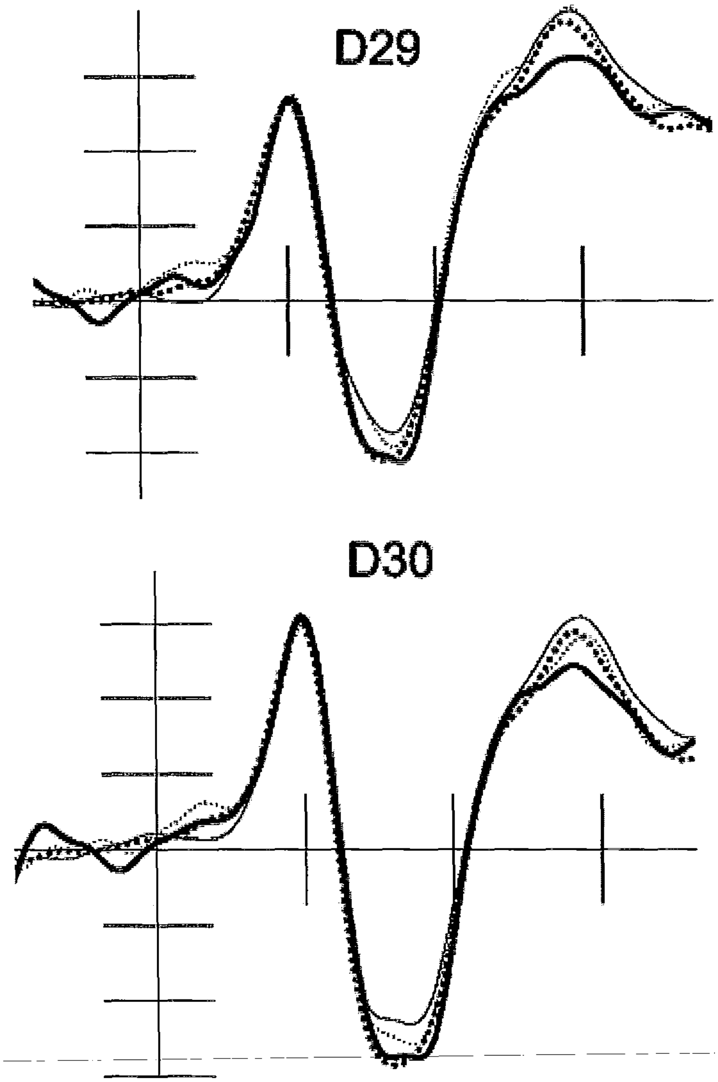
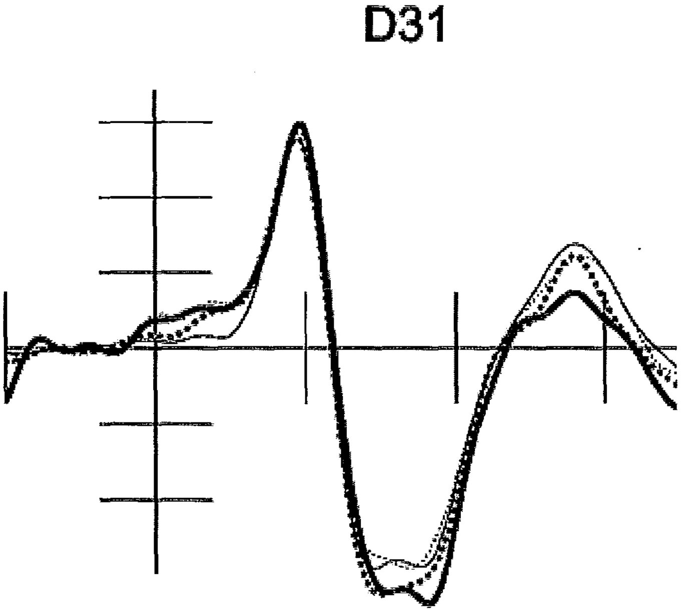


