On the Automaticity of Semantic Processing during Task Switching

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Abstract

■ There is growing evidence that processes formerly believed to be automatic are, in fact, strongly modulated by top–down influences. The purpose of the present work was to investigate how cognitive control can affect the purported automaticity of word processing by examining the impact of task switching on semantic processing using the ERP technique. In the context of the psychological refractory period dual-task paradigm, two experiments contrasted the context-sensitive N400 ERP elicited by the second of two target words under conditions that involved either a task switch or no-task switch. Although the N400 was not affected by SOA in the absence of switching, it was strongly attenuated at short SOAs when the psychological refractory period procedure involved a switch from a perceptual to a semantic task (Experiment 1) or a switch between two different semantic tasks (Experiment 2). These findings suggest that semantic processing cannot be performed in parallel with task switching and illustrate limitations in the ability of the cognitive system to adapt flexibly to the dynamically changing challenges of the environment according to task demands and behavioral goals. ■

INTRODUCTION

The concept of automaticity is central to many areas of psychology and neuroscience. Classically, a process is said to be automatic when it is independent of top–down control (i.e., attention, task set, action goals, and intention), is not capacity-limited and thus can function in parallel with other processes without interference, and is executed unconsciously (e.g., Schneider & Shiffrin, 1977; Posner & Snyder, 1975). According to this classical view of automaticity, automatic processes are initiated regardless of the actual configuration of the cognitive system whereas cognitive control is restricted to conscious processing. Numerous demonstrations of behavioral (see Neely, 1991) and electrophysiological (e.g., Kiefer, 2002; Deacon, Hewitt, Chien-Ming, & Nagata, 2000) semantic priming effects for masked (i.e., unconsciously perceived) prime words have led researchers to conclude that semantic processing is triggered automatically. However, subsequent work showed that such semantic priming effects can be affected by attentional factors, such as temporal attention (e.g., Kiefer & Brendel, 2006), attentional capacity (e.g., Martens & Kiefer, 2009), and task sets (e.g., Martens, Ansorge, & Kiefer, 2011), casting doubts on the automaticity of semantic processing. These seemingly paradoxical findings can be accommodated by assuming that automatic processing is dependent on top–down attention. In fact, refined theories of automaticity propose that semantic processing is automatic in the sense that it can be initiated uncon-

sciously and without intention but is nevertheless susceptible to top–down control and may depend on the way the cognitive system is configured (e.g., Kiefer, 2007; Naccache, Blandin, & Dehaene, 2002). In this article, we suppose this more flexible conception of automaticity.

To account for higher-level cognitive influences on automatic processing, Kiefer and Martens (2010) recently put forward the attentional sensitization model, which postulates that automatic processing relies on attentional sensitization by currently active task sets. In fact, the actual configuration of the cognitive system is claimed to enhance selectively the sensitivity of task-relevant pathways while attenuating that of task-irrelevant pathways. Such top–down regulation of neuronal activity "is assumed to orchestrate the conscious and unconscious information processing streams in congruency with the current task representations" (Kiefer & Martens, 2010, p. 467). When applied to semantic processing, the model states that processing of semantic information will be mediated by whether a previous mental activity required the activation of semantic processing pathways or not. More specifically, automatic semantic processing should be enabled if a semantic task set was previously established but attenuated if a previous task activated, for example, a perceptual task set.

Accordingly, the execution of semantic processing is expected to be particularly sensitive to situations where the actual configuration of the cognitive system (i.e., the task set) must be changed to adapt to new cognitive demands, such as in the case of task switching. Hence, the attentional sensitization model might also provide an explanation of

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the costs that are typically associated with task switching. The literature on task switching shows that people are usually slower and less accurate on task-switch trials than on task-repetition trials (see Monsell, 2003). Such interference, called *switch cost*, is often assumed to persist until a reconfiguration of the task set is completed to fit the cognitive requirements of the new task (e.g., Gilbert & Shallice, 2002; Rogers & Monsell, 1995). In the context of the attentional sensitization model, this switch cost would ensue from the desensitization of the processing pathways associated to the first task. On repeated trials, no cost would be observed because of the sensitization of the processing pathways associated with the execution of the first task. The objective of this study was to put the attentional sensitization model to the test by examining how semantic processing is affected in the context of task switching. To do so, we combined the ERP technique, which provides direct continuous indicators of semantic processing, with the psychological refractory period (PRP) paradigm, a dual-task paradigm in which task switching can be manipulated.

The attentional sensitization model predicts that in a dual-task setting, switching from a perceptual task to a semantic task should impair semantic processing for the second task, at least until a new semantic task set is established. This prediction was supported by behavioral (Vachon, Tremblay, & Jones, 2007) and electrophysiological evidence (Vachon & Jolicœur, 2011) that, in the context of the attentional blink (AB) paradigm—in which two targets are presented in close succession in a rapid serial visual presentation (Raymond, Shapiro, & Arnell, 1992)—semantic priming of the second target was strongly reduced at short target intervals when a perceptual judgment (e.g., comparing the physical similarity of two characters) had to be performed on the first target. These studies revealed no such semantic impairment when the same semantic judgment was carried out on both targets or when the two targets were separated by a long time interval. Such findings demonstrate that switching from a perceptual task to a semantic task hinders semantic processing for the second task, at least until a semantic task set is established. The model makes another prediction, which remains to be tested: Switching from a semantic task to another (i.e., different) semantic task should not disrupt semantic processing of the second task because the semantic processing pathways are enhanced by the activation of a matching task set for the first task. This study was designed to test these two predictions, that is, to examine whether the susceptibility of semantic processing to task switching is modulated by the nature of the tasks to be performed.

We investigated semantic processing using ERPs because they provide a sensitive measure of real-time stimulus processing at various underlying stages of processing. Of course, we also recorded behavioral performance, which provided sensitive information reflecting the output of the complete processing chain. One especially useful electrophysiological measure of semantic processing is the N400 component, a negative potential deflection that peaks at centroparietal electrode sites around 400 msec after the onset of words that violate semantic expectancy (Kutas & Hillyard, 1980). The amplitude of the N400 varies as an inverse function of the association of the word with a pre-established semantic context (i.e., larger N400 for less associated concepts; Kutas & Hillyard, 1984). For instance, the word *dog* would elicit a larger (i.e., more negative) N400 if preceded by the context word *flower* than if preceded by the context word *animal*. Although the exact functional significance of the N400 is still a matter of debate—it could reflect the process of semantic integration into the preceding context (Brown & Hagoort, 1993) or the access to lexical representations in long-term memory (Lau, Phillips, & Poeppel, 2008)—the presence of an N400 provides a definitive indication that the word has been identified with sufficient precision to be affected by the degree of semantic relation with the established meaning context. As such, there is good reason to believe that the N400 reflects processing necessary for meaning extraction. An absence of the N400, on the other hand, would suggest some disruption of the lexical and semantic processes, leading up to the extraction of meaning and the comparison with the current semantic context. If processing to meaning is fully automatic in the sense of the classical view of automaticity, then all processes up to and including semantic activation must be automatic, and this should be reflected by an invariant N400 response under a wide variety of semantic contexts and multitasking demands (e.g., Vogel, Luck, & Shapiro, 1998).

In this study, we extended the approach used by Vachon and Jolicœur (2011) in the context of the AB paradigm to the PRP paradigm. Vachon and Jolicœur contrasted the N400 evoked by the second of two targets in the AB, with and without task switching. In the present work, using the PRP paradigm, two target stimuli were presented in rapid succession, separated by varying stimulus onset asynchronies (SOA), and participants were required to perform a speeded task on each target (see Pashler, 1994, for a review). Typically, RT for the second task increases as SOA decreases. This slowing of the second response is often referred to as the PRP effect. The PRP effect is thought to reflect capacity limitations that create a processing bottleneck at central stages of processing such as response selection (see Lien & Proctor, 2002; Pashler, 1994; Pashler & Johnston, 1989). According to this central bottleneck account, perceptual, response execution, and any automatic (e.g., semantic) processes can proceed in parallel with any other stages while central stages operate only in a serial fashion. So, at short SOAs, Task 2 central operations must wait for the completion of Task 1 central operations, creating a period of "cognitive slack" between perceptual and central stages of Task 2 during which no useful processing takes place. This holds for very easy tasks as well as for tasks with no apparent sensory and/or response conflicts (see Lien & Proctor, 2002).

We specifically opted for the PRP paradigm to fulfill another purpose. In studying the automaticity of word

processing, Lien, Ruthruff, Cornett, Goodin, and Allen (2008) found that the N400 was strongly attenuated for Task 2 words presented during the PRP (see also Hohlfeld, Sangals, & Sommer, 2004). The authors concluded that, in contrast to the classical view of automatic processing, semantic processing requires central attention and, consequently, cannot be carried out in parallel with other central operations. However, in these studies, as in many other PRP studies (see Lien & Proctor, 2002), the passage from Task 1 to Task 2 involved a shift of sensory modality and task/response requirements. Vachon and Jolicœur (2011) demonstrated that, in the AB phenomenon, which is sometimes claimed to reflect overlapping central bottleneck mechanisms as for the PRP effect (e.g., Ruthruff & Pashler, 2001; Jolicœur & Dell'Acqua, 1998), the N400 elicited by the second target was attenuated exclusively in the presence of task switching. Hence, it is possible that the Task 2 N400 modulations obtained by Lien et al. (2008) and Hohlfeld et al. (2004) were mediated by task-switching interference instead of by central attention devoted to Task 1 processing. Yet another goal of this study was to determine whether semantic processing is still affected by limitations to central attention when potential task-switching effects are controlled for.

