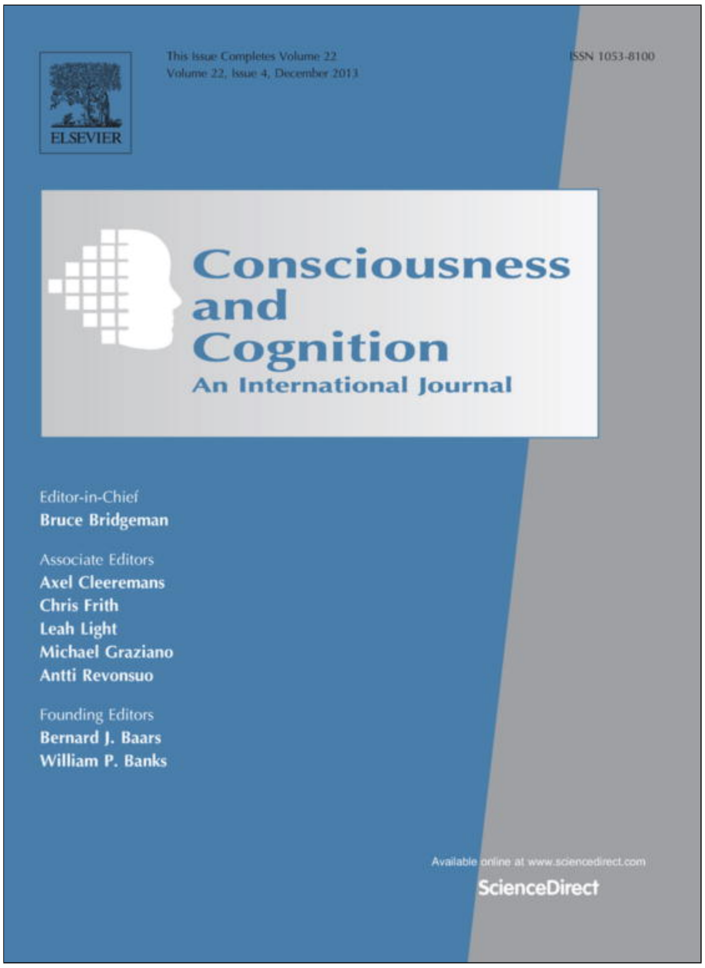
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Event-related potentials as brain correlates of item specific proportion congruent effects

Judith M. Shedden *, Bruce Milliken, Scott Watter, Sandra Monteiro

Department of Psychology, Neuroscience and Behaviour, McMaster University, Canada

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The item-specific proportion congruency (ISPC) effect is consistent with the idea that control processes can be applied rapidly in accord with previously experienced conflict for a particular category. An alternative account of this effect is that it reflects item-specific learning processes unrelated to control at the level of the category. The accounts predict the same behaviour but differ in terms of electrophysiological predictions. Two experiments examined the ISPC effect with a particular focus on neural correlates that might reveal whether, and how early in processing, high and low proportion congruent items are treated as distinct classes of stimuli. For both tasks, the proportion congruency category was distinguished prior to the congruence of the specific stimulus, as early as 100 ms post-stimulus onset for the global/local identification task (Experiment 1) and 150 ms for the Stroop task (Experiment 2). The results support an on-line control account of ISPC effects.

1. Introduction

The distinction between automatic and controlled processes has a long history in cognitive psychology. The dual process model that emerged in the 1970s, and that remains influential today, assumes that strongly automatic processes are fast, resource free, ballistic, and can occur in the absence of awareness of stimuli that elicit them. In contrast, cognitive control is thought to involve processes that are slow to initiate, resource demanding, subject to volition, and open to conscious inspection. This distinction has been illustrated in many types of attention and performance tasks, including Stroop (Stroop, 1935) and other Stroop-like tasks (Logan & Zbrodoff, 1979), visual search (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977), same-different matching (Posner & Snyder, 1975), and attentional cuing (Jonides, 1981), and also in a host of higher-order cognition domains (Jacoby, Toth, & Yonelinas, 1993).

In this article, we focus on a recent finding that appears to blur the distinction between automatic and controlled processes. In particular, our focus is a result reported by Jacoby, Lindsay, and Hessels (2003), which they referred to as an item-specific proportion congruent (ISPC) effect in the Stroop task. This effect is noteworthy because it appears to be a cognitive control effect that does not fit the conventional definition of controlled processes offered above. The present study examines the ISPC effect in both a global–local interference task and a Stroop interference task, with a particular focus on event-related potential (ERP) correlates of the effect. As will become evident, ERP correlates of the ISPC effect prove helpful in distinguishing among the potential implications of this effect for theories of cognitive control.

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* Corresponding author. Address: Department of Psychology, Neuroscience and Behaviour, McMaster University, Hamilton, Ontario L8S 4K1, Canada.
E-mail addresses: shedden@mcmaster.ca, judith.shedden@gmail.com (J.M. Shedden).

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1.1. The item-specific proportion congruent effect

Although it has long been known that the magnitude of Stroop interference depends on the proportion of congruent (word and colour match) trials within a block (Logan & Zbrodoff, 1979; Logan, Zbrodoff, & Williamson, 1984; Lowe & Mitterer, 1982; Tzelgov, Henik, & Berger, 1992), such demonstrations typically come from studies in which proportion congruent is manipulated either between blocks of trials, or between-subjects. When proportion congruent is varied in this manner, it is reasonable to conclude that participants evaluate the task context, discover that either many or few of the trials are congruent, and then adjust their task strategy accordingly. For example, when many of the trials are congruent, participants might adopt the strategy of reading the word despite the overt task requirement of naming the colour, as word reading is relatively fast and rarely affords an incorrect response. In contrast, when few of the trials are congruent, participants would be more likely to adopt a strategy that prevents word reading from occurring, as word reading more often than not leads response selection astray. The important point to note is that these adjustments in task strategy can easily be attributed to changes in rather slow, deliberate control processes that are set in response to an evaluation of the task context.

The ISPC effect reported by Jacoby et al. (2003) is noteworthy because it is not easily explained by such list-wide adjustments in task strategy. In the study by Jacoby et al., two categories of Stroop items were created, one of which was designated 'mostly congruent' while the other was designated 'mostly incongruent.' For example, the word RED might often appear in the colour red and rarely in the colour green (a mostly congruent item) whereas the word BLUE might often appear in the colour yellow and rarely in the colour blue (a mostly incongruent item). These two types of items were mixed at random within the experimental session, ensuring that participants could not predict the operative likelihood of congruency prior to stimulus onset. Despite the unpredictability of the item sets, the Stroop effect was larger for the mostly congruent items than for the mostly incongruent items. This result is not easily explained by reference to list-wide changes in task strategy, but is consistent with the view that processing of the distracting word can be controlled rapidly upon stimulus onset. Jacoby et al. referred to these on-line adjustments in word reading as 'automatic control'. Similar on-line control effects have now been reported for a range of Stroop-like effects (Bugg, Jacoby, & Toth, 2008; Crump, Vaquero, & Milliken, 2008; for reviews see Bugg, 2012; Bugg & Crump, 2012), as well as flanker effects (Cañadas, Rodríguez-Bailón, Milliken, & Lupiáñez, 2012; Corballis & Gratton, 2003; Lehle & Hübner, 2008; Vietze & Wendt, 2009; Wendt & Kiesel, 2011; Wendt, Kluwe, & Vietze, 2008), masked-priming effects (Heinemann, Kunde, & Kiesel, 2009) and task switching effects (Leboe, Wong, Crump, & Stobbe, 2008).

