Age and task difficulty effects on task-switching: An Event-Related Potentials study

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Abstract

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Aging has been associated with a decline in executive functions. The ability to switch between tasks is thought to require executive processes. Given that aging has been associated with relative sparing of semantic memory and relative decline in episodic memory, it was hypothesized a) that older subjects would be slower than their younger counterparts when switching to an episodic task, and b) that brain activation would be different in both groups. Event Related Potentials (ERP) and Reaction Times (RT) were measured in a cued task-switching paradigm where subjects had to switch between two semantic and two episodic tasks. As expected, episodic tasks were slower than semantic tasks and switch trials were slower than repeat trials in both groups. The absence of group RT differences was probably due to the high functioning status of the elderly participants. Contrary to expectations, episodic switch costs were smaller than semantic switch costs in both groups. As expected, the cue-locked waveform was characterized by a preparatory like negativity. Although the two groups' ERP waves had similar shapes, only the young group had significant condition effects. A significant N400 attenuation to the semantic repeat condition relative to the episodic repeat and switch conditions was interpreted as an index of task-set facilitation. As expected, target-locked activity was characterized by a larger P300 following repeat trials compared to switch trials and was interpreted as more efficient processing of repeat than switch trials. The results are discussed in relation to various task-switching models and in relation to aging and executive processes.

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Table of Contents

List of Figures

List of Tables

The ability to switch between two or more tasks is thought to require executive control because the individual must disengage from the old task, locate and engage the second task, recognize the stimulus, and evaluate it. Successful performance requires the temporal organization of these processes. For example, consider a tennis player who has just returned the tennis ball using the backhand stroke. Preparation for a forehand movement will require a time-consuming reconfiguration of body posture and handgrip.

Recent studies have shown small age-related effects on the ability to switch between tasks (Kramer, Hahn, & Gopher, 1999; Kray, Li, & Lindenberger, submitted; Kray & Lindenberger, 2000; Mayr, 2001). Given that aging has been associated with a relative decline in both episodic memory (Craik, Anderson, Kerr, & Li, 1995) and executive control processes (Raz, 2000; West, 1996), it was hypothesized that older subjects would show a reduced ability to switch between episodic tasks compared to their younger counterparts. The goal of this study was to examine age and task difficulty effects on behavioral and electrophysiological measures of task-switching. In the broader context, it was hoped that inferences could be made about executive processes involved in task-switching in particular and about the effect of aging on executive functions in general.

The question of the relative influence of internal and external factors on the control of behavior has been hotly debated since the beginnings of modern psychological research. The behaviorist school of thought has traditionally ascribed most control of behavior to environmental factors external to the organism, whereas the cognitive school of thought has allowed far more endogenous control of behavior, emphasizing the role played by internal representations, stored as memory traces in the central nervous system, thought to override or modulate the influence of external stimuli (Jenkins, 1979).

One model that has attempted to reconcile top-down and bottom-up contributions to the control of behavior is the Attention-to-Action (ATA) model proposed by Norman and Shallice (1986). While going about his or her daily functioning, a person is continually confronted with stimuli coming from the environment. As a stimulus enters the central nervous system by the sensory channels, it has the potential to activate several task sets (i.e., action patterns). A task-set is a set of cognitive rules needed to perform a task, which can be compared to a computer program. The stimulus is the input data and behavior is the output. Usually, the behavior that emerges as dominant is selected by a rapid and automatic process called "contention scheduling". This mechanism can be considered an example of bottom–up processing and does not require any top-down executive processes. However, "contention scheduling" cannot account for the complete range of behavior control. Sometimes an environmental stimulus is novel, ambiguous, or too complex and the system cannot automatically resolve the conflict between two or more task-sets. In this case, an executive system, the Supervisory Attentional System (SAS) steps in to guide behavior in a slow, flexible, and deliberate manner by biasing one task-set over another depending on the demands of the situation. The intentional and endogenous nature of the SAS makes it an excellent model of executive processes.

The ATA model is able to account for a wide range of behaviors, including the behavior of frontal lobe patients. For example, when confronted with an object (e.g., a comb), some patients with known frontal lesions are compelled to perform the stereotypical action most commonly associated with this object (e.g., combing their hair) even if this action may not be appropriate at the time (utilization behavior: Shallice, Burgess, Schon, & Baxter, 1989). The patient seems unable to override the dominant response. Yet another example of behavior typical of patients with frontal lesions is their inability to modify their behavior despite being aware that it is not optimal in that particular circumstance. The tendency to perseverate in the face of clear negative feedback suggests the patient cannot override previously learned responses (Milner, 1963). In all these cases the behavior is conceptualized as a failure of endogenous control to inhibit the dominant task-set.

Some controversy exists in the literature as to whether the central executive is a unitary construct or if it is better conceptualized as a collection of interdependent processes (Stuss & Alexander, 2000). Some examples of executive functions include the ability to plan a sequence of events to reach a goal (i.e., planning), the ability to inhibit a dominant response in order to perform a less practiced behavior that is more appropriate under the current circumstances (i.e., inhibition), the ability to hold in memory and manipulate information (i.e., working memory), the ability to attend to more than one thing at a time (i.e., divided attention), and the ability to flexibly move from one task to another (i.e., task shifting). Although the existence, or rather the failure, of executive processes has been inferred from clinical observations, strong evidence in favor of top-down contributions to the organization of behavior comes mainly from controlled laboratory experiments.

Task-switching literature review

One paradigm that has been productively used in the study of executive processes is the task-switching paradigm. The task-switching paradigm differs from other paradigms used in the study of executive functions such as the Psychological Refractory-Period (PRP) procedure in that executive demands are imposed primarily by conflictual stimulus-response mappings and not by the resolution of processing bottlenecks, since the tasks that must be performed are not temporally overlapping. Although, as will be discussed below in more detail, the task-switching paradigm has several forms, the essential element of the procedure is the contrast between trials where the participant must switch between performing a different task and trials where the participant is able to repeat a task. Consider the example of the tennis player who has just returned the tennis ball using the backhand stroke. Preparing for a forehand stroke will require a change in posture and handgrip that is not necessary if another backhand stroke has to be prepared, making the stroke switch slower than a stroke repetition. In an experimental context, the reaction time difference, which typically results from slower switch trials and faster repeat trials has been termed the switch cost.

Jersild (1927) pioneered the study of control processes by comparing reaction times in blocks where subjects had to switch between performing two tasks (heterogeneous blocks) with reaction times in blocks where subjects performed the same tasks in isolation for the whole block (homogeneous blocks). Jersild found that when subjects were required to switch between two tasks that were related to each other (e.g., adding six and subtracting three), they took more time to complete heterogeneous blocks than homogeneous blocks. However, when subjects were asked to switch between very different tasks (e.g., naming an antonym and subtracting three) no switch cost was found. Jersild also manipulated task complexity by comparing the switch cost when switching between simple tasks (i.e., adding and subtracting a single digit number) and the switch cost when switching between more difficult tasks (i.e., adding and subtracting two digit numbers) and found that the size of the switch cost was sensitive to task complexity.

Spector and Biederman (1976) replicated Jersild's results and concluded that the principal determinant of switch costs is the extent to which a stimulus is able to determine the appropriate task. The more ambiguous a stimulus (i.e., a stimulus that can evoke more than one response is ambiguous), the larger the switch cost. In one experiment (Experiment 4), participants switched between the same tasks as in a previous experiment, but this time the tasks to be performed were shown concurrently with the stimulus (i.e., the task was cued). Results showed that the switch cost was dramatically reduced. This result reinforced the authors' conclusion that the principal determinant of switch costs is the extent to which a stimulus is able to determine the appropriate task.

There are several reasons why inclusion of the cues diminished the switch cost in that study. First, as Spector and Biederman (1976) argued, cues may have reduced or eliminated stimulus ambiguity, decreasing S-R overlap, and lessening the need for the involvement of executive processes. Second, because the cues provided information on which task to perform next, the subject did not have to keep track of which task was performed on the previous trial (i.e., reduced working memory demands). Third, if part of what a subject can do to reconfigure a task-set is to access and retrieve task rules from long-term memory, then providing the task rules should short circuit this step and reduce switch costs.

Allport, Styles, and Hsieh (1994) also used Jersild's paradigm. Two stimulus ensembles made of two tasks each was used. One ensemble was incongruent Stroop color words where the participant was required to name the color or the word. The other ensemble was a set of displays containing from 1 to 9 digits (i.e. 11111 or 77777777) where the subject was required to judge the value or the number of digits (less or more than 5). They found that the switch cost was lower when the subject had to switch tasks between ensembles than when the subject had to switch tasks within ensembles, supporting Spector and Biederman (1976) suggestion that task switching is easier when the stimulus provides an effective cue for the task required. The activation of one task inhibits all similar tasks, so switching within the same ensemble requires more effort. Norman and Shallice (1986) suggest that only one of the several competing task-sets is selected. All other task sets that use the same processes are inhibited by the process of contention scheduling. "Schemas which require the use of any common processing structures will clearly need to inhibit each other" (Norman & Shallice, 1986, p.5). Allport et al. proposed that the principal determinant of switch cost is a form of proactive interference that they termed Task Set Inertia (TSI) exerted by previously activated S-R mappings.

One potential problem of the blocked design used by Jersild (1927), Spector and Biederman (1976), and Allport et al. (1984) is that in homogeneous blocks, subjects can simply attend to the present stimulus, but in heterogeneous blocks, subjects must also keep track of past trials to know when to switch tasks. This extra working memory requirement present in heterogeneous but not in homogeneous blocks may account for some of the switch cost. Also, between-block reaction time differences could be due to differences in arousal, motivation, and fatigue.