We examined, in two PRP experiments, the N400 elicited by Task 2 words under switch and no-switch conditions. A context word was presented before each trial, and participants were asked to judge whether the Task 2 word (T2) was related or not to the context word. To isolate the T2-evoked N400 from the ERP response triggered by the Task 1 stimulus (T1), the EEG signal elicited in T2-related trials was subtracted from that elicited in T2-unrelated trials. In the absence of switching, the same semantic judgment was performed on both T1 and T2. In the presence of switching, a task switch was induced by requiring participants to carry out a perceptual judgment on T1 (Experiment 1) or a semantic judgment on T1, different from the one to be performed on T2 (Experiment 2). The attentional sensitization model predicts that the shift from a perceptual to a semantic judgment in Experiment 1 will hinder (i.e., attenuate and/or delay) the T2-evoked N400 at short SOAs because the perceptual task set established for Task 1 would momentarily desensitize the semantic processing pathways necessary to perform Task 2. In Experiment 2, however, no such disruption of the N400 is expected by the model in the switch condition because executing a semantic Task 1 should enhance the activation of the semantic processing streams required for the semantic Task 2, regardless of the nature of semantic judgments to be performed. Although our primary focus is on the N400 elicited by T2, we also looked at the N400 to T1, and we examined behavioral measures for both targets.

EXPERIMENT 1

In Experiment 1, the methodology used by Vachon and Jolicœur (2011) was adapted to the PRP paradigm to test

(1) whether switching from a perceptual to a semantic task in a dual-task setting different from the AB paradigm can impair semantic processing for the second task and (2) whether semantic processing, as indexed by the N400, is affected by the PRP phenomenon. Each target stimulus was composed of a word surrounded by two larger characters (see Figure 1). In the switch condition, Task 1 was a digit comparison judgment on these surrounding digits, whereas Task 2 was a judgment on the semantic relation between the T2 word and the context word presented at the beginning of the trial. In the no-switch condition, participants performed this later semantic judgment on both T1 and T2, ignoring the surrounding digits. To avoid any sensory interference (e.g., masking) between the two targets, they were displayed at different locations; T1 always appeared above fixation, followed after an SOA of 100, 300, or 700 msec by T2, which was always displayed below fixation (see Figure 1).

Methods

Participants

Nineteen neurologically normal university students (10 men; mean age = 21.5 years) who reported normal or corrected-to-normal vision took part in the experiment for financial compensation. All were French native speakers.
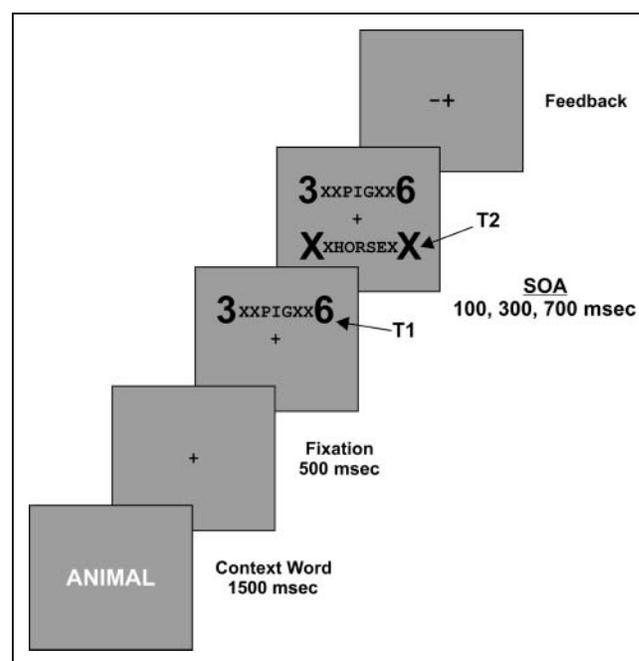

Figure 1. Schematic representation of the trial sequences used in Experiment 1. All stimuli appeared in black on a light gray background except the context word that was presented in light blue. The Task 1 stimulus (T1) always appeared above fixation, followed after a various SOA by the Task 2 stimulus (T2), which was always presented below fixation.

Stimuli

The stimuli were all generated by a computer running E-Prime 1.2 and were displayed on a 17-in. color monitor. The two target stimuli were composed of a seven-character central string surrounded by two bigger characters located at each extremity of the string (Figure 1). At a viewing distance of 60 cm, the height of string characters was 0.3° and the height of surrounding characters was 0.6°. The whole stimulus subtended a visual angle of 3.2° in width. The central string of each target was a word of three to seven uppercase letters. Words less than seven letters long were flanked by Xs to create a seven-character string, thereby equating low-level sensory responses for all stimuli (e.g., Vogel et al., 1998). The characters surrounding T1 were always two digits, either identical or different, randomly selected from the set 1–9. The characters surrounding T2 were either two Os or two Xs. T1 was always displayed above the fixation cross, whereas T2 always appeared below fixation. The center-to-center separation of the two targets was 0.9°. All stimuli were displayed in black on a light gray background.

The target word list was identical to that employed in Vachon and Jolicœur (2011). The list consisted of 360 French words equally distributed among 30 categories, so that there were 12 exemplars in each category. Each word constituted a good category exemplar and was common in French (e.g., *apple* in the category FRUIT).

Design and Procedure

Participants initiated a trial by pressing the spacebar of the computer keyboard. As shown in Figure 1, each trial began with the presentation of a context word, displayed in light blue for 1500 msec, followed by a 500-msec black central fixation cross. Then, T1 appeared above fixation followed by T2 below fixation, after an SOA of 100, 300, or 700 msec. Both targets remained on the screen until the participant had responded both in Task 1 (a judgment performed on T1) and in Task 2 (a judgment performed on T2). Participants were asked to respond to Task 1 before Task 2 and to respond to both tasks quickly and accurately. Half of the participants responded to Task 1 using their left index and middle fingers and to Task 2 using their right index and middle fingers whereas the other half did the opposite. Following the response to Task 2, feedback was provided in the form of two signs; the left one indicating Task 1 accuracy and the right one indicating Task 2 accuracy (see Figure 1). A "+" sign indicated a correct response, whereas a "−" sign indicated an incorrect response. If, at 4000 msec after the onset of T2, no response was recorded for Task 2, the target stimuli were replaced on the screen by the feedback signs. The "|" sign was displayed when no response was recorded for a particular target within the allotted time.

In the no-switch condition, Task 1 and Task 2 were identical. Participants had to indicate for Task 1 whether the T1 word was related or not to the context word and then to indicate for Task 2 whether the T2 word was related or not to the context word. In the switch condition, Task 1 was to indicate whether the two digits surrounding T1 were identical or different, whereas Task 2 was to judge whether the T2 word was related or not to the context word. Hence, the two switching conditions only differed in Task 1 instructions. For responses produced with the left hand, participants had to press the z key if the target word was related to the context word or if the surrounding digits were identical and the x key if the target and context words were unrelated or if the surrounding digits were different. For responses produced with the right hand, participants pressed the n key for the related/identical response or the m key for the unrelated/different response.

For each switching condition, participants performed three blocks of 120 experimental trials, preceded by 24 practice trials. Half of the participants started with the no-switch condition. Within each block, the semantic relation between the context word (a category label) and the target words (category exemplars) was manipulated so that T1 and T2 could be independently a member of the context category (i.e., related) or not a member (i.e., unrelated). This manipulation yielded four equiprobable conditions forming a 2 × 2 design with context–T2 relation crossed with context–T1 relation. Word triplets—the context word, T1, and T2—were selected in a pseudorandom fashion so that each exemplar of the word list served equally often as T1 and T2 and occurred in every semantic-relation trial type. When both target words were related to the context word, T1 and T2 were, by definition, related to each other. Within the quarter of trials in which the two targets were not related to the context word, the T1 and T2 words were related to each other in half of the trials and unrelated in the other half. Consequently, the presence of a semantic relationship between T1 and T2 was not sufficient to determine how to respond in either task. Semantic relation type and SOA varied randomly from trial to trial in each block.

Because the semantic relation between the target words and the context word served as the basis for the behavioral responses, the context–target relation factors cannot be included in the analysis of the behavioral data without introducing possible response-bias effects. Consequently, proportion of errors and mean RT were each examined through a 2 × 3 repeated measures ANOVA[1] with switching condition (switch vs. no switch) and SOA (100, 300, and 700 msec) as within-subject factors.