Figure 10.3 – Grand average waveforms for electrodes D29 and D30





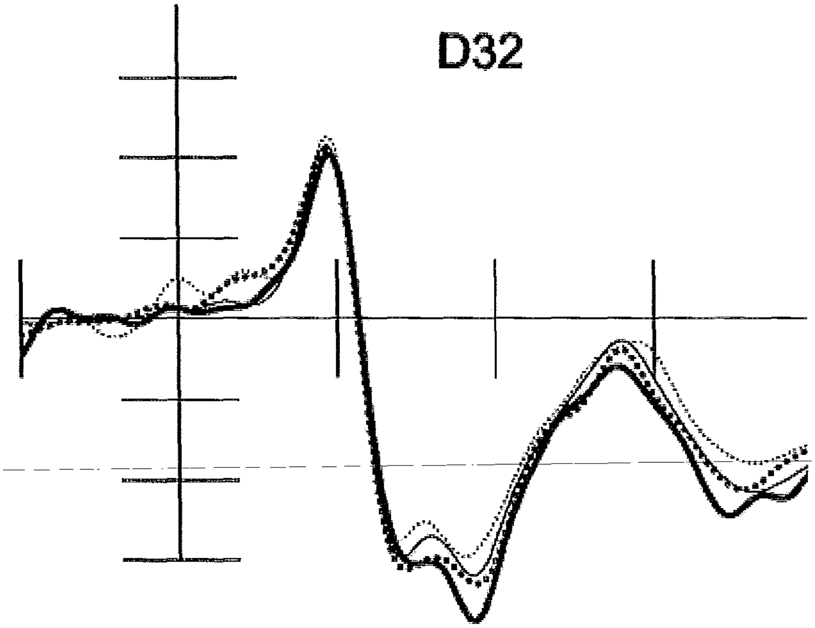


Figure 10.4 – Grand average waveforms for electrodes D31 and D32

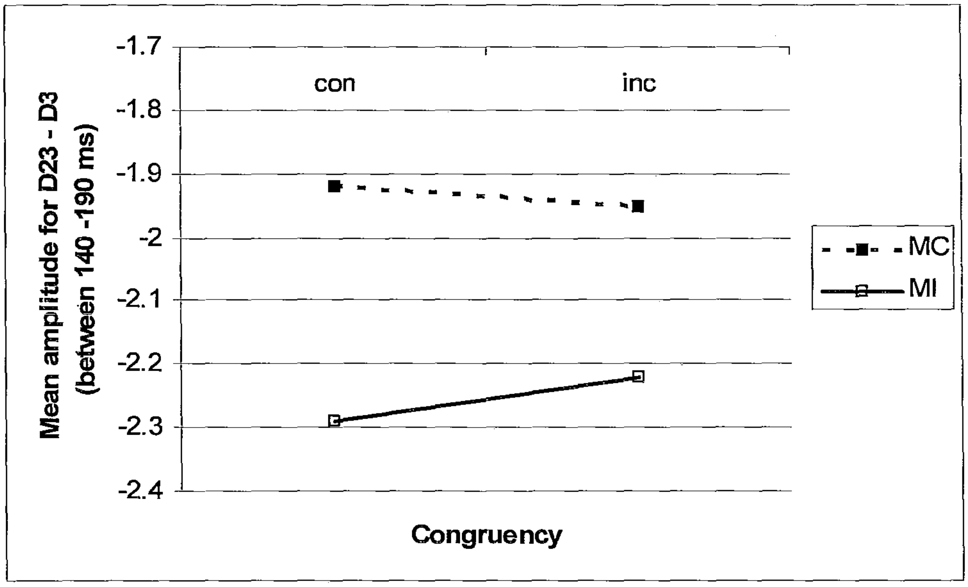


Figure 11.0 – A graph of the mean amplitude across all electrodes within a time window of 140 ms to 190 ms. Mostly Congruent items are represented by the dashed line and Mostly Incongruent items are represented by the solid line. The mean amplitude across this time window is consistent with the prediction of online control of processing as congruent and incongruent items have similar values within each proportion context.