Rogers and Monsell (1995) developed the "alternate runs" paradigm where participants are required to switch between two tasks (switch trials) or repeat the previous task (repeat trials) in the same block so to avoid between-block confounds. For example, on the first trial the subject is asked to decide whether the letter in the stimulus "K9" is a vowel or a consonant. On the next trial the subject is asked to decide whether the digit in the stimulus "3L" is odd or even. This is considered a switch trial because the subject has been asked to switch from categorizing the letter to categorizing a digit. On the next trial, the subject is asked whether the digit in the stimulus "A5" is odd or even. This is considered a repeat trial because the subject is asked to make a decision along the same dimension as the previous trial. The difference in average reaction time (RT) between switch trials and repeat trials (switch trial RT – repeat trial RT) is the switch cost.

Rogers and Monsell (1995; Experiment 3) showed that increasing the response stimulus interval (RSI; i.e., allowing subjects more time to prepare for the next trial) decreased the switch cost substantially. However, Rogers and Monsell (1995) found that these endogenous anticipatory processes did not fully prepare the participant for the upcoming trial as evidenced by a residual switch cost that persisted even after long preparatory intervals were allowed. Allport et al., (1994) had also reported this phenomenon and attributed it to slowly decaying residual TSI. Rogers and Monsell (1995; Experiment 5) showed that residual TSI could not account for the residual switch cost by allowing subjects to repeat a task three times after a switch trial. They reasoned that if residual TSI played a role, subjects should benefit from repeating a task more than once, but this was not found. Subjects' performance was the same for the first, second and third task repeat, suggesting that task-set reconfiguration was completed by the end of the first repeat trial.

In summary, Rogers and Monsell proposed a model in which control of behavior during task switching can be separated into two parts: a preparatory endogenous component and an exogenous component that is stimulus triggered. It should be noted though that the Allport et al.'s and Rogers and Monsell's theoretical perspectives are not mutually exclusive, that is, proactive interference and endogenous processes may both contribute to switch costs.

Evidence for the involvement of both endogenous and exogenous processes in task switching comes from the cued task-switching paradigm. In this paradigm, the interval between the response on the present trial and next trial stimulus (RSI) is broken down into two components by the introduction of a cue that informs the subject which task to perform on the following trial. Therefore, the RSI divides into the interval between the response on the present trial and the cue for the next trial (the response-cue interval, RCI) and the interval between the cue and the stimulus on the next trial (the cue-stimulus interval, CSI). Evidence for the existence of passive interference comes from the observation that increasing the RCI decreases switch costs (Meiran, 1996). During the RCI, no cue has yet been presented and the subject is not yet able to prepare for the upcoming trial. If increasing the RCI reduces switch costs it provides evidence for a time-limited passive interference from the previous trial. Evidence for advanced "task-set reconfiguration" comes from the observation that increasing the CSI while keeping the overall RSI constant – thus controlling for passive decay effects – reduced switch costs substantially (Meiran, 1996).

Evidence for the involvement of both endogenous and exogenous processes in task switching comes from a recent study (Ruthruff, Remington, & Johnson, 2001) that manipulated both top-down (expectancy) and bottom-up (recency) factors. Results suggest that endogenous (top-down) and exogenous (bottom-up) processes influence different stages during a task switch. Pre-stimulus executive processes reflect task-set reconfiguration whereas recency effects strongly predict the time it actually takes to execute the task (i.e., interference from previous task-sets, stimuli, and response-sets prolongs the response selection process).

Some theorists (De Jong, 2000) have proposed that there is only one type of executive process but, for a variety of reasons – such as fatigue and lack of motivation – participants often fail to completely reconfigure ahead of the stimulus. According to this account, the residual switch cost is a mixture of completely reconfigured and only partially reconfigured trials. Other theorists (Rogers & Monsell, 1995; Rubinstein, Meyer, & Evans, 2001) have argued that pre- and post-stimulus executive processes are distinct. Rubinstein et al. have hypothesized the existence of two distinct executive processes involved in task switching. The first, "goal-shifting" can be prepared before the stimulus is presented, whereas the second, "rule-activation" requires the presentation of the stimulus. A similar concept to Rubinstein's et al. "rule activation" process was brought forward by Mayr and Kliegl (2000) who proposed that much of what a subject can do to prepare for an upcoming task is to retrieve the task rules associated with the upcoming task from long-term memory.

In Experiment 3 (Mayr & Kliegl, 2000), subjects were asked to switch between two possible tasks chosen between two tasks with high task-rule retrieval demands (whether the word was originally presented in yellow or blue font or in the top or bottom half of the screen) and two tasks with low task-rule retrieval demands (judging whether a noun is living/nonliving or large/small). A cueing paradigm was used where the RCI and CSI was manipulated as well as the explicit nature of the cues. The retrieval demand effect was present in conditions where the subject had little time to prepare and where the cues were not very explicit. However, when the cues were very explicit (i.e., the stimulus-response associations were provided on the screen), no retrieval demand effect was found (i.e., semantic and episodic tasks had similar switch costs). Also, when subjects were allowed enough time to prepare (short RCI and long CSI), the retrieval demand effect disappeared even when the cue was not very explicit, although a small switch cost was still recorded. Contrary to Rubinstein et al.'s (2001) proposition, these results suggest that the retrieval of task rules can be performed in anticipation of the stimulus.

In summary, the evidence reviewed above suggests the involvement of executive control processes in task-switching. However, the precise nature of these processes – i.e., whether it is a unitary process or a collection of distinct processes – is still not clear.

Executive functions and aging

The study of age-related differences in task switching may be a promising way of examining the role of executive processes in task switching. Aging has been associated with a relative decline in executive control processes (Raz, 2000; West, 1996). An influential hypothesis that has attempted to describe this decline is that age-related cognitive decline is due to a decrease in inhibitory processing (Hasher & Zacks, 1988). Reduced inhibition results in poor selective attention skills and a reduced ability to keep unwanted information out of working memory. This inhibitory decline proposal is consistent with many but not all studies that have looked at cognitive age differences.

For example, age-related differences have been studied on the Stroop test (Stroop, 1935). In this test, the subject is asked to name the color of the ink the word is printed in. On some trials, the word is congruent with the color of the ink (e.g., the word red written in red ink) and on other trials the word and ink color are incongruent (e.g., the word red written in blue ink). Because the subject has to inhibit the dominant response (i.e., read the word) on incongruent trials, interference has been interpreted as an index of inhibitory function (MacLeod, 1991). Older adults are relatively more affected than younger subjects on incongruent trials (Houx, Jolles, & Vreeling, 1993).

More evidence of older subjects' inhibitory deficits comes from some negative priming studies. In this task, subjects are required to respond to some stimuli while disregarding other simultaneously presented stimuli that had been relevant the previous trial (Tipper, 1985). Hasher, Stoltzfus, Zacks, and Rypma (1991) found age related performance differences suggesting that older subjects were less efficient in inhibiting the currently irrelevant information.

However, other paradigms have failed to show age-related inhibitory differences. One example is the inhibition of return phenomenon and another is the backward inhibition paradigm that will be discussed shortly. This discrepancy has led some authors to propose that decreased inhibitory efficiency with age is not a unitary phenomenon (Kramer, Humphrey, Larish, Logan, & Strayer, 1994). One influential proposal is that inhibitory function declines with age insofar as it is subsumed by the frontal cortex (Arbuckle & Gold, 1993).

Anatomical and neurophysiological evidence suggest that aging is accompanied by an early and relatively selective reduction of the pre-frontal lobe cell volume and synaptic density (Raz, 2000; West, 1996). Further, prefrontal cortex has been frequently associated with executive processes. Simply put, a current widely accepted view of cognitive aging draws a strong parallel between executive functions, prefrontal cortex, and cognitive decline with age. It is therefore reasonable to expect that, if executive functions are involved in task-switching, aging will cause significant alterations of performance patterns.

Another executive function that is thought to rely on the frontal cortex and has been shown to be affected by age is the dual-task paradigm (Anderson, Craik, & Naveh-Benjamin, 1998). In this paradigm performance is compared when a primary and secondary task are performed alone and when they are performed concurrently. Older adults consistently perform more poorly than their younger counterparts on the secondary task (Whiting & Smith, 1997). To summarize, there is strong evidence that executive functions are affected by aging insofar as they are thought to rely on frontal cortex.

Task-switching and aging

Several studies have looked at age differences in task switching. Hawkins, Kramer, and Capaldi (1992) found that older adults were disproportionately slowed compared to younger counterparts on switch trials. This greater slowing held even when single-task response speed was taken into account. Kramer, Hahn, and Gopher (1999) showed that, initially, older adults had substantially higher switch costs compared to younger controls, but that with practice, age differences in switch costs were eliminated. In a follow-up study, Kramer et al. (1999) increased working memory demand by requiring subjects to keep track of the number of trials and to switch task every five trials. Results showed that even with extensive practice, older subjects were not able to reduce the age related switch cost deficit suggesting that it is working memory capacity and not attention switching per se that is affected by age.