Electrophysiological Recordings and Analyses

EEG activity was recorded using a BioSemi ActiveTwo (Amsterdam, Netherlands) system at a sampling rate of 256 Hz. The location of each of the 64 Ag–AgCl electrodes mounted on an elastic cap followed the International 10–10 system. Five additional electrodes were placed on the

left and right mastoids, on the left and right outer canthi, and below the left eye. EEG signals were re-referenced off-line to the average of the left and right mastoids and then band-pass filtered (0.01–40.0 Hz). The horizontal EOG, recorded as the voltage difference between the two canthi electrodes, was used to measure horizontal eye movements. The vertical EOG, recorded as the voltage difference between two electrodes placed above (Fp1) and below the left eye, was used to detect eye blinks. EOG signals were low-pass filtered at 5 Hz to facilitate the artifact rejection process. Trials containing ocular artifacts (blinks, eye movements) were discarded.

EEG signals were analyzed separately for each target. On the basis of the scalp distribution of the N400 response, we focused on measurements obtained at central (C3, Cz, and C4) and parietal electrodes (P3, Pz, and P4). The average ERP waveforms in all conditions were computed time-locked to the onset of each target and included a 200-msec prestimulus baseline. The N400 evoked by T2 was isolated by subtracting the ERP waveforms on T2-related trials from the ERP waveforms on T2-unrelated trials, whereas the N400 elicited by T1 was extracted by subtracting the ERP waveforms on T1-related trials from the ERP waveforms on T1-unrelated trials. Note that any potential effects of the relation (1) between the two targets and (2) between the other target and the context word on the N400 triggered by either of the targets were controlled by equating the number of trials in which these stimuli were related and unrelated across the relevant target-relation conditions. The magnitude of the N400 was quantified as the mean amplitude of the difference waves over a 350–600 msec post-target time window. For both T1 and T2, the N400 amplitude was submitted to the same 2 × 3 repeated measures ANOVA as for behavioral data to which the within-subject factor Electrode Site (C3, Cz, C4, P3, Pz, and P4) was added. However, unless otherwise stated in a footnote, the main and interaction effects involving the electrode site factor were not significant.

For latency estimates of the N400, where appropriate, the onset latency of all N400 waves was calculated using a jackknife-based method (see Kiesel, Miller, Jolicœur, & Brisson, 2008; Ulrich & Miller, 2001). We used the ERP signals averaged across target electrodes sites (C3, Cz, C4, P3, Pz, and P4), smoothed using an additional 5-Hz low-pass filter, using the time at which the N400 compound reached 50% of its maximum amplitude, starting at 250 msec after T2 onset. The resulting N400 latencies were analyzed according to the switching condition by SOA design and resulting F and t values were corrected (F_c and t_c, respectively) according to the procedure described by Ulrich and Miller (2001).

Results

Data from practice blocks were not analyzed. In addition, trials in which an error was made on either Task 1 or Task 2 were excluded from all analyses. Trials associated with extreme RT values (2% at each extreme of the percentile distribution for each participant in each condition) were also removed.

Behavioral Data

Errors. Table 1 presents mean proportions of errors for Task 1 and Task 2 in each condition. The ANOVA performed on Task-1 errors showed that performance was slightly better for the perceptual task (switch condition) than for the semantic task (no-switch condition), $F(1, 18) = 16.83$, $p < .001$. Whereas Task 1 errors decreased significantly with SOA, $F(2, 36) = 3.05$, $p < .06$, the interaction was not significant, $F(2, 36) = 0.96$, $p > .40$. When applied to Task 2 errors, the same ANOVA showed significant effects of Switching Condition, $F(1, 18) = 13.00$, $p < .002$, and SOA, $F(2, 36) = 4.65$, $p < .016$, indicating that performance was higher in the no-switch than in the switch condition

Table 1. Proportion of Errors for Task 1 and Task 2 (*SEM*, in Parentheses) as a Function of Switching Condition and SOA in Experiments 1 and 2

	Experiment 1			Experiment 2		
	SOA			*SOA*		
	100	*300*	*700*	*150*	*300*	*700*
Task 1						
Switch	.027 (.006)	.035 (.007)	.021 (.005)	.074 (.009)	.051 (.008)	.054 (.008)
No Switch	.067 (.012)	.062 (.008)	.052 (.005)	.075 (.011)	.063 (.007)	.051 (.007)
Task 2						
Switch	.119 (.014)	.093 (.009)	.102 (.011)	.100 (.009)	.091 (.008)	.084 (.008)
No Switch	.080 (.011)	.069 (.008)	.068 (.009)	.078 (.008)	.084 (.008)	.060 (.008)

and at an SOA of 300 msec relative to 100 msec. The interaction was not significant, $F(2, 36) = 0.84, p > .43$.

RTs. Mean RTs for Task 1 and Task 2 are plotted in Figure 2 as a function of switching condition and SOA. The ANOVA performed on Task 1 RTs showed no significant effects ($ps > .146$). The same ANOVA performed on Task 2 RTs revealed that RTs were longer in the switch than in the no-switch condition, $F(1, 18) = 16.22, p < .001$. The significant effect of SOA, $F(2, 36) = 482.89, p < .001$, the signature of the PRP effect, confirmed that RTs decreased as SOA increased. Most importantly, the interaction was significant, $F(2, 36) = 4.04, p < .027$, reflecting a larger PRP effect in the switch (470 msec) than in the no-switch condition (417 msec). Indeed, this interaction arose because the effect of switching condition (i.e., the difference between switch RTs and no-switch RTs) was smaller at 700 msec compared with 100 msec and 300 msec ($ps < .036$). These results are consistent with previous studies showing larger PRP effects in the presence than in the absence of task switching (e.g., Oriet & Jolicœur, 2003; Logan & Gordon, 2001).

ERP Data

N400 amplitude. The ERP results for T1 are summarized in Figure 3. Figure 3A shows the T1 difference waveforms for Cz, Pz, and the pooling of target electrode sites, and Figure 3B shows the mean T1-evoked N400 amplitude for each condition. The ANOVA carried out on the mean amplitude of the T1-evoked N400 revealed that the N400

Figure 2. Behavioral results of Experiment 1. Mean RT for Task 1 and Task 2 as a function of switching condition and SOA. Errors bars represent 95% within-participant confidence intervals.

was larger in the no-switch than in the switch condition, $F(1, 18) = 46.56, p < .001$. There was virtually no N400 in the switch condition, because the mean voltage amplitude within the N400 temporal window did not significantly differ from zero at any SOA in that condition ($ps > .21$). These findings suggest that semantic processing of T1, if any, was seriously restricted in the switch condition, in which Task 1 was perceptual in nature, despite the fact that T1 word was presented at fixation (see also Vachon & Jolicœur, 2011). None of the remaining effects were significant ($ps > .13$).

The ERP results for T2 are summarized in Figure 4. Figure 4A shows the T2 difference waveforms for Cz, Pz, and the pooling of target electrode sites and Figure 4B shows the mean T2-elicited N400 amplitude for each condition. The ANOVA performed on the mean amplitude of the T2-evoked N400 revealed that the N400 was larger in the no-switch than in the switch condition, $F(1, 18) = 4.5, p < .049$. Overall, the N400 amplitude significantly decreased with SOA, $F(2, 36) = 15.8, p < .001$. More importantly, the interaction between switching condition and SOA was significant, $F(2, 36) = 5.41, p < .009$. The decomposition of this interaction showed that the effect of SOA was significant in both the switch, $F(2, 36) = 10.56, p < .001$, and the no-switch condition, $F(2, 36) = 13.49, p < .001$, but that these two conditions showed a different SOA pattern (see Figure 4). In the switch condition, the N400 amplitude was lower at 100 and 300 msec relative to 700 msec ($ps < .001$), whereas it was lower at 100 msec compared with 300 and 700 msec in the no-switch condition ($ps < .005$). In fact, the N400 amplitude at 100 msec in the two switching conditions and at 300 msec in the switch condition did not significantly differ from 0 μV ($ps > .41$). Further decomposition of the switching condition by SOA interaction showed that the N400 elicited at 300 msec was larger in the no-switch than in the switch condition, $t(18) = 3.65, p < .002$, whereas no such a difference was found at 100 and 700 msec ($ps > .10$).[2]

N400 latency. Although analysis of the amplitude revealed no N400 for T2 in the 100 msec SOA condition in both switching conditions and at 300 msec in the switch condition within a 350–600 msec post-T2 window, Figure 4A shows a late T2-evoked negativity in these conditions. To assess whether these negativities might reflect a delayed N400, we proceeded in two steps. First, we calculated the mean amplitude averaged across target sites in a time window that was selected based on visual inspection of the waveforms in Figure 4A and contrasted this amplitude against zero. We found a significant N400-like effect in the 100-msec SOA condition in the no-switch condition within a 650–900 msec interval, $M = -0.95$ μV, $SE = 0.38, t(18) = 2.47, p < .024$, in the 100-msec SOA condition in the switch condition between 600 and 850 msec, $M = -0.76$ μV, $SE = 0.35, t(18) = 2.17, p < .044$, and the 300-msec SOA condition in the switch condition in a 475–725 msec window, $M = -0.66$ μV, $SE = 0.29, t(18) = 2.24$,