1.2. 'Automatic control' versus contingency and item frequency accounts

The ISPC effect has potentially interesting implications for the study of cognitive control. In particular, the ISPC effect suggests that appropriate ways of encoding and responding to stimuli are learned through experience, and can be retrieved rapidly during on-line performance. At first blush, this proposal may appear redundant with an instance theory of automaticity (Logan, 1988). However, a proposal unique from instance theory can be carved out by focusing on the retrieval of somewhat abstract control procedures that are appropriate for an item type, rather than the retrieval of specific encoding operations for a prior instance that matches perfectly with the current target. Grounding this distinction in an example may make it more clear. If the word RED usually appears in red and rarely appears in green, the idea is that onset of the word RED will cue word reading processes generally, rather than word reading processes associated with any particular instance in which the word RED was coloured red or green. By this view, a large Stroop interference effect that occurs for mostly congruent items owes to an increased contribution to performance of word reading processes that are appropriate for the word RED in red, but inappropriate for the word RED in green.

Yet, it must be noted that there is more than one way to account for the ISPC effect. As Jacoby et al. (2003) noted, rather than rapid on-line adjustments in control, the ISPC effect could result from rather simple associative learning processes. For example, if the word RED usually appears in red and rarely appears in green, then a stronger intra-experimental association might form between the word RED and the response red than between the word RED and the response green. This association might then magnify the Stroop effect. In contrast, if the word BLUE usually appears in yellow and rarely appears in blue, a relatively strong association between the word BLUE and the response yellow would shrink the Stroop effect. Together, this pattern of results would constitute an ISPC effect, but it would not require any novel inferences about on-line control.

On a similar theme, if one assumes nothing more than that speed of performance for an item depends on the frequency with which that item is presented within an experimental session, the ISPC effect is perfectly consistent with power law based learning processes that are specific to particular items (Logan, 1988). For example, if the word RED in green is presented 80 times within an experimental session, instance theory would predict that it would be responded to more quickly than if that same item were presented only 20 times within an experimental session. Therefore each presentation of the word RED would rapidly retrieve the response green. Relatively small Stroop interference effects for mostly incongruent items might therefore result from learning processes that are specific to particular items rather than forming the basis for rapid and generalized shifts in cognitive control for classes of items.

Indeed, Schmidt and Besner (2008) reported a set of results supportive of the idea that ISPC effects in Stroop colour naming reflect the learning of contingencies between words and responses, rather than on-line adjustments in control over word reading. For example, they pointed out that when the word RED appears in green on 80% of the trials while the word RED appears in RED on 20% of the trials, the word RED is more likely to cue the response 'green' than the response 'red', independent of any processing of the colour dimension of these stimuli. Greater activation of the response 'green' would naturally speed performance for RED in green and slow performance for RED in red, and thus reduce the size of the Stroop effect. Thus, learning of contingencies between the word dimension and responses could contribute to the ISPC effect. Schmidt and Besner reported both a re-analysis of the Jacoby et al. (2003) study and some of their own data in support of this contingency learning account of ISPC effects.

1.3. Beyond contingency learning; evidence for learned cognitive control settings

The contingency learning hypothesis of Schmidt and Besner (2008) might well be considered less complex than the 'automatic control' account of ISPC effects. Therefore, without compelling data to support the 'automatic control' account the contingency learning account might well be preferred. However, empirical support for the idea that participants learn more than the contingency between irrelevant words and a response has grown steadily over the past several years.

Crump, Gong, and Milliken (2006) presented participants with a white colour-word prime presented at fixation, followed by a coloured shape presented either above or below fixation. The colour-word prime was either congruent or incongruent with the colour of the following shape. Participants were asked to name aloud the colour of the shape. Critically, the proportion of congruent trials was manipulated separately for the coloured targets above and below fixation. For example, for some participants the proportion congruent for targets presented above fixation was .75, whereas the proportion congruent for targets presented below fixation was .25. For other participants, the opposite set of contingencies was employed. Importantly, a larger Stroop effect was observed for colour targets presented at the high proportion congruent location than for targets presented at the low proportion location. This context specific proportion congruent (CSPC) effect appears to demonstrate a similar learning process to that captured by ISPC effects, yet it occurs despite the fact that any particular word prime was equally predictive of all four responses. As such, word-response contingencies cannot explain the CSPC effect.

At the same time, the CSPC effect does not rule out a somewhat more complex contingency account in which word-location compounds activate specific responses. That is, in the Crump et al. (2006) procedure a particular word (e.g., RED) followed by a coloured target at a particular location together offered predictive information about the most likely response. To address this issue, Crump and Milliken (2009) conducted a follow-up experiment in which some word-location compounds or items were completely predictive of a given response, while other items were not predictive at all. The key question in this study was whether exposure to the predictive items would result in learning of a control setting that would transfer to the non-predictive items that shared the same context. Indeed, this result was observed; congruency effects for the transfer items were larger for the high proportion congruent context than for the low proportion congruent context despite the congruent and incongruent items appearing with equal frequency in both contexts.

Additionally, Bugg, Jacoby, and Chanani (2011) demonstrated that the ISPC effect can transfer to new, never before seen items. Bugg et al. (2011) trained participants on one set of picture-word pairs in a Stroop like task, with the picture as the relevant dimension and the word as the irrelevant dimension. Proportion congruent was manipulated separately for different picture-word pairs, such that either the word or picture in each pair could predict congruency. At a later stage in the experiments, participants were presented with new, never before seen picture-word pairs, for which only the pictures maintained their predictive value. Critically, if participants had learned nothing more than to rely on the word to signal a response, an ISPC effect would not be observed. However, Bugg et al. (2011) reported an ISPC effect for these new transfer items, indicating that participants had learned to rely on the picture to cue item-specific control settings. Transfer effects have also been demonstrated in a colour-word Stroop task in which words cued the item-specific responses (Bugg & Hutchison, 2013). The authors demonstrated ISPC effects in the absence of differences in contingencies, and transfer of control effects to new pairs of items, providing additional evidence for item-level control.

Moreover, Bugg and Hutchison (2013) argued in favour of the on-line control account in the following way. Traditionally, ISPC studies use an experimental design that contrasts one set of high proportion congruent items with one set of low proportion congruent items. Thus, there is a high contingency response for the mostly congruent set (the congruent items are more frequent) and a high contingency response for the mostly incongruent set (the incongruent items are more frequent), providing a reliable way for contingency learning to predict the correct response. However, in Experiment 3, the authors constructed the mostly incongruent condition from three different sets of items, so that there was no single high contingency response, compromising the effectiveness of contingency learning to predict correct responses. Nevertheless, ISPC effects and transfer of control effects remained (Bugg & Hutchison, 2013).

Although behavioural results have emerged that are consistent with the notion of on-line control (Bugg & Hutchison, 2013; Bugg et al., 2011; Crump & Milliken, 2009; for reviews see Bugg, 2012; Bugg & Crump, 2012), behavioural studies offer no direct method to test an important assumption of the on-line control hypothesis. Specifically, the on-line control hypothesis assumes that high proportion congruent and low proportion congruent items, whether congruent or incongruent, are treated as separate classes of items at some point very early in their processing. Indeed, it is the treatment of high proportion congruent items as a class that results in the recruitment of a common set of control operations for congruent and incongruent items of this class. This common set of control operations for all high proportion congruent items results in efficient performance for congruent items but inefficient performance for incongruent items, and thus a large interference effect. Importantly, item frequency and contingency learning accounts assume that processing hinges on how frequently particular items occur, rather than on whether items belong to a high or low proportion congruent class of items.