Kray and Lindenberger (2000) manipulated both task-switching and working memory. They compared young and old subjects performance on homogeneous (switching between two variants of the same task) and heterogeneous (switching between two different tasks) trials at different RSIs. They argued that the difference between a non-switch trial and trials on homogeneous blocks are due to the ability to maintain and select more than one task from working memory during the heterogeneous block (i.e., a general switch cost), whereas the traditional difference between switch and repeat trials within the same block reflects the ability to switch between task-sets. They termed the first general switch costs and the second specific switch costs. Given enough practice, older and young adults showed similar specific switch costs suggesting no impairment in specific task-switching abilities. However, older adults were proportionately slower in heterogeneous trials compared to homogeneous trials suggesting that older subjects had a decreased ability to maintain and coordinate task-sets in task-switching.

These results support the Kramer et al. (1999) suggestion that age-related decrements in task-switching performance are due to working memory limitations rather than attention switching per se. Another study by the same authors (Kray, Li, & Lindenberger, submitted) suggests a more refined explanation. Contrary to their previous experiment, the required task-set for the upcoming trial was externally cued and unpredictable thus minimizing working memory demands. Results showed that older subjects had larger switch costs compared to their younger counterparts suggesting that when demands on working memory were minimized age differences in task switching are allowed to surface. Another explanation for these results is that the investment of executive resources by older adults depends on the particular demands of the task. When tasks are not explicitly cued, executive resources are concentrated on keeping track of which task should be performed next. But when tasks are explicitly cued, executive resources can then be freed up to help in the control of specific set changes.

Meiran, Gotler, and Perlman (2001) also investigated age differences in task switching using a cued paradigm. By systematically varying the RCI and CSI, they concluded that aging has little or no effect on the preparatory component of the switch cost (i.e., older adults can prepare for the upcoming task as well as younger counterparts). Also, Meiran et al. found that, with increasing RCI, young subjects substantially reduced specific switch costs whereas older subjects did so to a lesser extent, suggesting that interference from the previous task-set lasts longer for elderly subject. This interference may be due to a failure to actively inhibit the previous task-set in anticipation for the next trial, or it may be due to a different time course of passive decay. In summary, whereas the ability to prepare a task-set seems to be preserved, inhibitory deficits may impair elderly subjects in the ability to actively inhibit the previous task-set.

Mayr (2001) examined the issue of age effects on backward inhibition during a cued task-switching paradigm. Backward inhibition was operationalized as the RT difference between a switch to a task abandoned recently (e.g., A-B-A) and a switch to a task not abandoned recently (e.g., C-B-A). In the first example, because task A had to be inhibited to perform task B, the subject should be slowed down when task A is presented again. The second trial triad example was the control condition since task A had not been recently inhibited.

Contrary to Hasher and Zacks (1988) inhibition-deficit hypothesis, Mayr's (2001) results showed a marked age-related increase in backward inhibition. If older subjects had an inhibitory deficit they should have performed similarly in the inhibitory and control conditions; instead, older subjects showed a large inhibitory effect (i.e., they were considerably slowed when the same task was recently performed) suggesting that inhibitory processes were relatively intact in older adults. The inhibition shown by older subjects may be explained as an index of the difficulty to activate a task. If task B is difficult, switching to it will require a strong inhibition of the previous task (i.e., task A). When task A must be engaged again, it will have been strongly inhibited and performance on it will be slowed. In summary, although the ability to coordinate and select from more than one task set seems to be strongly affected by age, the ability to actually switch between cued and randomly presented tasks seems to be only mildly affected by age. Whereas task preparation seems to be unaffected by age, interference from previous trials appears to affect older adults more than younger participants. Although inhibitory decline may be a possible process that could account for this increased interference from previous trials with age, the study by Mayr (2001) found no age-related inhibitory decline during task-switching.

Episodic vs. semantic memory

One interesting way to examine age differences in task-switching is to manipulate the difficulty of the primary tasks. On way to do this is to ask participants to switch between semantic and episodic tasks. Episodic memory is responsible for the encoding, storage, and retrieval of temporally and spatially defined events, and the temporal and spatial relationships among them (Tulving, 1983). By contrast, semantic memory is described as the memory of information necessary for language, including not only lexical information (word meaning and concepts) but also facts and general world knowledge (Tulving, 1983).

Evidence for a dissociation between semantic and episodic memory comes from the study of patients with circumscribed amnesia. Amnesic patients are especially impaired in their attempts to acquire new episodic information (i.e., anterograde amnesia), while their semantic memory appears to be intact. Although unable to remember a short list of words or a name and address for more than a few minutes, amnesic patients retain knowledge of arithmetical, geographic, and historical facts, and are able to name objects, and use rules of grammar and syntax in a normal fashion. Similarly to amnesic patients, AD patients show an initial impairment of episodic memory but, as the disease progresses, AD patients become increasingly impaired on tasks that are dependent on semantic memory. This dissociation indicates that semantic memory is not dependent upon the same medial temporal (hippocampus) or diencephalic (thalamus) brain structures that are damaged in amnesic patients and thought to underlie their episodic memory deficits (Squire, 1987). Rather, semantic memory may be stored in neocortical association areas presumed to be impaired in AD.

In contrast to AD patients, normally aging individuals typically show a mild gradual impairment of episodic memory accompanied by a relative sparing of semantic memory (Craik, Anderson, Kerr, & Li, 1995). Despite the compelling evidence supporting the idea that episodic and semantic memory are distinct memory systems, some have proposed that the two systems may be at different levels of a continuum (Mayr & Kliegl, 2000). At the physiological level, episodic tasks may require the activation of additional brain areas relative to semantic tasks. In particular, frontal cortex areas may need to be recruited when tasks are novel (Moscovitch & Winocur, 1995). Thus the distinction may be confounded by the fact that episodic tasks tend to be novel whereas semantic tasks tend to be overlearned. Because novel tasks tend to be more difficult than overlearned tasks, they tend to be more difficult to activate.

Since episodic retrieval demands are higher than semantic retrieval demands, younger subjects were expected to show higher switch costs on episodic tasks than semantic tasks, and since episodic retrieval demands were assumed to be higher for older adults compared to younger adults, it was hypothesized that although semantic switch costs should be comparable between the two groups, episodic switch costs should be significantly higher in the older group compared to their younger counterparts.

Neural substrates of task-switching

In a recent fMRI study, DiGirolamo, Kramer, et al. (2001), investigated the neural substrates involved during task-switching in both young and older adults. Results showed that for both young and older adults, both pre-frontal and posterior brain areas were involved. However, whereas young subjects involved frontal areas preferentially on switch trials, older adults tended to recruit pre-frontal areas during both switch and non-switch trials. These results bring up the possibility that, although age differences in specific switch costs were small, the mechanisms underlying this cognitive phenomenon may be different in young and older adults. In other words, young and older adults may perform similarly at the behavioral level because older adults expend more cognitive resources on repeat trials.

Although imaging studies using task-switching paradigms are still rare, many experiments have looked at the possible neural substrates involved in other attentional paradigms. Posner, Walker, Friedrich, and Rafal (1984) asked subjects to press a key as soon as a stimulus appeared. At the beginning of each trial, subjects were given a cue at a particular location on the screen (left or right visual field). On most trials, the stimulus appeared in the same visual field as the cue (i.e., validly cued trials) but on some trials the stimulus appeared in the opposite visual field relative to the cue (i.e., invalidly cued trials). Patients with parietal lesions performed as fast as normal subjects on validly cued trials but were markedly slower on invalidly cued trials suggesting a parietal role in the disengagement of attention (Posner, Inhoff, Friedrich, & Cohen, 1987).

The parietal lobe is not the only posterior region to be involved in selective attention. Corbetta, Miezin, Dobmier, Shulman, and Petersen (1991) presented normal subjects with a fixation point in the middle of the screen. A stimulus was presented for 400 ms followed 200 ms later by another 400 ms stimulus. Each stimulus was made up of a randomly spatially located group of identical (shape and color) objects moving at the same speed horizontally across the screen. In the second stimulus, the color, shape or speed of the objects might be changed. In one task, the subjects were asked to attend to one of the three features (e.g., shape) in the first stimulus and respond whether it had changed in the second stimulus. In another task subjects were asked to respond whether the second stimulus was different from the first at all. PET imaging data showed that in the first task, which can be considered a selective attention task, posterior areas were activated. In the second task, which can be considered a divided attention task, maximal activation was detected in the anterior cingulate and dorsolateral prefrontal cortex.

Posner and Petersen (1990) have proposed the existence of several attentional systems that come together during the switching of attention. The posterior parietal system is specialized in spatial attention and is required for the disengagement of attention from one stimulus and the engagement of attention to another. Further, the divided attention task in the Corbetta et al. (1991) study suggests the importance of frontal areas in attention. Although posterior regions may be responsible to detect the stimulus, locate it in space, and engage and disengage it, frontal areas are probably involved in the planning and control of complex tasks (Stuss & Alexander, 2000). Also, the anterior cingulate, a medial prefrontal area, has been associated with response selection (Posner & Petersen, 1990) and the dorsolateral prefrontal cortex has been associated with working memory, or the ability to maintain and manipulate active representations of a stimulus or task after the stimulus or task is no longer in the visual field (Goldman-Rakic, 1992).

Planning and control, response selection, and working memory are crucial functions that enable the switching of attention from one task to another. Successful performance on a complex task like task switching requires the temporal planning of all the sub-components. To switch between two tasks, an individual must disengage from the old task, locate and engage the second task, recognize the stimulus, and evaluate it. Successful performance requires that these subtasks be performed in the right sequence. Also, depending on the design of the experiment, the subject might have to maintain an active representation of the task online or might have to keep track of the position of the present trial in the alternating series of trials to determine if this is a switch or repeat trial. Further, once the stimulus has been evaluated, the subject must determine the appropriate response. Given the literature just reviewed, it is expected that task switching will evoke both posterior and anterior brain areas.