Figure 3. Task-1 ERP results of Experiment 1. (A) Grand-averaged ERP unrelated–related difference waveforms at central (Cz), parietal (Pz), and pooled target electrodes sites (i.e., C3, Cz, C4, P3, Pz, and P4) as a function of switching condition and SOA (100, 300, and 700 msec). (B) Mean amplitude, in microvolts (μV), of the N400 as a function of switching condition and SOA. Mean amplitude measurements were based on the mean voltage of the unrelated–related difference wave over a 350–600 msec post-T1 time window averaged across all electrodes sites. Errors bars represent 95% within-participant confidence intervals.
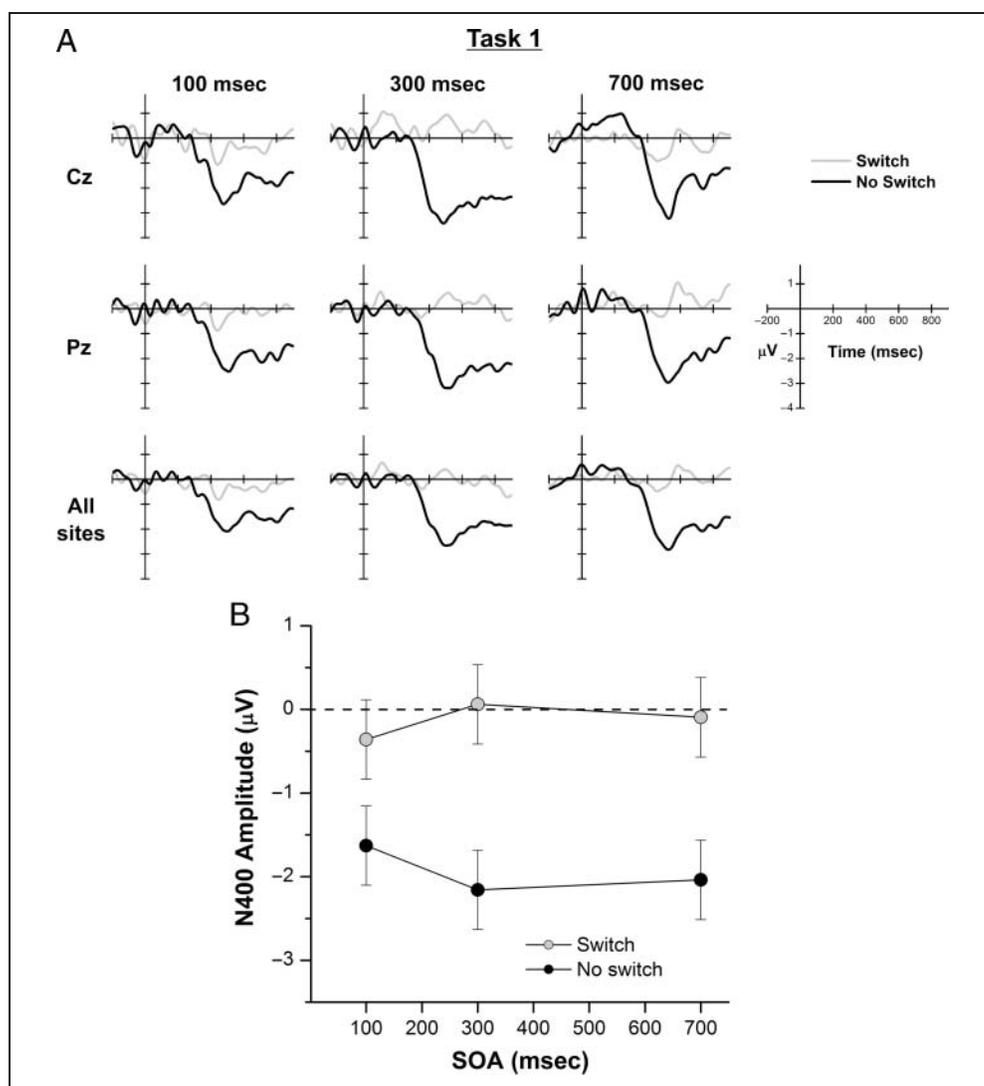
$p < .04$. Also, the scalp distributions of the unrelated–related difference waves displayed in Figure 5 reveal for each of these three intervals a centroparietal pattern of negative activation rather consistent with that of a typical N400. Then, to provide further evidence that these N400-like negativities were indeed delayed compared with the other conditions, N400 latencies were contrasted across the six conditions using the jackknife method. The resulting mean latencies are listed in Table 2. The ANOVA revealed no effect of switching condition, $F_c(1, 18) = 0.19, p > .67$, but the N400 latency decreased with SOA, $F_c(2, 36) = 11.28, p < .001$. Although the interaction was not significant, $F_c(2, 36) = 1.86, p > .17$, we nonetheless decomposed it because we suspected the nonsignificant interaction to be due to the high variability observed at 100 msec SOA in the switch condition. In fact, although the latency at 100 msec SOA appeared to be longer in the no-switch than in the switch condition, the difference was not significant ($p > .16$). However, the N400 latency was longer in the switch than in the no-switch condition at

300 msec SOA, $t_c(18) = 2.68, p < .008$, whereas no latency difference was found at 700 msec SOA ($p > .36$).

Discussion

When switching from a perceptual task to a semantic task, the N400 elicited by T2 was strongly attenuated and delayed if T2 appeared after an SOA of 100 or 300 msec after T1. This result extends Vachon and Jolicœur's (2011) findings from the AB to the PRP paradigm and suggests that semantic processing is impaired during task switching (see also Vachon et al., 2007). This result is inconsistent with the classical view of automaticity, which postulates that automatic processes do not depend upon top–down influences, such as task sets. However, such a finding was expected from an attentional sensitization point of view (Kiefer & Martens, 2010), according to which the sensitivity of semantic processing pathways decreases when previous mental activity involved no semantic processing. Yet, a delayed and attenuated N400 was also found at an

Figure 4. Task 2 ERP results of Experiment 1. (A) Grand-averaged ERP unrelated–related difference waveforms at central (Cz), parietal (Pz), and pooled target electrodes sites (i.e., C3, Cz, C4, P3, Pz, and P4) as a function of switching condition and SOA (100, 300, and 700 msec). (B) Mean amplitude, in microvolts (μV), of the N400 as a function of switching condition and SOA. Mean amplitude measurements were based on the mean voltage of the unrelated–related difference wave over a 350–600 msec post-T2 time window averaged across pooled target electrodes sites. Errors bars represent 95% within-participant confidence intervals.
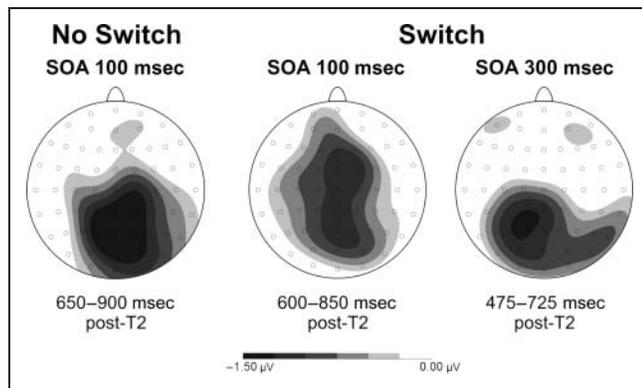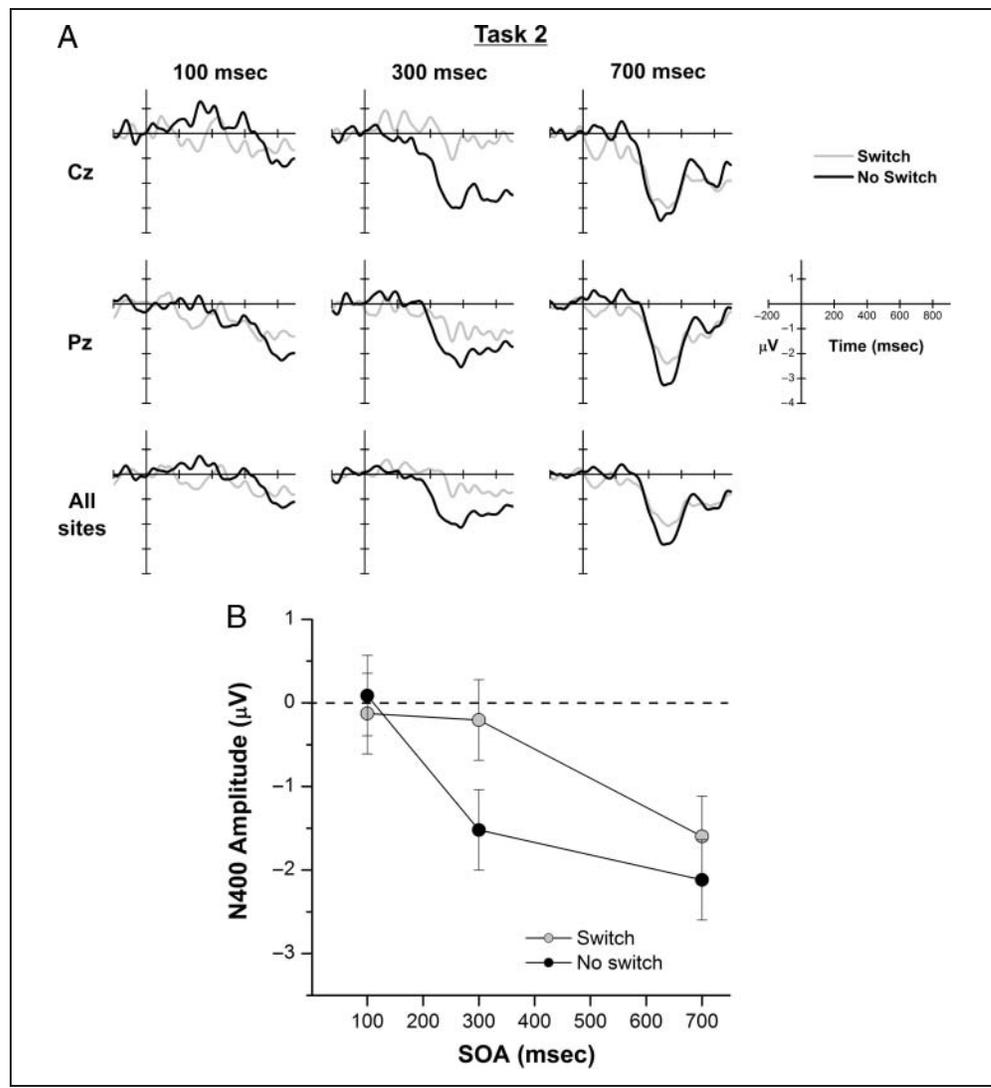
Figure 5. Results from Experiment 1. Scalp topography of the unrelated–related difference waveforms, in microvolts (μV), for Task 2 stimulus (T2) over the 650–900 msec post-T2 time window at 100 msec SOA in the no-switch condition, over the 600–850 msec post-T2 time window at 100 msec SOA in the Switch condition, and over the 475–725 msec post-T2 time window at 300 msec SOA in the switch condition.