1.4. The current study

Although behavioural methods provide no obvious way to identify whether high proportion congruent and low proportion congruent items are processed early on as if they are two different classes of item, ERP methods are ideally suited to this task. The experiments reported in this study examine the ISPC effect in a global–local identification task (Experiments 1A and 1B) and in a Stroop task (Experiment 2), with a particular focus on whether, and how early in processing, high and low proportion congruent items are treated as distinct classes. To foreshadow the results, in both experiments we observed differences in early ERP components between the processing of high and low proportion congruent items that were insensitive to item congruency. This is precisely the type of early processing difference predicted by the on-line control hypothesis, and not predicted by the item frequency or contingency learning hypotheses.

2. Experiment 1A

The aim of the present experiment was twofold. First, we examined whether an ISPC effect might be measured in a global–local task (Navon, 1977), in which participants attend to the local dimension and ignore the global dimension of hierarchically structured stimuli. Second, and assuming that an ISPC effect could be measured behaviourally, we were interested in the electrophysiological correlates of the ISPC effect for the global–local task. Of particular interest was whether there would be electrophysiological evidence of differential processing for high and low proportion congruent classes of stimuli that precedes differential processing of congruent and incongruent items types.

2.1. Materials and method

2.1.1. Participants

Forty undergraduate students (28 females, mean age 19) from McMaster University participated in this experiment. All of the participants reported normal or corrected-to-normal vision, and were fluent in the English language. Each participant gave informed consent to take part in the study, and received partial course credit for their participation. Five of the participants were eliminated from statistical analyses due to excessive eye-blink artifacts or technical errors in ERP acquisition. Furthermore, as we were most interested in measuring differences in early components, we selected only those participants with waveforms exhibiting strong positive peaks within 50 and 150 ms. Therefore, a further 4 participants were excluded as it was not possible to measure a positive peak for them within that time window. Participants who were excluded for these reasons were also excluded from the analysis of behavioural data.

2.1.2. Procedure and stimuli

The experiment was conducted in a dimly lit room with minimal noise. Each session was approximately two hours, including equipment set up, data acquisition, and clean up. Participants were instructed to maintain fixation and keep eye blinks to a minimum during trials. Participants were encouraged to rest their eyes between blocks and focus on both accuracy and speed of response throughout the experiment.

Presentation® experimental software (www.neurobs.com) was used to program stimulus presentation and manual response measurement running on a Pentium 4 computer with Windows 2000 operating system. The display was a 17-in. colour CRT display at a resolution of 1024 × 768 pixels at a frame rate of 75 Hz. The stimuli were hierarchical global–local items in which one large letter is constructed out of smaller letters (Navon, 1977). The global–local stimuli were black presented on a white background. Global letters were 70 mm in height and 40 mm in width, and a chinrest was used to maintain 80 cm between participants and the computer display, resulting in a visual angle of 5° by 2.86°. Local letters were 7 mm in height and 5 mm in width, with visual angle 0.5° by 0.36°.

Two sets of mutually exclusive hierarchical stimuli were constructed. One set consisted exclusively of the letters R and H (RH letter set), and the other set consisted exclusively of the letters J and S (JS letter set). Within each letter set, the global and local letters were congruent (e.g., global R made of local R's or global H made of local H's) or incongruent (e.g., global R made of local H's or global H made of local R's).

The RH and JS letter sets were presented with equal probability (50% RH stimuli and 50% JS stimuli). The ISPC manipulation was imposed on the two letter sets so that one letter set had a high proportion of congruent trials (80% congruent and 20% incongruent trials), and the other letter set had a low proportion of congruent trials (20% congruent and 80% incongruent trials). Blocks consisted of randomly ordered trials of all conditions, so that it was not possible to predict the condition from trial to trial. The proportion congruent assignments of the letter sets were counter-balanced across participants so that the RH and JS letter sets were assigned to the high proportion congruent condition equally often.

Following task instructions and one practice block of 20 trials, there were 20 test blocks of 40 trials. Each block began with a reminder of the task rules and a prompt to press the spacebar to begin the block. On each trial, a global–local figure was presented in the center of the display until response, followed by a random delay between 400 ms and 800 ms, followed by the onset of the next global–local stimulus. The task was to identify the local letter and respond by pressing one of four possible keys on the computer keyboard. The R and H letters were mapped to "z" and "x" keys, respectively (left hand middle and index finger responses), and the J and S letters were mapped to "." and "/" keys, respectively (right hand index and middle finger responses). Response mapping for each letter set was counterbalanced across participants; therefore this mapping was reversed for half the participants. Trial accuracy and response times were recorded.

2.1.3. Electrophysiology

The ActiveTwo Biosemi electrode system was used to record continuous electroencephalographic (EEG) activity from 128 Ag/AgCl scalp electrodes plus 4 additional electrodes placed at the outer canthi and just below each eye for recording horizontal and vertical eye movements. Two additional electrodes, common mode sense (CMS) active electrode and driven right leg (DRL) passive electrode were also used. These electrodes replace the "ground" electrodes used in conventional systems (http://www.biosemi.com/faq/cms&drl.htm). The continuous signal was acquired with an open pass-band from DC to 150 Hz and digitized at 512 Hz. The signal was bandpass filtered off-line at 0.03–30 Hz and rereferenced to a common average reference.

ERP averaging and analysis were performed using EEProbe software (ANT, www.antsoftware.nl). EEG and EOG artifacts were removed using a ±35 μV deviation over 200 ms intervals on all electrodes. Blink artifacts were selected manually and corrected by a subtraction of VEOG propagation factors via a regression algorithm on EOG components (using EEProbe signal processing software). A 1000 ms recorded EEG epoch, including 100 ms pre-stimulus baseline and 900 ms interval following stimulus onset, was chosen for ERP averaging. The segmented epochs were averaged (correct trials only) to create separate ERP waveforms for each condition.

2.1.4. Data analysis

The primary analyses investigated the effects of proportion congruency and trial congruency on mean response times, accuracy scores and mean amplitude using separate 2 (high proportion congruency vs low proportion congruency) × 2 (congruent vs incongruent) repeated measures ANOVAs. Analysis of EEG data focused on well-established cognitive ERP components previously studied as markers of visual attention and perception. Clusters of adjacent electrodes were used to define Regions of Interest (ROIs) at typical sites of maximum amplitude for specific components, to assess potential effects of Proportion Congruency and Trial Congruency manipulations. We assessed ERP mean amplitude for P1 (100–125 ms) and N1 (150–175 ms) components using a cluster of three electrodes centered anteroposteriorly on electrode Oz; and for N2 (225–275 ms), P3b (300–400 ms), and Late Parietal Positivity (600–800 ms) components using a cluster of three electrodes centered anteroposteriorly on electrode Pz. Analysis epochs for mean amplitude measures were selected following initial inspection of component latencies in individual participant and grand mean ERP waveforms, to most effectively isolate relevant components.

2.2. Results

2.2.1. Behavioural data

Initial analyses showed letter set ("RH" versus "JS" stimuli) did not produce any significant effects or interactions, and so analyses were collapsed over this factor. Mean response time and mean accuracy data separated by proportion congruency and trial congruency conditions for Experiment 1A are presented in Table 1. Overall mean response time was 764 ms and mean accuracy was 96.4%.