General review of ERPs

One technique that has successfully been used in conjunction with more classical performance measures in the exploration of cognitive phenomena is the event-related potentials (ERP). The ERP is a measure derived from the human electro-encephalogram (EEG). The EEG is a non-intrusive technique that records electrical brain activity from the scalp. As the name suggests, ERPs are time locked to a specific event. For example, a subject may be repeatedly presented with a stimulus, and brain activity is recorded prior to and following the stimulus and/or behavioral response. Then, using off-line averaging techniques, brain activity unique to the particular task is isolated by averaging-out cortical "noise" not related to the task. ERPs have been selected as the best tool to record brain activity in this experiment because it is a noninvasive technique, it offers acceptable spatial resolution (location of activity) and has excellent temporal resolution (time course of the activity) on the order of milliseconds, making it an ideal technique in the investigation of cognitive processes.

There is a rich tradition of using ERPs to study attentional functions and preparatory activity. When subjects are asked to flex the index finger at self-paced intervals, a slow increase in surface negativity starting 800-500 ms before the onset of the motor movement is observed, refered to as the Bereitschaftspotential (BP; Deecke, Bashore, Brunia, Grunewald-Zuberbier, Grunevald, & Kristeva, 1984). The amplitude is maximal over cortical areas containing representations of the index finger. Negativity rises earlier and reaches higher amplitudes with increasing complexity of the movement.

This negativity can be attributed to the preparation of the movement and not to the movement itself because (a) it precedes the movement itself, (b) it shifts from frontal to more central areas as the movement becomes automatic (i.e., over-learned), and (c) the negativity is observed even when the subject is asked to imagine the movement of the finger without overt behavior (Deecke et al., 1984). If cortical negativity is associated with preparatory activity, then tasks presented during periods of spontaneous high cortical negativity should be performed better than during periods of low cortical negativity (Potential-Related Event Paradigm; PRE). Semantic task facilitation has been observed during periods of high parietal negativity (Stamm, Whipple, & Born, 1987). Also, delayed-response task facilitation (associated with frontal lobe activity) has been observed during periods of high frontal lobe negativity (Born, Whipple, & Stamm, 1982).

Another paradigm where a large negative wave can be observed is the Contingent Negative Variation (CNV) paradigm. When one stimulus (i.e., the warning, or signal stimulus) always precedes (or is conditionally related to) another (i.e., the imperative stimulus), a negative potential is observed between the two stimuli. This negativity is monophasic when the interval is less than 3 seconds and is biphasic when the interval between the two stimuli is more than 3 seconds. The monophasic CNV has been related to cortical priming and can be considered an index of preparation for the second stimulus (Walter, Cooper, Aldridge, McCallum, & Winter, 1964).

There are strong parallels between the paradigms (BP, PRE, and CNV) designed to evoke Slow Negative Potentials (SNV), and the task switching paradigms (i.e., alternating runs and cuing paradigms) reviewed here. The CNV can be considered a good model of ERP activity during the cueing paradigm because of the use of an explicit cue.

The cue is analogous to a warning signal and the word stimulus is analogous to an imperative stimulus. In the alternating runs paradigm, although no explicit cue is given, the subject implicitly knows that the switch happens every fixed number of trials (in some paradigms a simultaneous cue is given to minimize working memory demands) and the response on the preceding trial can be considered the cue indicating that the next trial is coming. In either case, cortical negativity preceding the target stimulus can be associated with degree of preparation and increased performance.

ERPs and task-switching

A recent ERP study (Phillips, Poulsen, & Segalowitz, 2000) required a group of healthy young subjects to switch between the evaluation of nouns along two semantic dimensions. Consistent with the literature reviewed above, there was a significant correlation between pre-switch frontal negativity and switch costs, with higher negativity associated with lower switch costs (increased performance), suggesting that frontal negativity is an index of task preparation in young adults. Further, they recorded higher frontal negativity leading to repeat trials compared to switch trials and higher parietal negativity leading to switch trials compared to repeat trials. This may suggest that the preparatory activity leading to switch trials is not associated with frontal areas but rather with parietal areas. This is consistent with Meiran's observation of no age related effect on the preparatory component of the switch cost. However, other studies looking at ERPs during task switching (Lorist, Klein, Nieuwenhuis, De Jong, Mulder, & Meijman, 2000; Poulsen, Luu, Tucker, Speiser, Segalowitz, Phillips, & Davey, 2001) found the opposite pattern of negativity. Lorist et al. (2000) found a frontal early negativity that was higher in switch trials compared to repeat trials whereas a later parietal negativity was higher in repeat trials compared to switch trials. Poulsen et al. (2001) also found a frontal negative activation preceding stimulus presentation that was higher for switch trials.

It is not clear what can account for such discrepancy in the results, but several differences in the methods used in the three experiments may be observed. First, Lorist et al. and Phillips et al. used an alternating runs paradigm whereas Poulsen et al. used a cueing paradigm. Also, whereas Phillips et al. and Poulsen et al. used color cues, Lorist et al. used spatial cues to signal switch and repeat trials. Second, Phillips et al. used words as stimuli perhaps requiring more involvement of the parietal lobe than the simple letters used by Lorist et al. and the letters digits and simple neutral stimuli used by Poulsen et al. Third, Phillips et al. asked subjects to switch between abstract semantic memory tasks whereas Lorist et al. and Poulsen et al. asked subjects to switch between more simple tasks. Despite these differences, it is important to note that all three studies detected preparatory activity at both frontal and posterior sites. The functional significance of this pattern of activations remains to be explored.

Another ERP component that has been consistently observed during task switching is a P300-like posterior positivity that is attenuated following a task switch (Lorist et al., 2000; Phillips et al., 2001; Poulsen et al., 2001; Ullsperger, Freude, Dehoff, & Erdmann, 2001). The P300 has been interpreted as an index of resource allocation (Ullsperger et al., 2001), stimulus evaluation and working memory updating (Donchin & Coles, 1988). A larger positivity may suggest that non-switch trials are processed more extensively or are more fully encoded in working memory than switch trials.

The objective of this study was to examine age differences in performance and ERP measures when task difficulty was manipulated in a cued task-switching paradigm.

Subjects were asked to switch between four tasks of varying difficulty (Mayr & Kliegl, 2000). Given results previously obtained by other authors, slower performance on episodic tasks in general and higher episodic switch costs relative to semantic switch costs were expected. Also, because episodic tasks are thought to be especially challenging for older adults we expected them to be disproportionately slowed on episodic tasks, leading to very large episodic switch costs.

Further, both young and older subjects were expected to show a marked negative going potential in anticipation of the target stimulus and, consistent with previous studies (Phillips et al., 2000) this negativity was expected to significantly predict performance. Also, we expected to see an attenuation of the post-stimulus P3b during switch trials in accordance to previous studies (Lorist et al., 2000; Phillips, et al., 2001; Poulsen et al., 2001; Ullsperger et al., 2001). However, because aging is associated with a reduction of the P3b, older adults were expected to show a less marked difference between switch and repeat post-stimulus positivity.

In order to test these hypotheses, a group of young and a group of older adults were tested over two sessions using a cued task-switching paradigm where participants had to switch between four tasks, two episodic and two semantic. During the first session, participants learned the episodic associations and practiced the semantic and episodic tasks. During the second session, reaction time and ERP measures were collected during six experimental blocks.

Method

Participants

Two groups of healthy participant that were matched in years of education and general intelligence were tested. The two groups consisted of 13 young adults and 11 elderly adults. The young subjects were recruited from Concordia University undergraduate student population and through word of mouth. The older subjects were recruited from advertisements in local newspapers and a subject pool from the laboratory of Dr. Phillips. The first twelve subjects (6 young and 6 older) were paid 20$ CDN and the remaining fifteen subjects (7 young and 8 older) were paid 30$ CDN. All subjects were screened through a health and language-screening questionnaire (see Appendix A) administered over the phone. Inclusion criteria for all subjects included proficiency in English, self-reported good health and no prior history of heart disease, alcoholism, heavy tobacco usage, head injury, or any other medical illness or chronic use of medication which might influence cognitive functioning. Reflecting the demanding nature of the experiment, six elderly participants and one young participant did not complete the first phase of the study (Learning to Criterion Phase).

The young group consisted of 2 males and 11 females; the older group consisted of 1 male and 10 females. Mean years of education, age, and IQ estimated by the raw score of the Vocabulary subtest of the WAIS III (Wechsler, 1997) are shown in Table 1.

The two groups differed in years of education, $\underline{t}(21) = 2.36$, $\underline{p}<.05$; the young group had, on average, more years of education. However, the older group was very well educated for their cohort. Further, the difference in formal years of education was not reflected in the two groups performance on the Vocabulary test ($\underline{t}(22) = .51$, $\underline{p} > .05$).