SOA of 100 msec in the absence of switching, which is incompatible with the model. This result replicates those of Lien et al. (2008) and, consequently, supports their conclusion that semantic processing requires central attention. However, this N400 modulation found in the no-switch condition may have ensued from the need to shift between two different spatial locations. In the AB literature, a location switch is usually considered as a particular form of task switching (see Visser, Bischof, & Di Lollo, 1999), and its effects on target processing are similar to those of a nonspatial task switch (e.g., Vachon et al., 2007; Kawahara, Zuvic, Enns, & Di Lollo, 2003). Moreover, there is electrophysiological evidence that, when attention is focused in a particular spatial location, perceptual and semantic processing is temporarily disrupted for stimuli presented at other locations (e.g., Luck, Fan, & Hillyard, 1993; McCarthy & Nobre, 1993; Mangun & Hillyard, 1991). For instance, McCarthy and Nobre (1993) failed to obtain an N400 for words presented at an unattended location.

Table 2. Mean Latencies (in msec) of the T2-elicited N400 Averaged across All Electrodes (*SEM*, in Parentheses) as a Function of Switching Condition and SOA in Experiments 1 and 2 (Calculated in Jackknife Averages)

| | Experiment 1 | | | Experiment 2 | | |
| | SOA | | | SOA | | |
	100	300	700	150	300	700
Switch	566.47 (7.29)	501.09 (1.84)	385.05 (1.19)	–	–	369.80 (1.23)
No Switch	714.31 (2.40)	411.02 (1.44)	369.09 (0.95)	361.95 (1.51)	387.19 (0.80)	357.85 (0.73)

Thus, it is plausible that, at an SOA as short as 100 msec, attention was still focused at the T1 location when T2 was displayed, preventing momentarily the semantic processing of T2 even in the absence of a task switch. This issue was addressed in Experiment 2.

EXPERIMENT 2

In this experiment, we examined whether the nature of the task switch influences subsequent processing. According to the attentional sensitization model, it does: Processing is enhanced in pathways congruent with a previously established task set but attenuated in pathways incongruent with that task set (Kiefer & Martens, 2010). Accordingly, if the switch between Task 1 and Task 2 had occurred entirely within the semantic domain in Experiment 1, no disruption of semantic processing should have been observed. To test this prediction, participants were asked to perform two different semantic tasks in the switch condition: Whereas Task 2 was still to judge the semantic relation between T2 and the context word, Task 1 was to classify T1 as a natural or man-made object. This object classification task should entail the establishment of a semantic task set in the same way as the semantic relation judgment. In the no-switch condition, the same semantic task—that is, the target–context relation judgment—applied to both T1 and T2. Because all the tasks used in Experiment 2 required to process exclusively words, all surrounding and flanker characters were omitted from the target stimuli (see Figure 6). The location switch between T1 and T2 was removed by presenting both targets successively at the center of the screen. To reduce potential masking effects of one target to the other, the shortest SOA was extended from 100 to 150 msec.

Methods

The method was identical to that employed in Experiment 1, except as noted below.

Participants

Twenty new participants (eight men; mean age = 23.2 years) took part in the experiment.

Stimuli and Procedure

To fulfill the requirements of the new semantic object classification Task 1 of the switch condition, word categories were limited to those corresponding to either natural objects (e.g., FRUIT) or man-made objects (e.g., BUILDING). Consequently, the number of categories was reduced from 30 to 24. To compensate for the resulting loss of words, we increased the number of exemplars in each of the remaining categories from 12 to 14.

Each target was a word with no filling flankers or surrounding characters (see Figure 6). All stimuli were presented in the center of the screen. Each trial began with the presentation of a context word for 1500 msec, followed by a fixation cross. After 500 msec, the fixation cross was replaced by T1, which remained on the screen for 150 msec. T2 appeared 150, 300, or 700 msec after the onset of T1
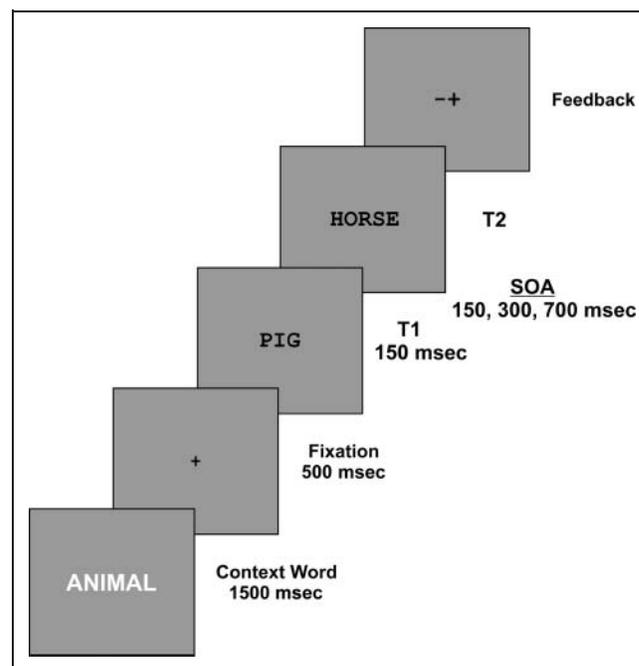

Figure 6. Schematic representation of the trial sequences used in Experiment 2. All stimuli appeared in black on a light gray background except the context word that was presented in light blue. Task 1 stimulus (T1) and Task 2 stimulus (T2) were both displayed in the center of the screen, separated by a various SOA.

and remained visible until a response was recorded for Task 2.

In the no-switch condition, participants had to indicate for both Task 1 and Task 2 whether the target word was related or not to the context word, starting by Task 1. In the switch condition, participants performed two different semantic judgments, one for each task. Task 1 was to judge whether T1 corresponded to a natural object or to a man-made object, whereas Task 2 consisted in indicating whether T2 was related or not to the context word. Participants performed three blocks of 112 experimental trials, preceded by 24 practice trials, for each switching condition.

Results

As in Experiment 1, excluded from all analyses were data from practice blocks, trials in which an error was made on either Task 1 or Task 2, and trials associated with extreme RT values (2% at each extreme of the percentile distribution for each participant in each condition).

Behavioral Data

Errors. Table 1 presents mean proportions of errors for Task 1 and Task 2 in each condition. The ANOVA performed on Task 1 errors revealed that more errors were produced at 150 msec than at 700 msec SOA, $F(2, 38) = 5.51$, $p < .008$. No other effects were significant ($ps > .34$). For Task 2 errors, the ANOVA showed significant effects of Switching Condition, $F(1, 19) = 8.39$, $p < .01$, and SOA, $F(2, 38) = 4.5$, $p < .018$. These results indicated that accuracy was higher in the no-switch than in the switch condition and at an SOA of 700 msec relative to 150 and 300 msec. Again, the interaction was not significant, $F(2, 38) = 1.56$, $p > .22$.