Response time analysis revealed a significant main effect of trial congruency, $F(1,30) = 21.49$, $p < .001$ as participants were faster on congruent trials (752 ms) than incongruent trials (776 ms). As well, there was a significant interaction between proportion congruency and trial congruency, $F(1,30) = 35.15$, $p < .001$, with no main effect of proportion congruency, $F(1,30) = 0.34$, $p = .57$. In the high proportion congruent condition, participants were faster on congruent trials (741 ms) than incongruent trials (796 ms), $t(30) = 6.68$, $p < .001$, whereas in the low proportion congruent condition, response time did not differ between congruent (764 ms) and incongruent trials (757 ms), $t(30) = 1.09$, $p = .29$. This pattern of data replicates ISPC effects in the literature (e.g., Jacoby et al., 2003).

Accuracy data mirrored effects in RT data, with overall high levels of accuracy, and no evidence of a speed-accuracy tradeoff. Congruent trials (96.7%) showed a marginal main effect of greater accuracy over incongruent trials (96.2%), $F(1,30) = 3.35$, $p = .077$, with a marginal interaction with proportion congruency, $F(1,30) = 3.09$, $p = .089$. Akin to the RT data,

Table 1

Mean response time and mean accuracy data for Experiments 1A and 1B. Values in parentheses indicate within-subjects adjusted standard error of the mean.

	Mean response time (ms)		Mean accuracy (% correct)	
	Congruent	Incongruent	Congruent	Incongruent
Experiment 1A				
High proportion congruency	741 (9)	796 (8)	97.0 (0.3)	96.0 (0.3)
Low proportion congruency	764 (8)	757 (8)	96.4 (0.3)	96.4 (0.2)
Experiment 1B				
High proportion congruency	747 (10)	771 (8)	96.5 (0.3)	94.9 (0.4)
Low proportion congruency	729 (8)	764 (8)	95.5 (0.3)	95.1 (0.3)

the difference between congruent (97.0%) and incongruent trials (96.0%) in the high proportion congruent condition was observed to drive these effects, $t(30) = 2.28$, $p < .05$, with no difference in trial congruency for low proportion congruency trials, $t(30) = 0.05$, $p = .96$.

2.2.2. Electrophysiological data

Fig. 1 shows grand mean waveforms for Oz and Pz electrodes, demonstrating effects of proportion congruency and trial congruency for P1, N1, N2, P3b and Late Slow Parietal Positivity ERP components.

2.2.2.1. P1 (Oz ROI; mean amplitude 100–125 ms). We observed a strong effect of proportion congruency on P1 mean amplitude, with high proportion congruency stimuli (2.45 μV) eliciting a larger P1 than low proportion congruency stimuli (1.60 μV), $F(1,30) = 6.32$, $p < .05$. There was no effect of trial congruency, and no interaction, $Fs < 0.1$.

2.2.2.2. N1 (Oz ROI; mean amplitude 150–175 ms). We observed a sizable N1 component at the Oz ROI. This N1 component did not show any effects of proportion congruency or trial congruency in this experiment, all $Fs < 0.6$.

2.2.2.3. N2 (Pz ROI; mean amplitude 225–275 ms). A notable N2 component was observed in data from the Pz ROI. Mean N2 amplitude was influenced by trial congruency, with congruent trials (0.84 μV) observed to be more negative than incongruent trials (1.16 μV), $F(1,30) = 4.69$, $p < .05$. There was no effect of proportion congruency on N2 mean amplitude, $F(1,30) = 1.27$, $p = .27$, and no interaction, $F(1,30) = .16$, $p = .70$.

2.2.2.4. P3b (Pz ROI; mean amplitude 300–400 ms). A sizable P3b component was observed over the Pz ROI. For this epoch capturing the peak of the P3b component, we observed no effects of proportion congruency or trial congruency on mean amplitude, all $Fs < 0.3$.

2.2.2.5. Late Parietal Positivity (Pz ROI; mean amplitude 600–800 ms). Extended P3-like parietal positivity was observed maximally over midline parietal electrodes, and assessed at our Pz ROI. We observed a clear effect of trial congruency, $F(1,30) = 6.01$, $p < .05$, with mean amplitudes for incongruent trials larger than for congruent trials. There was no significant effect of proportion congruency, $F < .1$, and no interaction, $F(1,30) = 1.99$, $p = .17$.

2.3. Discussion

The behavioural results replicate the pattern found in other similar studies using Item-Specific Proportion Congruent (ISPC) manipulations (Bugg, Jacoby, and Chanani (2011); Crump et al., 2006; Jacoby et al., 2003). In particular, the congruency effect was larger for the high proportion congruent condition than for the low proportion congruent condition. This ISPC effect cannot be explained by strategies imposed block-wide because the two proportion congruent conditions were randomly mixed within the same block. To our knowledge this is the first such demonstration using a global/local interference task, and thus it adds to the list of effects that are sensitive to item-specific manipulations of proportion congruent.

The more critical issue addressed here was whether electrophysiological data would indicate that high proportion congruent and low proportion congruent items are processed differently shortly after stimulus onset. Such a finding would be consistent with the online control hypothesis. Indeed, the electrophysiological results indicate that the two categories of proportion congruency (high vs low) are processed differently shortly after stimulus onset, as reflected by systematic amplitude differences in the P1 component. This early component was not at all sensitive to item congruency, implying that the mechanism responsible for this effect is also insensitive to specific item frequency. In other words, particular congruent items that appeared four times more often than particular incongruent items nonetheless produced identical P1 components when the two items belonged to the same proportion congruent condition. It is not clear how an item frequency or simple contingency learning account would handle this result.

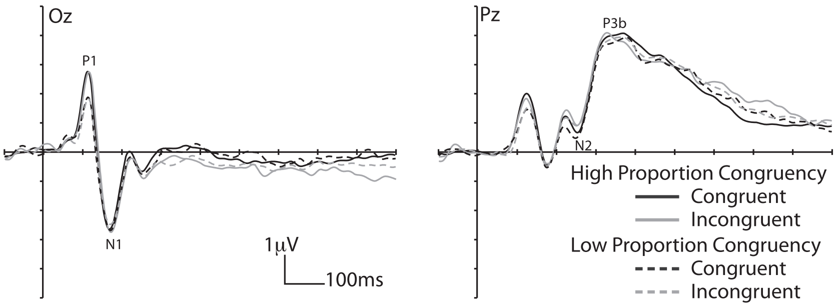

Fig. 1. Experiment 1A grand mean waveforms for Oz and Pz. The P1 at Oz illustrates the early contrast between waveforms elicited by both congruent and incongruent stimuli in the High Proportion Congruency category (mean: 2.45 μV) compared to waveforms elicited by both congruent and incongruent stimuli in the Low Proportion Congruency category (mean: 1.60 μV).

In contrast to the proportion congruency effects observed at the occipital P1, sensitivity to item congruency was detected at later parietal components: N2 (225–275 ms) and late slow wave positivity between 600 and 800 ms. Both of these later components revealed sensitivity to item congruency but not proportion congruency. Together these observations support a hypothesis that upon presentation of an item, detection of the category of the item and subsequent selection of control processes appropriate for that category occur very early, prior to selection and identification of the specific features of the item.

3. Experiment 1B

The results from Experiment 1A suggest that the P1 component is sensitive to differences in proportion congruent. The present experiment aimed to confirm this finding. The method was identical to Experiment 1A, with the exception that both RH and JS stimulus sets were composed of an equal number of congruent and incongruent trials, essentially removing the proportion congruency manipulation. If the proportion congruency effect at P1 was truly due to differences in proportion congruency, then of course re-weighting both letter sets with 50% congruent and incongruent trials should eliminate the amplitude difference at P1.