Table 1

Demographic and Neuropsychological Data for Younger and Older Subject Groups

	Young (n = 13)		Old (n = 11)	
Sex	2 males, 11 females		1 male, 10 females	
	M	SD	M	SD
Age *	24.7	3.87	65.2	3.52
Education *[a]	18.9	2.71	15.9	3.39
Vocabulary[b]	56.0	10.21	53.9	11.32
TMT % Increase[c]	119.2	54.85	154.1	108.90
LNS *[d]	15.0	3.74	11.3	3.53
Stroop % Increase[e]	144.18	63.19	190.4	45.76

* Groups are statistically different p<.05

a. Years of education including Kindergarten.

b. Raw scores on the Vocabulary subtest of the WAIS III.

c. % increase in time to finish the second relative to the first phase of the Trail Making Test. [(Trails B RT – Trails A RT)/ Trails A RT] x 100.

d. Raw scores on the Letter Number Sequencing subtest of the WAIS III.

e. % increase in time to finish the second relative to the first trial of the Stroop Test. [(Interference trial RT – Control trial RT) / Control Trial RT] x 100.

Materials

All subjects were tested individually using the following general procedure. The first session would begin with the administration of the neuropsychological tests (see Table 1) then subjects learned the arbitrary episodic associations to criterion and practiced the semantic and episodic key assignments. The second session consisted of six experimental blocks of 256 trials each, where each cue and target was presented in white font in the center of the screen.

These data are part of a larger design that examined age differences in backward inhibition. Although the details of the larger experiment are not relevant here, one of the aspects of the design was that, due to the number of variables and the considerable number of trials needed for each condition due to ERP averaging requirements, repeat trials comprised 20% of the total number of trials. Only data from switch and repeat trials are presented here.

The stimuli consisted of sixteen concrete nouns and four task word cues. The cues represented the four relevant dimensions under which the sixteen words could be considered. Each word, stimuli and cues, were saved as a cut file and presented in white 24 point Times New Roman font on a black computer screen background. Stimuli were distinguished from cues by a distinctive rectangle surrounding the word (see Figure 1). Each word was classifiable in terms of two semantic dimensions: living/nonliving and large/small, evoked by the cues "existence" and "size" respectively, creating four cells of four nouns each. The sixteen nouns were selected in order to balance the four cells on the basis of word length, familiarity, concreteness, and imageability according to the MRC

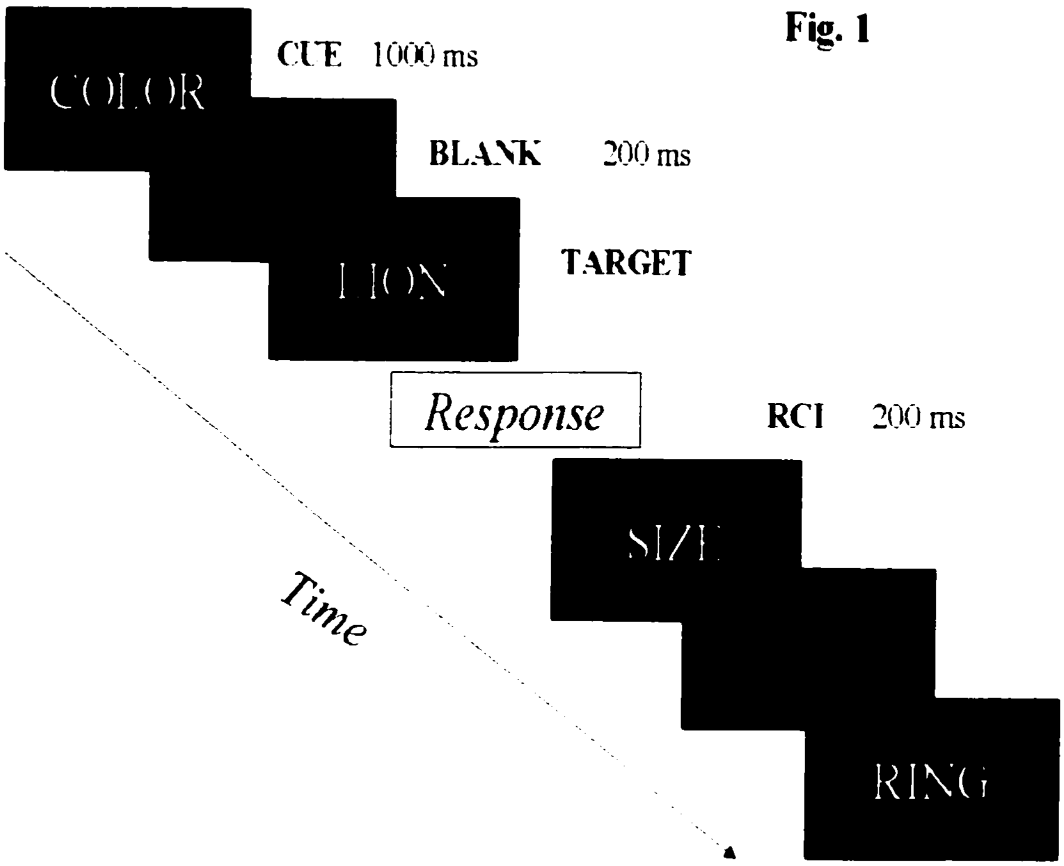

Figure 1. Time course of stimulus presentation.

Psycholinguistic Database on the University of Western Australia's website (http://www.psy.uwa.edu.au/MRCDataBase/uwa_mrc.htm; Table 2).

In addition to the semantic classifications, the sixteen nouns were also associated with two episodic memory dimensions paired during training: font color (red or yellow), and screen location (top or bottom). The four possible episodic combinations were completely orthogonal with the four possible semantic combinations resulting in each word being represented by a unique combination. Further, the majority of subjects received a unique set of episodic (word-color and word-position) associations[1]. The two episodic dimensions were evoked by the cues "color" and "position" respectively.

Procedure

Informed consent approved by the Jewish General Hospital and Concordia University review boards was obtained for all participants. The experiment was divided into two sessions usually performed on subsequent days (except for four young subjects who were run in one 5-hour session). The first session (the learning to criterion session) lasted approximately two to two and a half hours and the second session (the experimental session) lasted from three to four hours, depending on subjects' ERP preparation and general performance speed. At the end of the second session, participants received compensation for their participation.

Neuropsychological Testing

Young and elderly adults were administered the following neuropsychological tests: the Color-Stroop test, the Trail Making test, the Letter Number Sequencing test and the Vocabulary test.

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[1] The same episodic associations were administered to subjects e03 and e04.

Table 2

Target stimuli linguistic properties by semantic dimensions.

Living Large	**Concreteness**	**Familiarity**	**Imageability**
Lion	627	511	626
Tree	604	613	622
Horse	613	560	624
Bear	585	526	572
Total	2429	2210	2444
Living Small			
Fruit	612	590	587
Baby	589	597	608
Flower	584	566	618
Leaf	593	556	608
Total	2378	2309	2421
Nonliving Large			
Table	604	599	582
Ship	615	553	612
Truck	595	620	621
Sofa	629	564	597
Total	2443	2336	2412
Nonliving Small			
Ball	615	575	622
Book	609	643	591
Coin	581	564	603
Ring	593	589	601
Total	2398	2371	2417

These tests were administered for the following reasons. The vocabulary test was administered to verify that the two groups were matched on verbal intelligence. Because the ability to actively maintain two or more tasks may be an important determinant of task-switching ability (Kray & Lindenberger, 2000), the Letter Number Sequencing test was administered as an estimate of working memory. Similarly, because inhibitory function may be an important process involved in task-switching, the Stroop Test was administered as an index of inhibitory function (Mayr, 2001). Finally, due to its shifting requirements the Trail Making Test was administered as an estimate of task-shifting ability.

Trail Making Test (TMT; Lezak, 1995). The subject is asked in the first phase of the test to connect consecutively numbered circles. Then, in the second phase, the subject is asked to alternate between the number sequence and a letter sequence as fast as possible. The dependent measure was calculated by subtracting the time taken to complete the first trial from the second trial, dividing it by the time necessary to complete the first trial and expressed as a percentage increase. This test requires sustained visual scanning and visual-motor coordination abilities. Further, the requirement on the second part of the test, to alternate between numbers and letters makes this test sensitive to attention and task-shifting deficits. Electrophysiological studies have suggested the recruitment of frontal regions in both phases of the test (Segalowitz, Unsal, & Dywan, 1992). This test has been shown to be sensitive to age and education, with performance declining significantly with each successive decade (Lezak, 1995).

Color Stroop Test (CST: Lezak, 1995). The subject is asked in the first phase of the test to read out-loud and as fast as possible a list of colored words. Then, in the second phase of the test, the subject is asked to name the ink color of a similar list of colored words. The interference measure was calculated by subtracting the time taken to complete the first list from the second list, dividing it by the time necessary to complete the first list and expressed as a percentage increase. The slowing on the interference trial has been attributed to the need to effectively inhibition the dominant response. Successful performance on this test requires sustain concentration and selective attention (Dyer, 1973). Reliable age-related slowing has been documented especially on the interference trial (Spreen & Strauss, 1991).

Letter Number Sequencing (LNS: Wechsler, 1997). The subject is asked to repeat a series of digits and letters presented orally by the examiner, by sorting first the numbers and then the letters in ascending order. This test is thought to be a very sensitive measure of working memory. Results from WAIS III standardization data show a steady moderate decline in Letter Number sequencing performance from the second to the sixth decade of life followed by severe decline thereafter (Kaufman & Lichtenberger, 1999).

Vocabulary (Voc; Wechsler, 1997). The subject is required to give a definition to words presented orally and visually by the experimenter. This test has been shown to be stable throughout an adult's life and is highly correlated with full scale IQ (Kaufman & Lichtenberger, 1999). In this study, it was administered as an estimate of Full Scale IQ in order to verify that groups were matched on verbal intelligence.