RTs. Mean RTs for Task 1 and Task 2 are plotted in Figure 7 as a function of switching condition and SOA. The ANOVA performed on Task 1 RTs showed significant effects of Switching Condition, $F(1, 19) = 40.4$, $p < .001$, and SOA, $F(2, 38) = 7.73$, $p < .002$, indicating that RTs were longer in the switch than in the no-switch condition and at an SOA of 700 msec relative to 150 and 300 msec. The interaction was not significant, $F(2, 38) = 0.80$, $p > .45$. The corresponding ANOVA carried out on Task 2 RTs revealed longer RTs in the switch than in the no-switch condition, $F(1, 19) = 93.91$, $p < .001$. The PRP effect was confirmed by RTs decreasing as SOA increased, $F(2, 38) = 387.4$, $p < .001$. As expected, the interaction was significant, $F(2, 38) = 31.24$, $p < .001$, reflecting a larger PRP effect in the switch condition (438 msec) than in the no-switch condition (302 msec). Another way to describe the interaction was that the effect of switching condition (i.e., the difference between switch RTs and no-switch RTs) was smaller at 700 msec compared with 150 and 300 msec ($ps < .001$). As for Experiment 1, these results
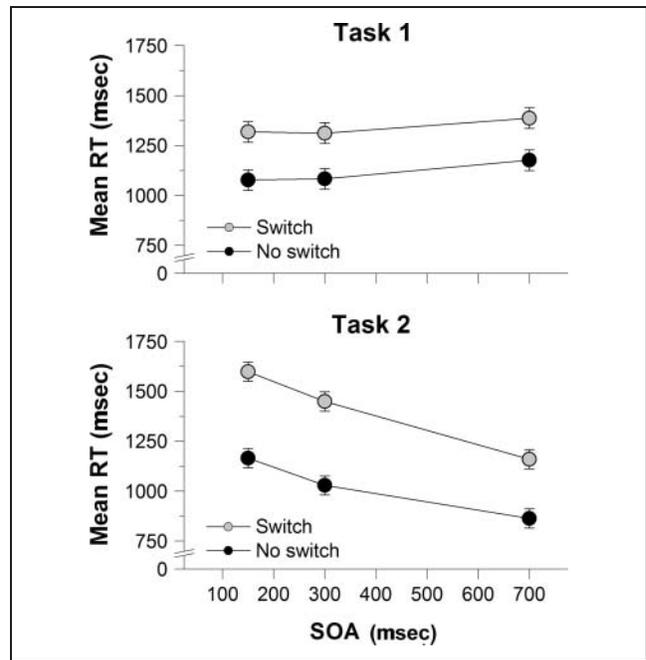
Figure 7. Behavioral results of Experiment 2. Mean RTs for Task 1 and Task 2 as a function of switching condition and SOA. Errors bars represent 95% within-participant confidence intervals.

replicated previous demonstrations that task switching increases RTs for both tasks as well as the PRP effect (e.g., Oriet & Jolicœur, 2003; Logan & Gordon, 2001).

ERP Data

N400 amplitude. The ERP results for T1 are summarized in Figure 8. Figure 8A shows the T1 difference waveforms for Cz, Pz, and the pooling over target electrode sites (C3, Cz, C4, P3, Pz, and P4), whereas the mean T1-evoked N400 amplitude is plotted in Figure 8B for each condition. The ANOVA carried out on these data showed that the T1-evoked N400 was larger in the no-switch than in the switch condition, $F(1, 19) = 6.65$, $p < .019$. However, T1 elicited reliable N400 in both the switch ($ts > 2.35$, $ps < .03$) and no-switch conditions ($ts > 4.77$, $ps < .001$), confirming that the target underwent significant semantic processing in the two semantic Task 1 conditions. The remaining effects were not significant ($ps > .10$).

The ERP results for T2 are summarized in Figure 9. Figure 9A shows the T2 difference waveforms for Cz, Pz, and the pooling over target electrode sites, whereas the mean T2-elicited N400 amplitude is plotted in Panel B for each condition. The ANOVA performed of the T2-elicited N400 mean amplitude indicated that the N400 was larger in the no-switch condition than in the switch condition, $F(1, 19) = 22.18$, $p < .001$. More importantly, the interaction between switching condition and SOA was significant, $F(2, 38) = 3.27$, $p < .049$. The decomposition of this interaction showed a significant effect of SOA in the switch condition, $F(2, 38) = 6.25$, $p < .005$, but not in the no-switch

Figure 8. Task 1 ERP results of Experiment 2. (A) Grand-averaged ERP unrelated–related difference waveforms at central (Cz), parietal (Pz), and pooled target electrodes sites (i.e., C3, Cz, C4, P3, Pz, and P4) as a function of switching condition and SOA (100, 300, and 700 msec). (B) Mean amplitude, in microvolts (µV), of the N400 as a function of switching condition and SOA. Mean amplitude measurements were based on the mean voltage of the unrelated–related difference wave over a 350–600 msec post-T1 time window averaged across all electrodes sites. Error bars represent 95% within-participant confidence intervals.
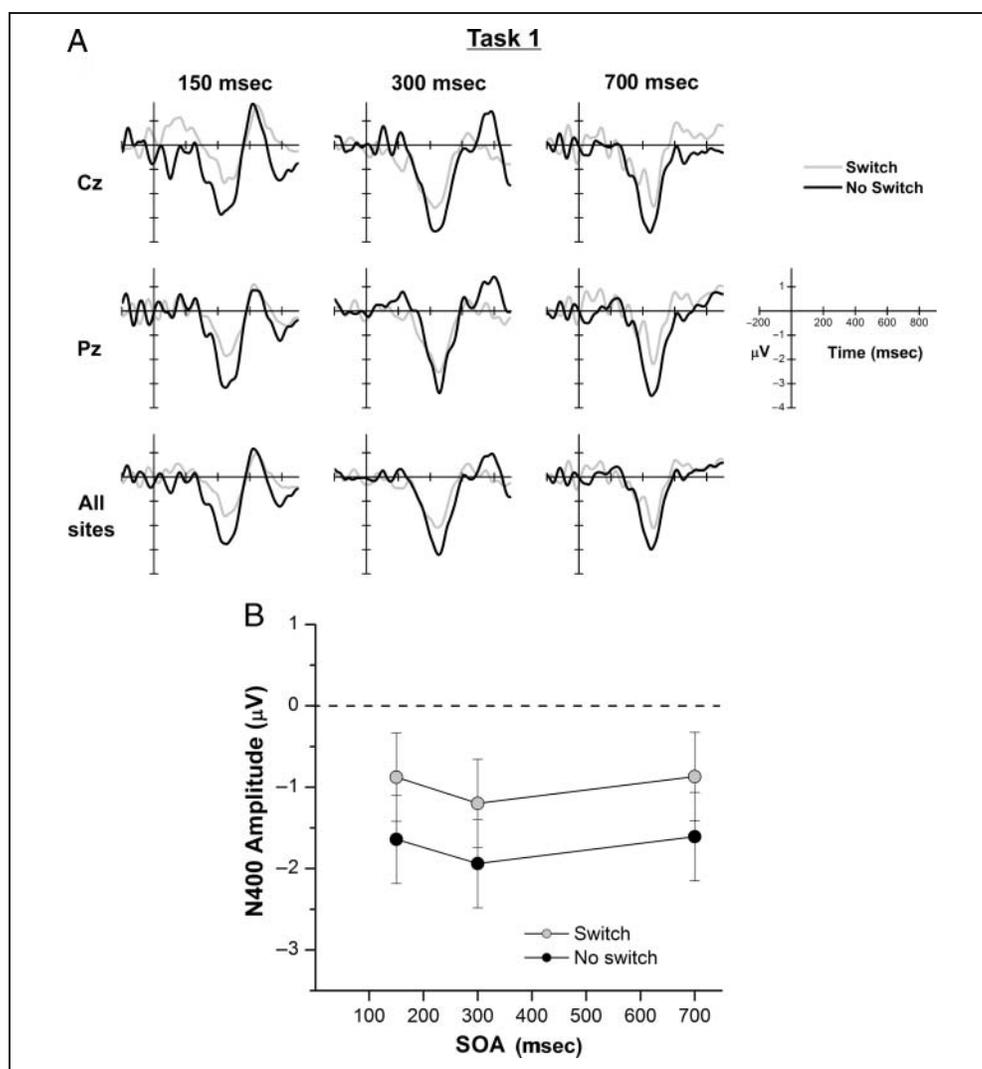
condition, $F(2, 38) = 0.43$, $p > .65$. The effect of SOA in the switch condition arose, because the N400 was larger at 700 msec than at 150 and 300 msec ($ps < .10$). Further decomposition of the switching condition by SOA interaction revealed a switching condition effect at 150 msec SOA, $t(19) = 3.88$, $p < .001$, and at 300 msec, SOA $t(19) = 4.10$, $p < .001$, but not at 700 msec SOA ($p > .43$). Actually, the mean amplitude measured at 150 and 300 msec in the switch condition did not significantly differ from $0 \,µV$ ($ps > .09$). All the remaining effects were not significant ($ps > .06$).