3.1. Materials and method

3.1.1. Participants

Twenty-eight undergraduate students (mean age 19) from McMaster University participated in this experiment. All participants reported normal or corrected-to-normal vision, and were fluent in English. Each participant gave informed consent to take part in the study, and received partial course credit in return for their participation. Data from six participants were excluded due to excessive eye-blink artifacts and technical issues with ERP collection.

3.1.2. Procedure and stimuli

Apparatus and stimuli were the same as in Experiment 1A. Experiment 1B followed the same procedure as Experiment 1A, except for the manipulation of the proportion of congruent stimuli within "RH" and "JS" stimulus sets. In this experiment, each stimulus set had equal proportions of congruent and incongruent global–local stimuli (50% congruent and 50% incongruent). We maintained the independent variable of Proportion Congruency as a dummy variable for methodological purposes, although the "high" and "low" proportions were the same in this experiment (50% each).

3.1.3. Electrophysiology

We used the same methods and data analyses as in Experiment 1A. In addition, we statistically compared ERP data from Experiments 1A and 1B to more thoroughly assess the proportion congruency manipulation across experiments.

3.2. Results

3.2.1. Behavioural data

Mean response time (ms) for correct responses and accuracy (proportion correct) were analysed as in Experiment 1A. Initial analyses showed letter set ("RH" versus "JS" stimuli) did not produce any significant effects or interactions, and so analyses were again collapsed over this factor. Mean response time and mean accuracy data separated by proportion congruency and trial congruency conditions for Experiment 1B are presented in Table 1. Overall mean response time was 753 ms and mean accuracy was 95.5%.

As in Experiment 1A, response time analysis showed a significant main effect of trial congruency, $F(1,21) = 17.53$, $p < .001$, with faster responses for congruent trials (738 ms) than incongruent trials (767 ms). In contrast with Experiment 1A, there was no interaction of trial congruency with proportion congruency, $F(1,21) = 1.55$, $p = .23$. There was also no main effect of proportion congruency (now a dummy variable), $F(1,21) = 1.08$, $p = .31$. Accuracy data were in accord with response times, with higher accuracy for congruent trials (96.0%) than incongruent trials (95.0%), $F(1,21) = 8.06$, $p < .01$. There was no significant effect of proportion congruency, $F(1,21) = 1.24$, $p = .28$, and no significant interaction, $F(1,21) = 2.62$, $p = .12$.

3.2.2. Electrophysiological data

Fig. 2 shows grand mean waveforms for Oz and Pz electrodes. Inspection of individual participant and grand mean ERP waveforms for Experiment 1B data showed comparable latencies of P1, N1, N2, P3b and Late Parietal Positivity components, and as such we used the same analysis epochs to assess mean amplitude effects for these components using the same ROIs as for Experiment 1A. To better assess the effects of proportion congruency, we directly compared mean amplitude data from Experiments 1A and 1B with mixed-model ANOVAs, with proportion congruency and trial congruency as within-subjects variables, and including Experiment (1A versus 1B) as a between-subjects variable.

3.2.2.1. P1 (Oz ROI; mean amplitude 100–125 ms). For the P1 component, in contrast to the effects of proportion congruency we observed in Experiment 1A, in the present control experiment we observed no effect of proportion congruency on P1 amplitude, $F(1,21) = .57$, $p = .50$. Similar to Experiment 1A, we observed no effects of trial congruency, $F(1,21) = .76$,

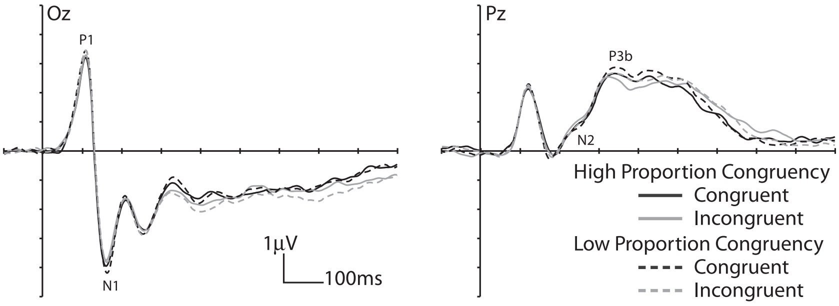

Fig. 2. Experiment 1B grand mean waveforms for Oz and Pz electrode sites.

$p = .39$, and no interaction, $F(1,21) = 1.04$, $p = .32$. Comparing P1 amplitude for the two experiments directly, via ANOVA with an additional between-subjects variable of Experiment, we observed an interaction of proportion congruency with Experiment, $F(1,51) = 5.10$, $p < .05$, with no main effect of proportion congruency, $F(1,51) = 1.60$, $p = .21$, and no other effects or interactions, $F\text{s} < 1$.

3.2.2.2. N1 (Oz ROI; mean amplitude 150–175 ms). In contrast to Experiment 1A, we observed a main effect of trial congruency on N1 mean amplitude, $F(1,21) = 13.97$, $p < .01$, with larger negative N1 mean amplitude for congruent trials ($-3.84\ \mu$V) compared to incongruent trials ($-3.58\ \mu$V). There was no effect of proportion congruency and no interaction, $F\text{s} < 0.7$. Additional ANOVA comparing N1 amplitude effects between experiments showed a main effect of trial congruency, $F(1,51) = 6.01$, $p < .05$, with no significant interaction with Experiment, $F(1,51) = 2.24$, $p = .14$. There was no effect of or interactions with proportion congruency, all $F\text{s} < 1$. A marginal main effect of Experiment, $F(1,51) = 2.81$, $p = .10$, reflected an overall larger negative mean N1 amplitude in the present experiment ($-3.71\ \mu$V) compared to Experiment 1A ($-2.35\ \mu$V).

3.2.2.3. N2 (Pz ROI; mean amplitude 225–275 ms). The N2 component was much less prominent in this present experiment than in Experiment 1A. Analysis of mean amplitude data for the same N2 time epoch showed no effects of trial congruency or proportion congruency, and no interaction, all $F\text{s} < 0.7$. ANOVA comparing data between experiments showed a main effect of trial congruency, $F(1,51) = 4.24$, $p < .05$, akin to Experiment 1A, with no other effects or interactions, all $F\text{s} < 1.4$.

3.2.2.4. P3b (Pz ROI; mean amplitude 300–400 ms). For the P3b component, we observed similar effects to those in Experiment 1A. We observed no significant effect of trial congruency, $F(1,21) = 1.57$, $p = .22$, no significant effect of proportion congruency, $F(1,21) = 2.01$, $p = .17$, and no significant interaction, $F(1,21) = 0.01$, $p = .92$. Comparing amplitude effects directly between Experiments 1A and 1B, we observed no significant main effects or interactions involving trial congruency or proportion congruency, all $F\text{s} < 1.2$. The main effect of Experiment was marginally significant, $F(1,51) = 2.89$, $p = .10$, with larger P3b mean amplitudes overall in Experiment 1A ($3.79\ \mu$V) than in the present Experiment 1B ($2.49\ \mu$V).

3.2.2.5. Late Parietal Positivity (Pz ROI; mean amplitude 600–800 ms). We observed a strong effect of trial congruency, $F(1,21) = 6.57$, $p < .05$, with more extended Late Parietal activity reflected in larger mean amplitudes for incongruent trials ($0.86\ \mu$V) compared to congruent trials ($0.61\ \mu$V). There was no effect of proportion congruency, and no interaction, $F\text{s} < 0.5$. Additional ANOVA comparing effects between experiments showed a strong main effect of trial congruency, $F(1,51) = 10.00$, $p < .01$, no significant interaction of trial congruency and proportion congruency, $F(1,51) = 1.72$, $p = .20$. There was no main effect of proportion congruency and no interactions with Experiment, all $F\text{s} < 1$. The main effect of Experiment was also not significant, $F(1,51) = 1.09$, $p = .30$.