For the first twelve subjects (six young and six older), only vocabulary was administered during the first session. Nine (four young and five elderly) of these twelve subjects were later re-contacted after a four month delay and tested on the rest of the neuropsychological tests (Trail Making, Letter Number Sequencing, and the Color Stroop tests)[2]. For the remainder of the participants, all neuropsychological tests were administered during the first session of the experiment.

Learning to Criterion Procedure

The learning of associations between nouns and their arbitrary episodic dimensions took place during a learning-to-criterion procedure that subjects underwent after the administration of the neuropsychological tests. The procedure consisted of a learning phase and a test phase. During the learning phase, each noun appeared on the computer screen in a random order for five seconds in their episodic context. Thus, each noun was presented either in yellow or red font at the top or bottom of the screen. In the test phase, each noun was presented in random order, centrally, and in white font. The subject was asked to respond according to the appropriate cued dimension by pressing the appropriate key (e.g., right for red and top, left for yellow and bottom). Each noun was presented twice, once requiring a font color response and once requiring a screen position response for a total of thirty-two word-dimension stimuli. The learning–test cycle was repeated until the subject responded correctly four times in a row to each of the 32 word-dimension association for a maximum of 9 cycles. If a subject did not learn all the associations after 9 cycles the experimenter decided whether to terminate training or to continue.

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[2] Age and Education data was missing for one young subject. Trail Making Test and Letter Number Sequencing Data were missing for two young and one older subjects. Stroop Test Data were missing for three young subjects and one older subjects.

If the criterion was not reached because of an isolated mistake testing was continued; however, if the subject persistently made the same mistake for more than one association, testing was terminated and the participant was remunerated for his/her participation in the session.

Semantic Tasks Practice

Following the episodic association training, subjects underwent two practice blocks of 96 trials each to become familiar with the semantic tasks' key assignment. The target was preceded by the cue by an interval of 1200 ms. Cues and stimuli were presented randomly.

A practice block of 32 trials involving all four tasks intermixed finished the first session.

Experimental Task

The experimental task immediately followed a practice block. Subjects were tested for six blocks of 256 trials. The approximate duration of each block was from ten to fifteen minutes. Subjects were given long pauses between blocks and were allowed to stand up and walk around.

On each trial, the cue appeared centrally (24 font size) in white font on black background and remained on the screen for 1000 ms. Then, the cue disappeared and a blank screen was visible for 200 ms followed by the target that was distinguished from the cue by a surrounding white rectangle. Subjects were instructed to respond as fast as they could but keeping errors to a minimum. Once the subject responded using a keypad, a 200 ms response stimulus interval (RSI) was followed by the appearance of the next cue. Feedback in case of an error was signaled by a 400 Hz 100ms tone immediately following the response.

The same block was repeated six times for each participant. Within each block, words were selected randomly without replacement with the following constraints: first, given previous findings highlighting the effect of response repetition on switch costs (Mayr, 2001), no more than four response repetitions were allowed. Second, each block had the same number of tasks (i.e., 64 trials for each of the four tasks). Third, each block had the same number of left and right responses (128 each). Fourth, as mentioned earlier, these data were part of a larger design. Due to methodological constraints not relevant here, no run of three repeated tasks was allowed.

Each participant within a group received a slightly different stimulus sequence. This was done to make sure that no more than four response repetitions were presented. Only slight changes in the stimulus order were necessary and, on average, 90% of the stimulus sequence was identical for all participants. Whereas the stimulus sequence was slightly different across participants within each group, the task sequence was identical for all subjects.

Electrophysiological Recording

A nylon EEG cap containing tin electrodes (Electro-Cap International) was used for EEG recording. The EEG was recorded from six midline sites (FPz, Fz, FCz, Cz, CPz, Pz) and 24 lateral sites (prefrontal: FP1, FP2; frontal: F3, F7, F4, F8; frontocentral: FC3, FC4; frontotemporal: FT7, FT8; central: C3, C4; centroparietal: CP3, CP4; temporal: T3, T5, T4, T6; temporoparietal: TP7, TP8; parietal: P3, P4; occipital: O1, O2). A forehead location was used as ground. All sites were referenced to the right ear.

Electro-oculogram activity (EOG) was recorded from electrodes placed at the outer canthi of both eyes (horizontal EOG) and above and below the left eye (vertical EOG). EOG artifacts were corrected off-line for all subjects using a regression algorithm (Gratton, Coles, & Donchin, 1983). EEG was sampled continuously with stimulus and response locked EEG epochs. EEG data was amplified using Neuroscan Synamps in a DC-30 Hz bandwith and sampled at 100Hz for 1300 msec (100 msec pre-stimulus baseline) for both cue-locked and target-locked waveforms. ERP recording was time-locked to the presentation of both the cue and the target.

Results

T-tests, repeated measures analyses of variance (ANOVA) and correlations were conducted on the neuropsychological, event-related potential, and behavioral data using SPSS v.11.0 statistical software for Windows. The Greenhouse-Geisser (1959) non-sphericity correction was employed in repeated measures ANOVA when appropriate. Following convention, unadjusted degrees of freedom are reported, along with the Greenhouse-Geisser adjusted p-value. Mean square error (MSE) values reported are those corresponding to the Greenhouse-Geisser correction. Main effect of variables are reported first but described only if they did not interact with other variables. In the case of significant interactions, the highest order interaction is reported and follow-up Bonferroni-corrected ANOVAs were conducted where appropriate. Statistical significance is assumed at the $\alpha = .05$ level.

When necessary, up to three main analyses were conducted on each dependent variable. (1) Age-related differences were assessed by comparing young and elderly groups. (2) The effects of switch and repeat trials as well as episodic and semantic tasks were assessed. For ERP data, both cue-locked and target-locked data were analyzed separately. (3) ERP and performance data were correlated to analyze individual differences.

Behavioral Data

Behavioral data were obtained simultaneously with ERP data. Participants' reaction times (RT) were measured as the time taken to respond to the target stimulus after it appeared on the screen.

Reaction times were collected for correct trials only. Further, the two trials that followed an incorrect response were excluded from analysis. For each subject, trials with reaction times exceeding three standard deviation from the mean and trials with reaction times less than 200 ms were excluded.

Percent Error

Percent error was directly compared in younger and older subjects using a mixed factorial ANOVA with the factors of task condition (semantic and episodic), switch condition (switch and repeat) and age condition (young and old). Analysis indicated that older adults error rate (M = 4.6%, SE = .673%) and younger adults error rate (M = 3.0%, SE = .619%) were not significantly different (F(1,22) = 3.33, MSE = 19.92, p = .082).

Overall, subjects made more errors during episodic tasks (M = 5.7%, SE = .763%) than semantic tasks (M = 1.9%, SE =.287%; F(1,22) = 28.61, MSE = 11.78, p < .001). This pattern did not interact with the group factor (F(1,22) = 4.01, MSE = 11.78, p =.058). This suggests that the lack of reaction time differences between the two groups, as described below, was probably not due to a trade-off between speed and accuracy.

Reaction Time

Similarly to percent error, reaction time data were directly compared in younger and older subjects using a mixed ANOVA with the factors of task condition (semantic and episodic) and switch condition (switch and repeat). As illustrated in Figure 2, average response time did not differ between younger and older adults (F(1,22) = 1.18, MSE = 284569.9, p =.289). Overall, responses to switch trials were slower than to repeat trials (F(1,22) = 64.46, MSE = 5102.6, p < .001). Also, responses on episodic trials were slower than on semantic trials (F(1,22) = 19.93, MSE = 13818.6, p < .001). Further, there

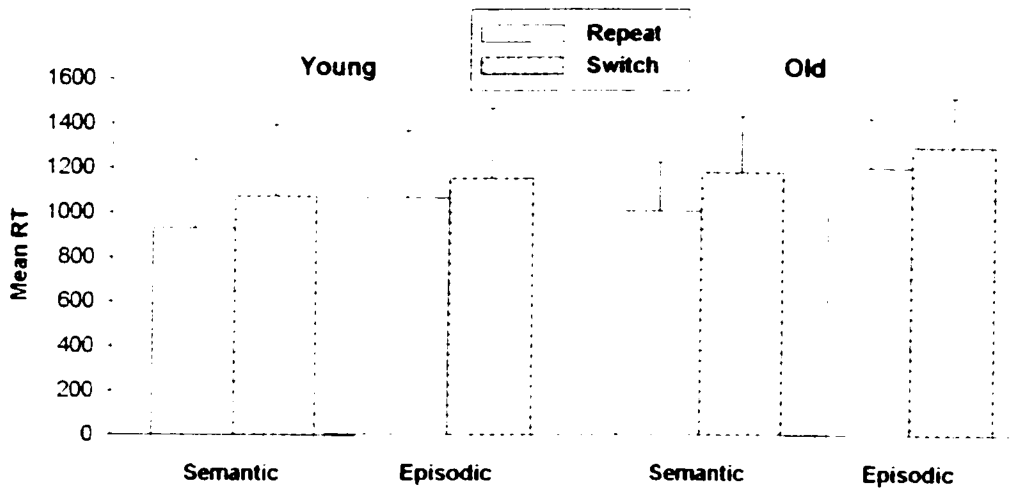

Figure 2. Mean Reaction Time for Semantic and Episodic Switch and Repeat trials for Young and Older Adults. Error bars represent the condition's standard Deviation.

was a significant interaction between the switch and task factors ($F(1,22) = 25.31$, $MSE = 1220.3$, $p < .001$). Semantic repeat trials ($M = 967.1$, $SE = 267.98$) were faster than the semantic switch ($M = 1124.9$, $SE = 290.57$), episodic repeat ($M = 1131.0$, $SE = 272.75$) and episodic switch trials ($M = 1222.2$, $SE = 281.96$). In order to analyze this interaction, a proportional switch cost was derived for each task condition (i.e., semantic and episodic). The switch cost variable was computed by subtracting, at the individual subjects level, the mean repeat reaction time from the mean switch reaction time and dividing this result by the repeat reaction time. This transformation is necessary when comparing age groups in order to factor out possible age-related declines in processing speed. Contrary to the stated hypothesis, episodic switch costs ($M = 7.6$; $SE = 1.427$) were smaller than semantic switch costs ($M = 16.8$, $SE = 2.156$; $F(1,22)= 27.34$, $MSE = 36.64$, $p<.001$). Further, there were no group differences in switch costs magnitudes ($F(1,22) = .08$, $MSE = 36.64$, $p = .735$).