N400 latency.   The absence of N400 for T2 at 150 and 300 msec in the switch condition within a 350–600 msec post-T2 interval was not compensated by any late negativity in these conditions (see Figure 9). Indeed, we found no evidence for mean amplitude greater than $0 \,µV$ in later time windows, suggesting that the N400 was abolished in these conditions. Nevertheless, we performed an N400 latency analysis in the no-switch condition to examine whether the onset of the N400 was affected by SOA as in

Experiment 1. The mean latencies resulting from the jack-knife method, plotted in Table 2, were compared across SOAs. The ANOVA was not significant, $F_c(2, 38) = 0.63$, $p > .53$, confirming that, unlike Experiment 1, the N400 latency was not affected by SOA in the absence of switching.

Discussion

Three important findings emerged from Experiment 2. First, when the two targets were presented at the same spatial location, the N400 elicited by T2 was not modulated by SOA in the absence of task switching. To our knowledge, this result constitutes the first demonstration that the N400 is unaffected by the PRP effect. This is a clear indication that the attenuation of the N400 found in the no-switch condition of Experiment 1 was because of the need to shift visual spatial attention from one location to another between T1 and T2. Furthermore, this finding strongly suggests that previous attenuations of the N400 found in the context of the PRP paradigm (Lien et al., 2008; Hohlfeld et al., 2004) were a consequence of task

switching rather than limitations of central attention producing the PRP effect.

The second key finding was that switching from a semantic task to a different semantic task disrupted the N400 elicited by T2 at short SOAs. Whereas the attentional sensitization model (Kiefer & Martens, 2010) states that semantic processing should be primed when the cognitive system was previously configured to process semantic information, our data rather suggest that such a claim stands only when the same semantic judgment is applied to both tasks. When Task 1 required focusing on a semantic dimension (e.g., natural vs. man-made objects) that differed from the semantic dimension to be processed in Task 2 (e.g., relation with context), T2 semantic processing was temporarily impaired. Interestingly, the consequences of switching between two semantic tasks seemed more detrimental for semantic processing than shifting between a perceptual and a semantic task. Indeed, although the N400 was attenuated and delayed at short SOAs in the switch condition of Experiment 1, the N400

was virtually abolished in the corresponding conditions of Experiment 2. Such findings are somewhat surprising when considering that switch costs tend to diminish when switching between similar tasks as opposed to dissimilar tasks (Arrington, Altmann, & Carr, 2003). Although this issue is beyond the scope of this study, it is noteworthy that Pashler (1998) observed that "task similarity can exacerbate interference" (p. 294) when the two tasks overlap in time such as in the PRP paradigm while such overlap never occurred in the study of Arrington et al. (2003).

The third key finding in Experiment 2 was the observation of a significant N400 for Task 1 in the switch condition (see Figure 8). This context-dependent N400 effect was smaller than in the no-switch condition, probably because the context word was relevant to the semantic relation judgment on T1 (no-switch condition) but not to the object classification task (switch condition). Yet, this result is interesting because it shows that even if the activation of the task set required to perform Task 1 was not initially sufficient to abolish the N400 for T1, it nevertheless lead

Figure 9. Task 2 ERP results of Experiment 2. (A) Grand-averaged ERP unrelated–related difference waveforms at central (Cz), parietal (Pz), and pooled target electrodes sites (i.e., C3, Cz, C4, P3, Pz, and P4) as a function of switching condition and SOA (100, 300, and 700 msec). (B) Mean amplitude, in microvolts (μV), of the N400 as a function of switching condition and SOA. Mean amplitude measurements were based on the mean voltage of the unrelated–related difference wave over a 350–600 msec post-T2 time window averaged across all electrodes sites. Errors bars represent 95% within-participant confidence intervals.
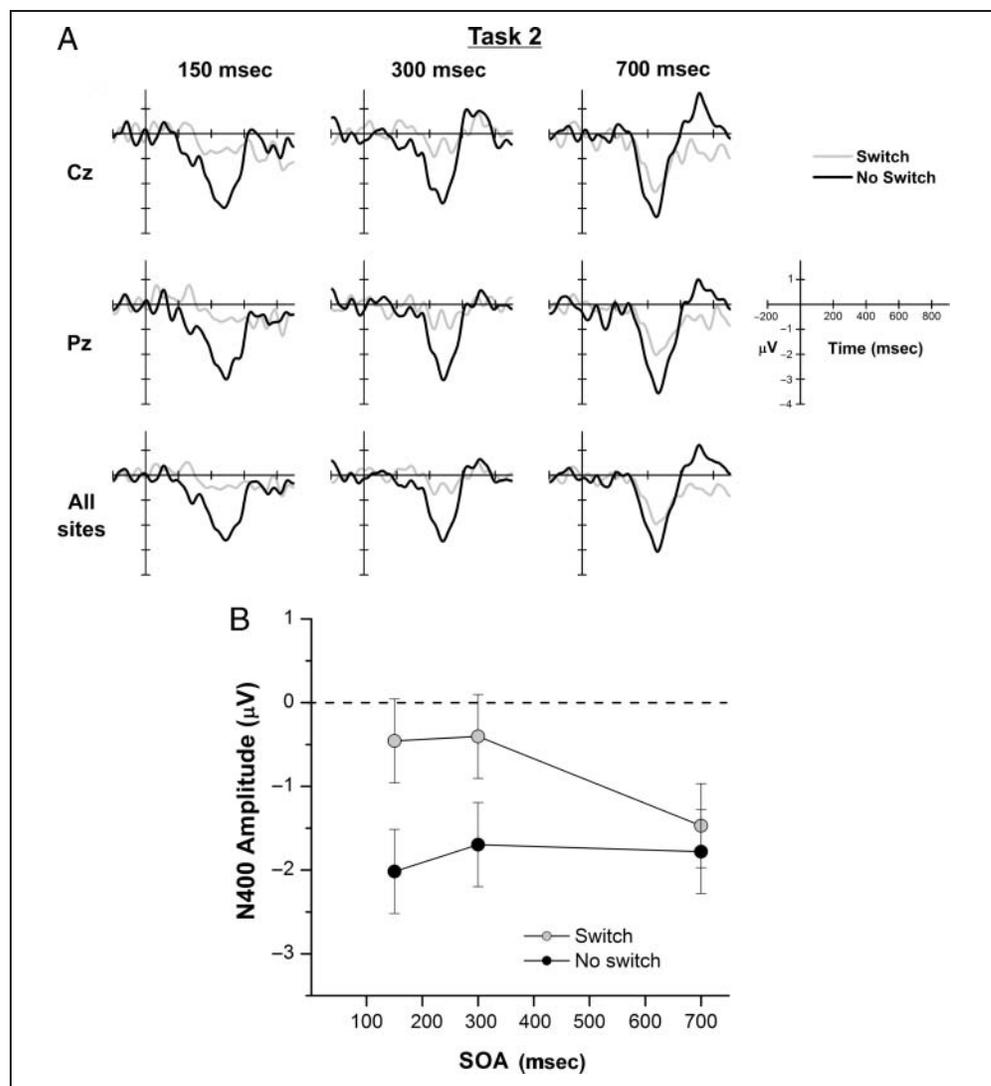
to the disruption of the N400 for T2. Consequently, this transitory impairment of the T2-evoked N400 cannot be attributed to some carryover effect from being previously in a processing mode that prevents N400-related processes, such as in the digit comparison in Task 1 from Experiment 1. Instead, it appears that it is engaging on T1 with another task set, regardless of whether it, itself, is sufficient to elicit an N400 or not, that eventually turns off the N400 processes momentarily for T2.

GENERAL DISCUSSION

The purpose of the present work was to investigate the influence of task switching and PRP interference on semantic processing using ERPs to track the flow of information processing of the two target stimuli, but most importantly the second one (T2). Two experiments contrasted semantic processing, indexed by measuring the N400 ERP component evoked by T2, between conditions with and without task switching. The results showed that the N400 was not affected by SOA in the absence of switching. By contrast, the N400 was strongly attenuated (or even completely suppressed) at short SOAs when the PRP procedure involved a switch from a perceptual to a semantic task (Experiment 1) or a switch between two different semantic tasks (Experiment 2). Moreover, task switching produced larger PRP effects in both experiments (cf. Oriet & Jolicœur, 2003; Logan & Gordon, 2001), although PRP deficits were found in the absence of switching. These findings clearly indicate that switch costs and PRP effects reflect distinct phenomena, which is important as most PRP studies involved a shift of task set between Task 1 and Task 2.