3.3. Discussion

Experiment 1B tested the hypothesis that the early P1 proportion congruency effect observed in Experiment 1A would be eliminated by equating the number of congruent and incongruent trials in the two stimulus sets. For ease of comparing the results, we retained the "high" and "low" proportion congruent labels in the analyses, figures, and tables for Experiment 1B, however, these are essentially dummy variables because the so-called "high" and "low" proportion congruent stimulus sets are the same (50% congruent and 50% incongruent).

The behavioural data revealed an effect of trial congruency; congruent trials produced faster responses and higher accuracy than incongruent trials. As expected, and in contrast to Experiment 1A, there were no effects or interactions involving proportion congruency.

Importantly, the electrophysiological results revealed no effect or interactions involving proportion congruency at P1 (or at any of the components), consistent with our prediction that the early P1 effect apparent in Experiment 1A was due to the proportion congruency manipulation. Coincidentally, Experiment 1B also addresses hypotheses related to possible confounds. For example, hand of response covaries with the proportion congruency manipulation, and one might entertain the hypothesis that the P1 effect reflects early perceptual-motor processes related to selecting hand of response. Experiment 1B maintained this covariation with the letter sets (and all other design characteristics) and altered only the proportion congruency manipulation, essentially ruling out the contribution of these other design elements to the P1 effect in Experiment 1A.

One additional result merits comment. It appears that sensitivity to trial congruency may have emerged slightly earlier in Experiment 1B than in Experiment 1A. In Experiment 1A there was a trial congruency effect at N2 but not at N1. In Experiment 1B, this pattern was reversed, with amplitude differences at N1 but not at N2. Although this result suggests that congruency may be detected sooner when proportion congruency is not manipulated, this conclusion is speculative at this point, as the direct comparison between the two experiments was not significant.

Together, the ISPC results in Experiments 1A and 1B provide support for the online control hypothesis. There is an early and clear distinction between the responses to different categories of stimuli, defined in this set of experiments by proportion congruency of the information presented at the local and global levels of spatially hierarchical stimuli. Behaviourally, we observe the outcome of a control process that implements two different control settings, one which enhances the interference effect for items belonging to the high proportion congruent set, and one which reduces the interference effect for items belonging to the low proportion congruent set. The critical information offered by the ERP measures is that the stimulus set categories are discriminated early upon stimulus onset (100 ms), and earlier than discrimination of item congruency.

4. Experiment 2

The results of Experiments 1A and 1B are consistent with the prediction of the online control hypothesis. To examine this idea further, we examined electrophysiological correlates of the ISPC effect in a second task. The Stroop colour-word task (Jacoby et al., 2003) was an obvious choice for this additional study. Whereas the global–local task may capture interference from one level of spatial hierarchy on another, the standard Stroop task is thought to measure interference caused by automatic word reading processes on colour identification. As the underlying processes that drive interference differ between the global–local and Stroop tasks, it seemed possible that the electrophysiological evidence of online control could differ across tasks. Nonetheless, the online control hypothesis would predict that, although the spatio-temporal locus may differ from that observed with the global–local task in Experiment 1A, there ought to be electrophysiological evidence of discrimination between the two proportion congruency categories prior to discrimination of the items themselves (item congruency or item frequency).

4.1. Materials and method

4.1.1. Participants

Forty-one undergraduate students (35 females, mean age 19) from McMaster University participated 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. Five participants were excluded from further analysis for failure to comply with task instructions, which included participants who did not respond to colour and participants with over 15% errors. An additional five participants were excluded due to excessive eye-blink artifacts and technical issues with ERP collection, leaving a total of 31 participants for subsequent analyses.

4.1.2. Procedure and stimuli

The apparatus used was identical to Experiments 1A and 1B. The stimuli were colour Stroop words presented in Arial font. Individual letters measured 1 cm in height and subtended a visual angle of 0.44°. The words subtended a range of horizontal visual angles from 1.6° (for the word RED) to 2.9° (for the word GREEN). There were two distinct sets of colour word stimuli. One set consisted of the words RED and BLUE presented in the colours red and blue, while the other set consisted of the words BLACK and GREEN presented in the colours black and green.

As in Experiment 1A, within each set there were both congruent and incongruent items, and the relative proportions of congruent and incongruent items varied between the two sets. One set was designated high proportion congruent; items from this set were 80% congruent and only 20% incongruent. The other set was designated low proportion congruent; items from this set were 20% congruent and 80% incongruent. Items from the two sets were intermixed randomly throughout the experiment. The task was to indicate the colour of each word using one of four keys. 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 (counterbalanced across participants).

4.1.3. Electrophysiology

EEG recording and processing of ERP data was conducted as described in Experiment 1A. Data analysis again focused on mean amplitudes for P1 (100–125 ms), N1 (150–175 ms), N2 (225–275 ms), P3b (300–400 ms) and Late Parietal Positivity (600–800 ms) components as for previous experiments, initially at the same Oz (for P1 and N1) and Pz (for P3b and Late Parietal Positivity) regions of interest. Following initial visual inspection of individual participant and grand mean ERP waveforms, we identified maximal P1/N1 ERP component activity localized to the left of our previous midline Oz region of interest, centered over the PO7 electrode region. As such, for the present experiment, we included two additional regions of interest for P1 and N1 component analyses centered on PO7 (left) and PO8 (right) electrode sites, each composed of three electrodes: over left parieto-occipital scalp, PO7, P7, and a third electrode 2 cm anterior to the midpoint of PO7 and PO3 sites (PO7'), and corresponding PO8, P8, and PO8' electrodes over the right parieto-occipital scalp. In addition, the P3b component was observed to have a broader morphology in the present experiment. To better capture potential P3b effects, we included an additional "Extended P3b" analysis epoch (mean amplitude, 400–500 ms).

4.2. Results

4.2.1. Behavioural data

Response time data were analysed in the same manner as previous experiments. A preliminary analysis did not reveal any significant effects involving the between-subject word set factor (RED/BLUE versus GREEN/BLACK as the high proportion congruent set), and therefore subsequent analyses collapsed across this factor. Mean response times for each condition defined by the factorial combination of the proportion congruency and trial congruency factors were submitted to a repeated measures ANOVA. Mean response times and mean accuracy rates for each of these conditions, collapsed across participants, are presented in Table 2. Overall mean response time was 739 ms, and mean accuracy was 95.5%.

Response time analysis revealed a significant main effect of trial congruency, $F(1,30) = 68.46$, $p < .001$, as participants were faster for congruent trials (705 ms) than incongruent trials (773 ms). There was also a significant interaction between proportion congruency and trial congruency, $F(1,30) = 30.28$, $p < .001$, with a significantly larger Stroop congruency effect (incongruent minus congruent mean RT) in the high proportion congruency condition (106 ms) than in the low proportion congruency condition (30 ms). These results constitute a replication of the ISPC Stroop effect reported in previous studies (e.g., Jacoby et al., 2003) .

The accuracy data mirrored the RT data, with no evidence of a speed-accuracy tradeoff. There was a significant main effect of trial congruency; participants were more accurate for congruent trials (96.9%) than for incongruent trials (94.1%), $F(1,30) = 23.85$, $p < .001$. There was also a significant effect of proportion congruent, with participants more accurate overall in the low proportion congruent condition (96.1%) than the high proportion congruent condition (94.9%), $F(1,30) = 4.21$, $p < .05$. The interaction of these two factors was significant, $F(1,30) = 8.70$, $p < .01$, with the congruency effect (accuracy for congruent minus incongruent trials) being larger in the high proportion congruent condition (4.4%) than in the low proportion congruency condition (1.1%).