Event-Related Potential Data

Event-related potentials were collected for cue-locked and target-locked epochs and were analyzed separately. Both cue-locked and target locked epochs were 1200 ms long. Statistical analyses were performed on mean waveform amplitudes averaged across the following intervals: 200-400 ms, 400-600 ms, 600-800 ms, and 800-1000 ms for cue-locked activity and 200-400 ms, 400-600 ms, and 600-800 ms for target-locked activity. The six midline electrode sites (FPz, Fz, FCz, Cz, CPz, Pz) were chosen for the analyses since in both groups the effect was most prominent there.

Cue-locked Data

Figure 3 shows, for the selected sites, ERP grand average waveforms averaged across subjects in younger (left side) and older (right side) groups. Central and posterior sites (i.e., Cz, CPz, and Pz) exhibited a generally negative sloping waveform whereas frontal sites (FCz, Fz, and FPz) did not.

The N100 and P200 components reflect early responses of the visual cortical system to the presentation of stimuli. For both groups, they did not differ across conditions. Differences arose only later, when meaning had to be extracted from the stimulus.

ERP data were directly compared in younger and older subjects using a mixed ANOVA with the factors of task condition (semantic and episodic), switch condition (switch and repeat), electrode site (FPz, Fz, FCz, Cz, CPz, Pz) and time (t1: 200-400 ms, t2: 400-600 ms, t3: 600-800 ms, t4: 800-1000 ms). There was a trend towards a main effect of group (F(1,22) = 4.03, MSE = 616.0, p = .057). The group variable significantly interacted with the switch and time factors (F(1,22) = 7.03, MSE = 4.1, p = .002) as well as the site and time factors (F(1,22) = 3.23, MSE = 16.2, p = .037). In light of these interactions, separate ANOVAs were conducted on the two subject groups using the Switch (i.e. Switch and Repeat Conditions), Task (i.e., Semantic and Episodic Conditions), Site (the six electrode sites), and Time (the four time intervals) factors.

Young Adults: ERP grand averages for the episodic and semantic repeat and switch conditions are shown in Figure 3 (left side). Appendix D shows a higher resolution view of the waveforms at site CPz. Waveforms at posterior sites were

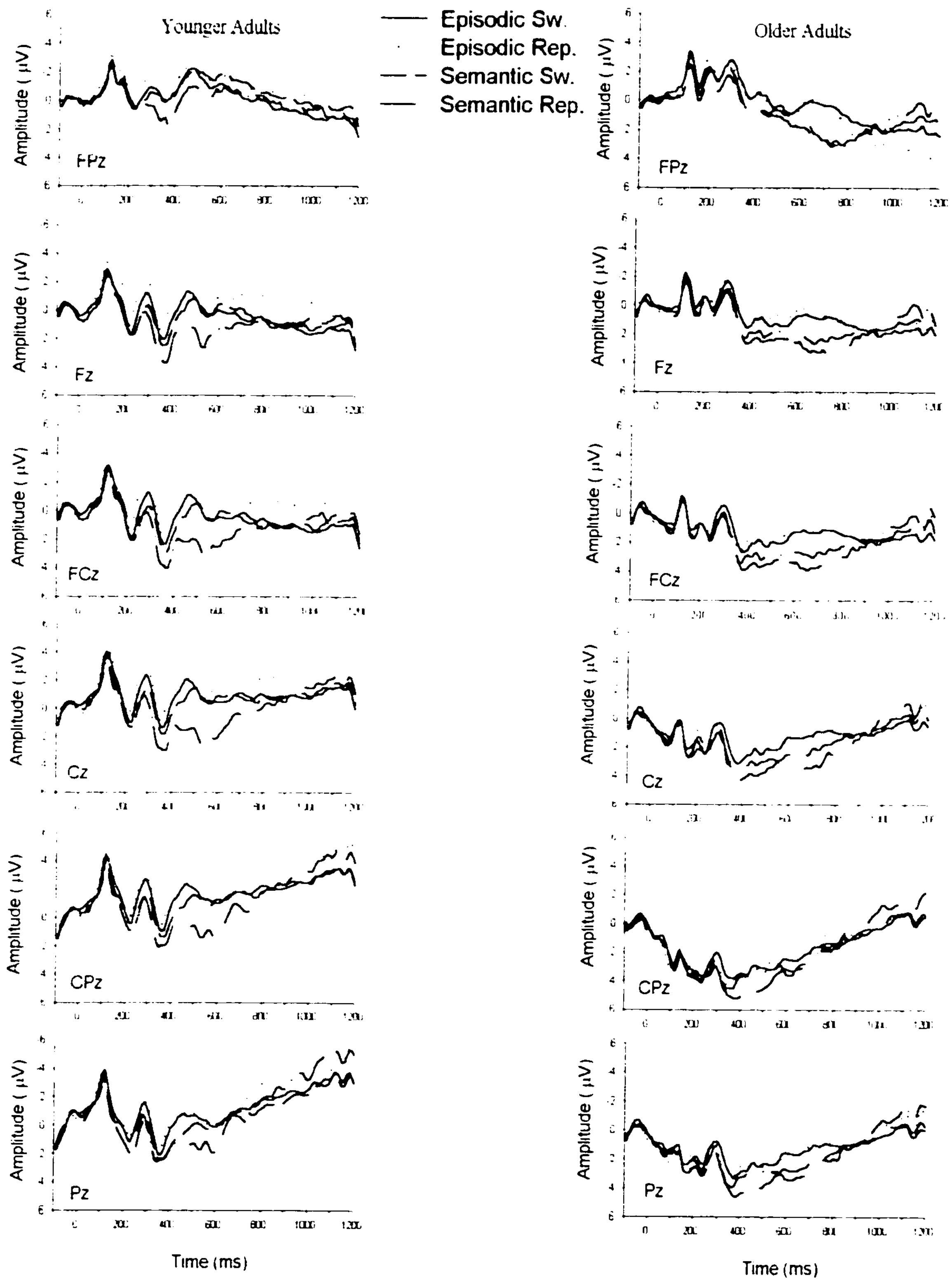

Figure 3. Cue-Locked ERP grand average waveforms for selected midline sites. Young group on the left, Older group on the right.

characterized by a general negative going wave 400-1200 ms following cue onset, whereas frontal sites did not show this rising negativity over the time interval.

Analysis showed that there was a main effect of task; semantic trials (M = -.812, E = .845) were more negative than episodic trials (M = .186, SE = .794; F(1,12) = 10.38, MSE = 30.0, p = .007). There was also a significant interaction between the switch, task and time factors (F(3,36) = 4.11, MSE = 2.3, p = .029). A series of Bonferroni-corrected (p < .012) follow-up ANOVAs conducted at each time interval revealed that there were no significant interactions at intervals 1,3 and 4. At interval 2 (i.e., from 400 to 600 ms following cue presentation), there was a trend toward a significant interaction between the switch and task factors (F(1,12) = 8.25, MSE = 12.5, p =.014) where negativity to semantic repeat cues (M = 1.3, SE = .876) was reduced compared to semantic switch (M = -.4, SE = .826), episodic repeat (M = -1.4, SE = .911) and episodic switch cues (M = -.8, SE = .751), while the latter two did not differ.

Older Adults: ERP grand averages are shown in Figure 3 (right side). Appendix D shows a higher resolution view of the waveforms at site CPz. Similar to the younger group, waveforms at posterior sites were characterized by a general negative going wave 400-1200 ms following cue onset, whereas frontal sites did not show this rising negativity over the time interval. However, contrary to their younger counterparts, there were no significant differences between the waveforms (i.e., no main effect of switch, no main effect of task, no interaction effects, all ps > .170). Further, the older group did not show a reduced negativity to the semantic repeat condition.

Target-locked Data:

Figure 4 shows midline sites target-locked ERP grand average waveforms averaged across subjects in younger (left side) and older (right side) groups. Appendix E shows a higher resolution view of the waveforms at site CPz. Similarly to the cue-locked waveforms, the N100 and P200 components did not differ across conditions for both groups. Also, in both groups, the waveforms were characterized by a general positivity 400-800 ms following target onset, which was most prominent at posterior sites. The positive deflection was generally enhanced following repeat trials.