Appendix A

McMaster University
Department of Psychology, Neuroscience & Behaviour
Debriefing Information Sheet

Item Specific Proportion Congruent Experiment

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SECTION A - OVERVIEW

In the experiment you just completed, we measured reaction time, accuracy, and event-related potentials (ERP's) while you identified the colour of words. ERP's are voltage changes measured at the scalp that represent neural activity associated with perceptual and cognitive events. The colour-naming task has a long history in experimental psychology. The finding usually observed in this type of study is that colour naming response times are slower and less accurate when the colour named does not match the word (i.e. the stimulus is incongruent) and faster when both colour and word match (i.e. the stimulus is congruent). The difference in performance between these two conditions is known as the Stroop effect, named after the researcher who discovered the effect (Stroop, 1935).

One theory used to explain the Stroop effect proposes that it occurs because word reading is an automatic process. In other words, although your task is to name the colour, you cannot help but read the word. Consequently word reading can interfere with colour naming. However, researchers have shown that the size of the Stroop effect is sensitive to the proportion of congruent and incongruent items. In other words, if the Stroop effect is particularly large when many of the stimuli are congruent and few of the stimuli are incongruent, and particularly small when many stimuli are incongruent and few are congruent (i.e. the proportion congruency effect), then this suggests that we may be able to control the extent to which word reading interferes with colour naming.

Jacoby, Lindsay, and Hessels (2003) intermixed sets of high proportion and low proportion congruency Stroop items in the same block and found that the Stroop effect was sensitive to the proportion of congruent items within a set of words. Therefore, the Stroop effect within any block of trials was larger for the set of items that were composed of a higher proportion of congruent items, but smaller for the set of items that were low proportion congruent. This and other studies like it have shown that different processing strategies can be recruited on-line, as the experiment progresses, rather than one strategy being selected experiment-wide. The processes involved in controlling the contribution of word reading to performance on the Stroop task are of interest to researchers because they provide a testing ground for the more general question of how we modulate the contribution of relatively automatic or habitual processes to our behaviour. In this study, we are especially interested in the neural processes that occur when a stimulus introduces conflict between different possible behavioural responses. We have shown in our laboratory that a very early ERP component is sensitive to proportion congruency. We are particularly interested in the early ERP component called the P1, which occurs about 100 ms following stimulus onset. Participants show a larger amplitude P1 for high proportion congruent items compared to low proportion congruent items, regardless of whether the items are congruent or incongruent. These results support a fast and automatic on-line response to stimuli that require very different responses as suggested by Jacoby et al. (2003).

Hypothesis: The processes that control word reading will be sensitive to the proportion of congruency for a particular set of words. Consequently, the Stroop effect will be different for low proportion congruent items than high proportion congruent items. The amplitude of the P1 component will be larger in response to items from a high proportion congruent set.

SECTION B – DETAILS

Independent variables:	(1) Item Congruency: (Congruent vs. Incongruent Stroop items) (2) Proportion Congruency: (80% congruent and 80% incongruent letter sets).
Dependent variables:	(1) Reaction time (2) Accuracy (3) Amplitude of the P1 ERP component.
Experimental Design:	Within Subjects Design
Type of Analysis:	2 Factor Repeated Measures ANOVA (Proportion Congruency x Item Congruency)

SECTION C - NOTES

We would like to thank you for your participation in our study. Please do NOT share this information with any other individuals who may be potential subjects in this study. Knowing the details before participating may influence their performance and/or the results. If you are interested in reading further about these issues, you may find the following articles useful:

References:

Jacoby, L. L., Lindsay, D. S., & Hessels, S. (2003). Item-specific control of automatic processes: Stroop process dissociations. *Psychonomic Bulletin & Review*, **10**, 638-344.

Macleod, C. M. (1991). Half a century of research on the Stroop effect: An integrative approach. Psychological Bulletin, 109, 163-203.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, **18**, 643-662.