4.2.2. Electrophysiological data

Fig. 3 shows grand mean waveforms for Oz, PO7, PO8, and Pz electrodes, demonstrating effects of proportion congruency and trial congruency for P1, N1, N2, P3b and Late Parietal Positivity ERP components.

4.2.2.1. P1/N1 at Oz ROI (mean amplitude 100–125 ms, 150–175 ms). Substantial P1 and N1 components were observed at our midline Oz region of interest. No effects of proportion congruency or trial congruency were seen to influence component amplitudes at Oz. The interaction of proportion congruency and trial congruency in P1 amplitude was not significant, $F(1,30) = 2.55$, $p = .12$; all remaining Fs < 0.6.

4.2.2.2. P1 at PO7/PO8 ROIs (mean amplitude 100–125 ms). Substantial P1 components were observed bilaterally, with larger mean P1amplitudes at the PO8 ROI (3.50 μV) compared to the PO7 ROI (1.73 μV), $F(1,30) = 12.66$, $p < .001$. There were no main effects of proportion congruency or trial congruency, Fs < 0.4. The interaction of proportion congruency and hemisphere was not significant, $F(1,30) = 1.72$, $p = .20$, with no other interactions, all other Fs < 1.2.

4.2.2.3. N1 at PO7/PO8 ROIs (mean amplitude 150–175 ms). Substantial N1 components were also observed bilaterally at PO7 (mean −1.51 μV) and PO8 (mean −1.06 μV) ROIs, with the main effect of hemisphere not significant, $F(1,30) = 1.41$, $p = .25$. A main effect of proportion congruency was observed for mean N1 amplitude, with more negative amplitudes for the low proportion congruency condition (−1.43 μV) compared to the high proportion congruency condition (−1.14 μV), $F(1,30) = 4.86$, $p < .05$. There was no main effect of trial congruency, $F(1,30) = 0.19$, $p = .67$. There were no significant interactions of hemisphere with proportion congruency, $F(1,30) = 1.11$, $p = .30$, or with trial congruency, $F(1,30) = 2.66$, $p = .11$, and no three-way interaction, $F(1,30) = 1.40$, $p = .25$. Finally, there was no interaction of proportion congruency and trial congruency,

Table 2
Mean response time and mean accuracy data for Experiment 2. Values in parentheses indicate within-subjects adjusted standard error of the mean.

	Mean response time (ms)		Mean accuracy (% correct)	
	Congruent	Incongruent	Congruent	Incongruent
Experiment 2				
High proportion congruency	682 (8)	788 (11)	97.1 (0.4)	92.7 (0.7)
Low proportion congruency	729 (10)	758 (9)	96.6 (0.4)	95.5 (0.4)

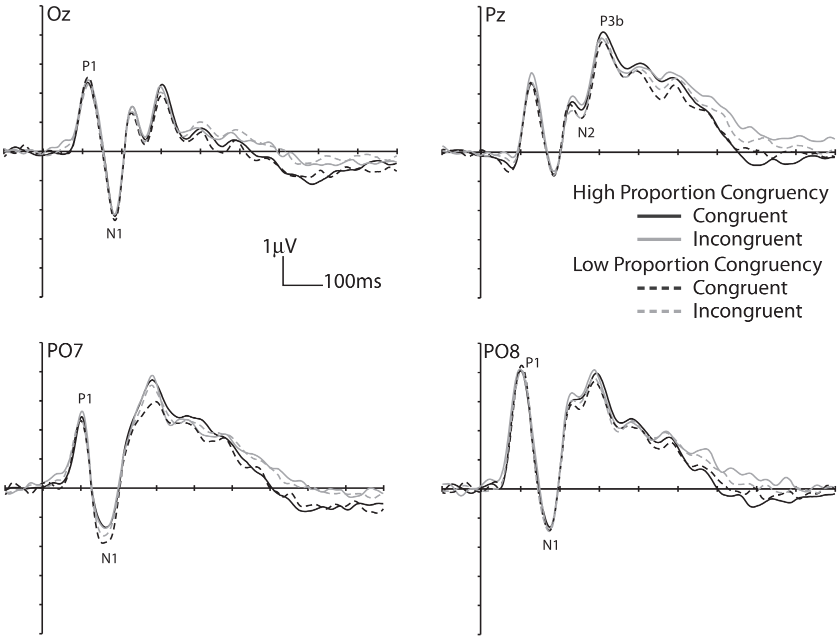

Fig. 3. Experiment 2 grand mean waveforms for Oz, PO7, PO8, and Pz electrode sites.

F(1,30) = 0.82, *p* = .37. To better assess the source of the proportion congruency effect, we analysed PO7 and PO8 ROI data separately. For PO8 data, there was no significant effect of proportion congruency, *F*(1,30) = 1.11, *p* = .30, with no effect of trial congruency and no interaction, *F*s < 0.3. For PO7 data, an effect of proportion congruency was observed, *F*(1,30) = 5.45, *p* < .05, with larger mean negative amplitudes in the low proportion congruent condition (−1.71 μV) compared to the high proportion congruent condition (−1.30 μV). There was no significant effect of trial congruency on N1 amplitude, *F*(1,30) = 1.32, *p* = .26, and no significant interaction, *F*(1,30) = 2.59, *p* = .12.

4.2.2.4. N2 (Pz ROI; mean amplitude 225–275 ms). A notable N2 component was observed in Pz ROI data. N2 mean amplitude was observed to be more negative for the low proportion congruent condition (1.40 μV) compared to the high proportion congruent condition (1.75 μV), *F*(1,30) = 4.57, *p* < .05. There was no effect of trial congruency and no interaction, *F*s < 1.

4.2.2.5. P3b (Pz ROI; mean amplitude 300–400 ms). A discrete maximal P3b component peak was observed. There were no mean amplitude differences for proportion congruency, *F*(1,30) = 1.17, *p* = .29, or trial congruency, *F*(1,30) = 0.80, *p* = .38, and no interaction, *F*(1,30) = 1.91, *p* = .18.

4.2.2.6. Extended P3b (Pz ROI; mean amplitude 400–500 ms). Inspection of grand mean ERP waveforms suggested an extended P3b-like component beyond the early discrete maximal peak, which we assessed separately in this experiment. We observed larger positive sustained mean amplitudes in the high proportion congruent condition (2.69 μV) compared to the low proportion congruent condition (2.32 μV), *F*(1,30) = 6.97, *p* < .05. There was no significant main effect of trial congruency, *F*(1,30) = 2.73, *p* = .11, and no interaction, *F*(1,30) = 0.84, *p* = .37.

4.2.2.7. Late Parietal Positivity (Pz ROI; mean amplitude 600–800 ms). The late positive slow wave over the Pz region of interest showed greater sustained activity for incongruent trials compared to congruent trials, reflected in a main effect of trial congruency, *F*(1,30) = 22.73, *p* < .001. Although there was no main effect of proportion congruency, *F*(1,30) = 0.02, *p* = .90, the interaction was significant, *F*(1,30) = 4.38, *p* < .05. The interaction may reflect a late parietal positivity sensitive to trial frequency; for both proportion congruency conditions, the low frequency stimuli showed larger positive sustained amplitudes than high frequency stimuli. Specifically, in the high proportion congruent condition, sustained amplitudes for the 20% incongruent trials were larger than the 80% congruent trials, and in the low proportion congruent condition, sustained amplitudes for the 20% congruent trials were larger than the 80% incongruent trials.