The classical view of automaticity (e.g., Schneider & Shiffrin, 1977; Posner & Snyder, 1975), which postulates that automatic cognitive processes are autonomous and independent from top–down control, has no reserve to account for the present pattern of results. On the contrary, such findings are in line with refined theories of automaticity assuming that automatic processes are susceptible to higher-level cognitive influences such as attention, intention, and task sets (e.g., Kiefer, 2007; Naccache et al., 2002). When addressing the consequences of the nature of the task switch on subsequent processing, the attentional sensitization model (Kiefer & Martens, 2010) can provide an account for task switch costs by postulating a sensitization mechanism that enhances processing pathways congruent with the currently active task set and attenuates task-incongruent pathways. Consistent with the model, Experiment 1 results suggest that, in the switch condition, semantic processing was temporarily impaired because semantic streams were desensitized while the perceptual task set established to perform Task 1 was still activated. In addition, no such impairment occurred in the no-switch condition because semantic processing pathways were already sensitized by the activation of a semantic task set for Task 1. In Experi-

ment 2, however, the suppression of the N400 in the presence of switching cannot be accounted for by the model, which predicted instead enhancement of semantic processing in both switching conditions where both tasks relied on a semantic task set. On the basis of the current findings, the sensitization mechanism would not be modulated by the nature per se (e.g., semantic or perceptual) of the activated task representation but rather by the precise parameters of each task set. Indeed, having to perform two different semantic judgments in close succession momentarily hinders subsequent semantic processing. However, the present results cannot be taken to refute the model of Kiefer and Martens. Indeed, our findings may reflect the temporarily disruption of the sensitization mechanism action during task switching. This conclusion parallels the theory of executive control of Logan and Gordon (2001), which provides an account for the impact of task switching on dual-task crosstalk. Crosstalk effects occur in dual-task situations "when the stimuli from one task are relevant to the task set for the other task, and consequently influence how the other task is performed" (p. 405). According to the theory, crosstalk is triggered by the activation of "conditionally" automatic processes, such as semantic processing, which depends on the attentional state (i.e., task set) of the individual. Accordingly, crosstalk effects are severely limited during task switching (e.g., Logan & Gordon, 2001; Logan & Schulkind, 2000). If we assume that the sensitization mechanism is responsible for dual-task crosstalk effects, then the attentional sensitization model (Kiefer & Martens, 2010) can account for the present findings by postulating the temporary deactivation of the mechanism during task switching.

Other Theories of Task Switching

Several theoretical models of task switching postulate the existence of a relatively time-consuming process of reconfiguring the cognitive system. During this process, a specific configuration appropriate for performing a specific task optimally is reset and replaced by another task set best suited for another task. This task set reconfiguration process is assumed to be responsible, at least in part, for switch costs (e.g., Meiran, 1996; Rogers & Monsell, 1995). Although these models share the same serial stage-like cognitive architecture, they differ with regard to where the reconfiguration process takes place in the stream of information processing and, consequently, to which processes task set reconfiguration interfere with. For instance, some models have proposed that task set reconfiguration impedes the response selection stage (e.g., Ruthruff, Remington, & Johnston, 2001; Sohn & Anderson, 2001). The present results do not support these models as we demonstrated that the impact of task switching is independent from the PRP effect (see also Oriet & Jolicœur, 2003), which is thought to reflect response selection limitations (e.g., Pashler, 1994; DeJong, 1993). Other models

locate the reconfiguration process before the response selection stage, inserting it either before the stimulus identification stage (e.g., Meiran, 1996) or after (e.g., Rubinstein, Meyer, & Evans, 2001). The present electrophysiological data can help to specify at what stage of processing task set reconfiguration occurs. Indeed, the N400, which provides an indication that a word has been identified up to the point of meaning extraction, was attenuated during the reconfiguration process, therefore suggesting that task set reconfiguration interferes with semantic integration (e.g., Brown & Hagoort, 1993) and/or lexical access (e.g., Lau et al., 2008). Thus, the reconfiguration process seems to occur at or before stimulus identification is completed. On the basis of our results, we conclude that semantic processing cannot be carried out in parallel with task set reconfiguration (cf. Vachon & Jolicœur, 2011; Vachon et al., 2007; Oriet & Jolicœur, 2003). Beyond the reconfiguration control process, the impact of task switching on the N400 seemed slightly larger in Experiment 2, in which switching took place within the semantic domain, than in Experiment 1, where the switch occurred between a perceptual and a semantic task. The additional interference may reflect the action of an additional inhibition process that actively deactivates the representations and processes of the components included in the previous task set (e.g., Allport, Styles, & Hsieh, 1994). Further work is required to determine how, in the context of the attentional sensitization model, task set reconfiguration and backward inhibition of abandoned task sets would contribute to the temporary desensitization of semantic pathways during task switching.

Implications for Multitasking Interference

The first studies to measure the N400 in the PRP paradigm have reported an attenuation of N400 amplitude during the PRP effect (Lien et al., 2008; Hohlfeld et al., 2004), suggesting that semantic processing relies on central attention. As we mentioned above, the passage from Task 1 to Task 2 was accompanied by task switching in these studies. For example, Lien et al. (2008) asked participants to indicate, with their foot, whether they heard a pure tone or a noise sound for Task 1 and then to perform a semantic judgment on a visual word with their hand for Task 2. We demonstrated, in this study, no PRP modulation of the N400 when the same task set applied to both tasks, suggesting that previous N400 variations in the PRP paradigm were likely a consequence of task switching interference and, consequently, that semantic processing is not prevented while central attention is devoted to Task 1.

The N400 component has been recorded in another dual-task setting, namely, the AB paradigm. In this paradigm, two targets (T1 and T2) are embedded in a rapid sequence of distractors, and typically, the T2 report is impaired when it follows T1 by less than 500 msec (for a review, see Dux & Marois, 2009). So far, research on the N400 within the AB paradigm has yielded mixed re-

sults: Whereas early research found no effect of the temporal lag between the targets—and thus of the AB—on the N400 (Rolke, Heil, Streb, & Hennighausen, 2001; Vogel et al., 1998; Luck, Vogel, & Shapiro, 1996), more recent studies reported suppressed N400 during the AB (Batterink, Karns, Yamada, & Neville, 2010; Giesbrecht, Sy, & Elliott, 2007). Given that the mediating effect of task switching on the N400 that we observed in the context of the PRP has also been established in the AB paradigm (Vachon & Jolicœur, 2011), it is not surprising to find the presence of task switching in those studies in which the N400 was attenuated in the AB (Batterink et al., 2010; Giesbrecht et al., 2007).

Although the impact of task switching on the N400 appears unequivocal, the portrait is not as clear as it seems. In fact, factors other than task switching have been found to moderate the N400 elicited by T2 in the AB paradigm. Giesbrecht et al. (2007) manipulated T1 perceptual load and observed N400 suppression only under high T1 load, meaning that they found a robust N400 in a low-load condition involving task switching. This perceptual load effect could explain, at least partially, why Batterink et al. (2010) found a strong attenuation of the N400 in a paradigm very similar to that of Luck et al. (1996), who reported only a nonsignificant trend toward attenuation. Indeed, while the later required an odd/even judgment on a T1 digit repeated seven times (e.g., 5555555) that pops out from the other letter-string stimuli, the former required the same judgment on a digit written out in letters and flanked by Xs (e.g., XFIVEXX). Although more work is required to better understand the contribution of task switching and perceptual load to N400 modulations, it is clear that future research assessing the outcome of lexical/semantic processes (and possibly of earlier, low-level processes; see Oriet & Jolicœur, 2003) in a multitasking context should take into account these factors.

It has been assumed that both the PRP and AB effects reflect, at least in part, the same central bottleneck (e.g., Ruthruff & Pashler, 2001; Jolicœur & Dell'Acqua, 1998). However, the fact that the N400 typically survives the AB but not the PRP led Lien et al. (2008) to conclude that both phenomena reflect instead distinct limitations. Our demonstration that the N400 can in fact be immune to the PRP effect when task switching is not required reconciles the apparent electrophysiological discrepancies between the AB and the PRP literatures. Notwithstanding the similarities between the resource limitations underlying these two phenomena, the present results combined with those of Vachon and colleagues (Vachon & Jolicœur, 2011; Vachon et al., 2007; see also Oriet & Jolicœur, 2003) provide strong evidence for a dissociation of the locus of interference of the AB and the PRP on one hand, and that of task switching on the other hand. The immunity of the N400 to the AB and the PRP is consistent with the claim that these dual-task deficits occur at a late, postperceptual stage of processing (e.g., Ruthruff & Pashler, 2001; Jolicœur & Dell'Acqua, 1998) whereas alterations of semantic processing during

task switching suggest that switch costs occur at an earlier stage of processing.

Conclusion

In summary, our results support the argument that semantic processing, as indexed by the N400, is automatic but dependent upon top–down attentional control (Vachon & Jolicœur, 2011; Batterink et al., 2010; Kiefer & Martens, 2010) as it is severely limited for words appearing while the cognitive system is occupied to reconfigure processing parameters to adapt to a new task. Meanwhile, that the N400 can survive multitasking interference, as long as the cognitive requirements remain the same, provides evidence that such "conditional" automaticity (cf. Logan & Gordon, 2001) is not because of the processing capacity limitations creating the AB or the PRP effects. Rather, these findings illustrate how our cognitive system can flexibly adapt to the dynamically changing challenges of the environment in accordance with behavioral goals and task demands.

Acknowledgments

Notes

1. For every repeated measures ANOVA performed in this study, the lower bound procedure (Box, 1954) was applied on every within-subject effect for which the sphericity assumption was violated.

2. While the effect of Electrode Site approached significance, $F(5, 90) = 3.91, p < .063$, the interactions between SOA and Electrode Site, $F(10, 180) = 1.92, p < .045$, and between Switching Condition, SOA, and Electrode Site were significant, $F(10, 180) = 2.05, p < .031$, mainly because the difference in the amplitude of T2-evoked N400 found between the two switching conditions at 300 msec tended be smaller at the left parietal site than at the other electrode sites.

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