4.3. Discussion

As for the global–local task in Experiment 1A, the behavioural results from the colour-word Stroop task in Experiment 2 revealed an ISPC effect (Jacoby et al., 2003). Responses were faster and more accurate for congruent trials overall, and the Stroop congruency effect was larger for the high proportion congruency condition than for the low proportion congruency condition.

Moreover, we observed the same temporal order effects in the ERP results, such that sensitivity to proportion congruency was detected earlier than trial congruency. The Stroop task elicited the first proportion congruent effect at the N1 component, slightly later than the P1 effect in the global–local task. The N1 effect in the Stroop task was also left lateralized over parieto-occipital regions. These differences in locus of the proportion congruent effects likely owe to differences in the processes driving performance in the global–local and Stroop tasks. The most important observation for this paper is that there is evidence of discrimination between high and low proportion congruent stimuli (N1, N2) well before we observe differences between congruency of individual trials (late parietal positivity). Our interpretation is that the system quickly identifies the proportion congruent category of the item and then automatically selects and implements control settings appropriate for that category. In the high proportion congruent condition, this selection of a control set favours word reading, and consequently responding is relatively efficient for congruent items, but inefficient for incongruent items.

5. General discussion

The online control account of the ISPC effect was tested in two experiments using ERP techniques to observe the online time course of processing. Converging evidence from a global–local selection task (Experiments 1A and 1B) and a colour-word Stroop task (Experiment 2) supports the flexible online control hypothesis, revealing early sensitivity to the category of stimulus items (high vs. low proportion congruent) before sensitivity to the congruency of the items themselves (whether the specific item was congruent or incongruent).

More specifically, the present results distinguish between two opposing explanations for the ISPC effect. According to the online control hypothesis, the onset of a stimulus item triggers a rapid retrieval of appropriate control processes based on the category of the stimulus, or the context in which that stimulus is most often encountered. Thus, whether the item is congruent or incongruent is not as important to online control as whether the item is part of the class of mostly congruent or mostly incongruent items. An alternative associative learning account of the ISPC effect involves item specific learning based on item frequency. A congruent item from the high proportion congruent set is encountered more frequently than a congruent item from the low proportion congruent set. With practice, faster responses develop for the more frequently seen congruent item. Likewise, the more frequent incongruent items from the low proportion congruent set develop faster responses compared to the other incongruent items. These differences in item specific frequency could lead to the enhanced vs. reduced congruency effects evident in ISPC experiments.

The online control hypothesis and the item frequency hypothesis predict the same pattern of behavioural responses, so they are difficult to tease apart based on behavioural data alone. However, they differ in terms of predictions about online time course of processing, which can be measured electrophysiologically. According to the online control account, the onset of the stimulus triggers a rapid selection of appropriate control processes that should be observed as a distinction between the two stimulus categories at early ERP components. Moreover, this sensitivity to stimulus class should be evident before sensitivity to the congruency of the specific stimulus. The item frequency or contingency learning accounts do not make this prediction; rather, efficiency of processing develops based on specific stimulus frequency and detection of category is not a critical element.

The experiments reported here produced the expected behavioural ISPC effects for both the global–local task (Experiment 1A) and the colour-word Stroop task (Experiment 2). Moreover, the ERP results support the prediction made by the online control account, revealing early processing differences related to stimulus class. The global–local task produced a category sensitive difference between 100 and 125 ms (P1) over a medial occipital region (Oz). Differences in item congruency were not apparent until a later component, between 225 and 275 ms (N2) over medial parietal (Pz). The difference between the categories was driven by the proportion congruency manipulation; when the categories were equated (Experiment 1B; equal number of congruent and incongruent items in each set), the ISPC behavioural effects and the early P1 effect were eliminated.

The colour-word Stroop task produced similar results in terms of the temporal order of sensitivity, although the absolute timing was a little different, likely due to differences in the cognitive demands and perceptual cues involved in the global–local task (e.g. spatial selection) versus the Stroop task (e.g. colour naming and reading). For example, selection of the local letters in the global–local task may involve tuning at early visual processing stages due to feature overlap between local and global letters; similar visual features belonging to local versus global items need to be sorted out at an early stage. In contrast, the critical perceptual cues in the colour Stroop task are the colour of the ink and the word itself; these cues do not have the same feature overlap as the hierarchical letters in the global–local task, and the conflict between opposing processes (colour naming and word reading) may involve tuning at a slightly later visual processing stage. The earliest component to distinguish between high and low proportion congruent categories in the colour-word Stroop task was the N1 (150–175 ms), over a left parieto-occipital region (PO7), followed by the N2 (225–275 ms), and a positive component (400–500 ms) over the medial parietal area (Pz). Similar to the observation at the P1 in the global–local task, these later components in the Stroop task were not sensitive to the congruency of specific items, but only to the category. Congruency of specific items was distinguished across a later slow wave (600–800 ms).

The early cognitive ERP components P1 and N1 reveal potential influences on early visual attention, whereas the later cognitive ERP components are typically sensitive to selective or strategic attentional effects. In both global–local and colour-word Stroop tasks, when categories were defined by the proportion congruency manipulation the sensitivity to category was observed before sensitivity to trial congruency. In general, we might say that when category is not relevant for priming of control processes, control processing relevant to the specific identity of the trial is observed at an early stage. When category is relevant for priming of control processes, discrimination of category differences occurs early, and discrimination of specific trial congruency is not observed until later. Even when the particular task processes result in a later response to category differences, as occurred in the Stroop task, trial congruency discrimination is also later. In each case, stimulus class is discriminated before stimulus identity, supporting the idea that analysis of the category of the stimulus takes precedence over the specific identity of the stimulus. This idea is consistent with behavioural findings that control settings learned through exposure to one set of items can transfer to new items based on shared context or category membership (Bugg & Hutchison, 2013; Bugg et al., 2011; Crump & Milliken, 2009). Participants learn more than contingencies between particular stimuli and associated responses.

Recent evidence to support the precedence of context-specific control processes over stimulus–response contingencies provides an anatomical model. King, Korb, and Egner (2012) provided fMRI evidence for medial superior parietal lobule (mSPL) involvement in context-specific online control processes, and demonstrated functional interactions between mSPL and the early visual regions involved in task processing. Importantly, the mSPL was more sensitive to contextual cues than whether a particular trial was high or low in conflict. According to their interpretation, mSPL is involved in retrieval and execution of the contextually appropriate control settings and this function can be primed by contextual cues (such as the features that mark a stimulus set as high versus low proportion congruent). They demonstrated a tight coupling between mSPL activity and task-relevant visual areas, suggesting a mechanism for rapid, online biasing of sensory processing via context-specific top-down control (King et al., 2012). It is possible that the sensitivity to contextual cues at the early ERP components in the current work reflects this functional coupling between medial parietal regions involved in top-down control and the early visual areas. More work is required to explore the link between the high temporal resolution ERP effects and the high spatial resolution fMRI effects.

6. Conclusion

In conclusion, we have provided electrophysiological evidence for a rapid, online engagement of flexible cognitive control appropriate for a class of stimuli, observed behaviourally as the ISPC effect. Upon onset of a stimulus item, the system quickly identifies the category of the item and automatically selects and implements control settings appropriate for that category. When we acquire skill at a task, we learn more than contingencies between particular items and associated responses. We are able to retrieve and apply appropriate control settings automatically and on the fly in response to contextual cues.

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