ERP data were directly compared in younger and older subjects using a mixed ANOVA with the factors of task condition (semantic and episodic), switch condition (switch and repeat), electrode site (FPz, Fz, FCz, Cz, CPz, Pz) and time (t1: 200-400 ms, t2: 400-600 ms, t3: 600-800 ms, t4: 800-1000 ms). There was no significant main effect of group (F(1,22) = 2.72, MSE = 534.9, p = .113). However, the group variable significantly interacted with the task and time factors (F(1,22) = 3.30, MSE = 10.6, p = .045) as well as the site and time factors (F(1,22) = 3.72, MSE = 32.3, p = .018). In light of these interactions, separate ANOVAs were conducted on the two subject groups using the Switch (i.e. Switch and Repeat Conditions), Task (i.e., Semantic and Episodic Conditions), Site (the 6 electrode sites), and Time (the 4 time intervals) factors.

Young Adults: Analysis showed that there was a main effect of the switch factor (F(1,12) = 12.75, MSE = 36.9, p = .004). Repeat trials (M = 1.1, SE = .773) were more positive than switch trials (M = -.14, SE = .655). There was also a significant main effect of site (F(1,12) = 10.06, MSE = 220.0, p = .001), with posterior sites (e.g., Pz: M = 3.7, SE = .739) being more positive than anterior sites (e.g., Fz: M = -1.4, SE = .744). The

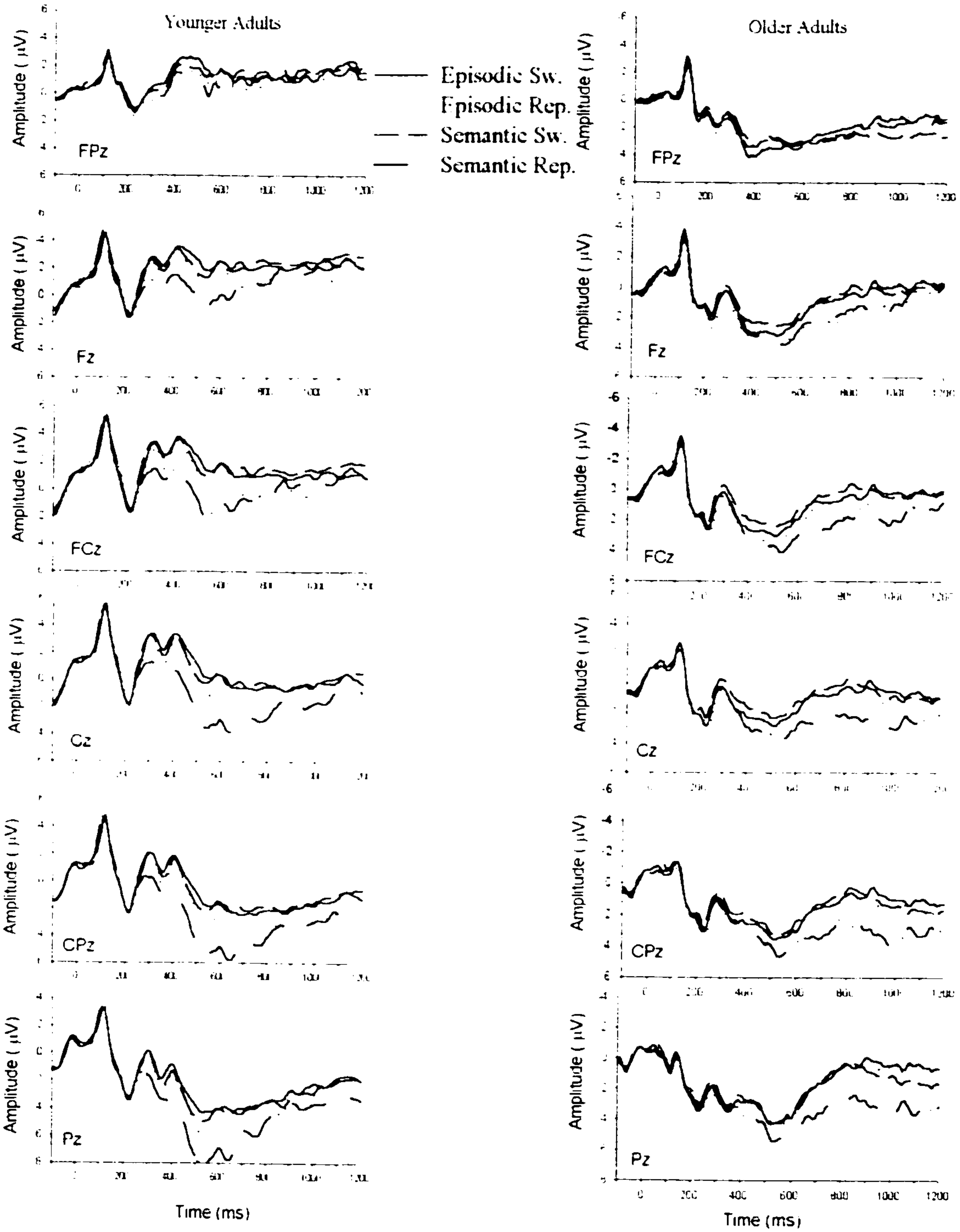

Figure 4. Target-Locked ERP grand average waveforms for selected midline sites. Young group on the left, Older group on the right. Scale at site Pz (-4 , 8 µV) for both groups is different from scale at other sites (-6 , 6 µV)

interaction between the switch, task, and time factors barely missed conventional levels of significance (F(3,36) = 3.04, MSE = 3.0, p = .054). However, because it reached significance using a less stringent sphericity correction (Huynh-Feldt, p = .041), a series of Bonferroni-corrected (p<.012) follow-up ANOVAs were nonetheless conducted at each time interval. The analysis revealed that there were no significant task by switch interactions at interval 1 (F(1,12) = 1.25, MSE = 1.70, p = .285), interval 3 (F(1,12) = 1.81, MSE = 10.80, p = .204), and interval 4 (F(1,12) = 0.02, MSE = 5.37, p = .966). Although the task by switch interaction also did not reach significance at time 2 (i.e., from 400 to 600 ms from target presentation), the effect was clearly more pronounced than at the other intervals (F(1,12) = 3.50, MSE = 10.63, p = .086). Although visual inspection of the waveforms (Figure 4, left side; Figure E1), clearly suggests that positivity to semantic repeat trials is enhanced relative to all other conditions, the difference is not statistically significant.

Older Adults: ERP grand averages are shown in Figure 4 (right side). Appendix E shows a higher resolution view of the waveforms at site CPz. Similar to the younger group, the waveform is characterized by a general positivity 400-800 ms following target onset most prominent at posterior sites. Although this positivity in the 400-800 ms interval appears increased in the semantic condition relative to all other conditions, the difference did not satisfy conventional levels of significance. The switch by time by site interaction barely missed conventional levels of significance (F(15,150) = 3.54, MSE = 2.21, p = .063). Bonferroni-corrected (p < .012) follow-up ANOVAs revealed a trend toward significance at FCz in the 600-800 ms interval (F(1,10) = 5.53, MSE = 4.34, p = .04) and at Cz in the 600-800 ms interval (F(1,10) = 5.33, MSE = 4.72, p = .044).

Correlations between Neurophysiological, Neuropsychological and Behavioral measures

Pearson product-moment correlations were conducted to determine the relationships between ERP activity, neuropsychological performance (Stroop interference, Letter Number Sequencing, Trail Making, and Vocabulary scores) and reaction time.

Several significant correlations were found between behavioral and neuropsychological data (Table 3). Repeat RT was used as an estimate of processing speed and it significantly negatively correlated with performance on the Letter Number Sequencing (r_{21}=-.529, p=.014) and the Vocabulary subtests of the WAIS III (r_{24}=-.47, p=.019). Interestingly, the general measure of switch cost did not correlate significantly with any other variable. Age had a significant negative correlation with Letter Number Sequencing (r_{20}=-.54, p=.013). TMT performance correlated significantly only with Stroop test performance (r_{19}=.50, p=.013). Aside from the already mentioned correlation with TMT performance, Stroop test performance correlated significantly with Letter Number Sequencing (r_{19}=-.56, p=.013), and Vocabulary (r_{19}=-.49, p=.033). Aside from the previously mentioned correlations, LNS also correlated significantly with Vocabulary (r_{21}=.55, p=.01).

The significant correlation between Letter Number Sequencing and Repeat reaction time is an interesting finding that will be discussed later. In light of its implication for the results, Letter Number Sequencing was correlated with semantic and episodic repeat reaction times while controlling for age (i.e., this was done to control for

Table 3

Correlations between Neuropsychological and Behavioral Data

Subjects (n = 24)	1	2	3	4	5	6	7
1. Repeat RT [a]	--	-.17	.34	.06	.35	-.53*	-.47*
2. Switch Cost [b]		--	-.01	-.19	-.01	-.09	-.12
3. Age			--	.16	.38	-.54*	-.17
4. Trail % Incr. [c]				--	.50*	-.26	-.12
5. Stroop % Incr. [d]					--	-.56*	-.49*
6. LNS [e]						--	.55**
7. Vocabulary [f]							--

* $p < .05$

** $p < .01$

a. Repeat Reaction Time includes both episodic and semantic repeat trials.

b. Switch Cost includes episodic and semantic switch costs.

c. % increase in time to finish the second relative to the first phase of the TMT

d. % increase in time to finish the second relative to the first trial of the Stroop Test

e. Raw scores on the Letter Number Sequencing subtest of the WAIS III.

f. Raw scores on the Vocabulary subtest of the WAIS III.

the known effects of age on working memory; Baddeley, 1986). No significant correlation was found between Letter Number Sequencing and episodic repeat reaction time ($\underline{r}_{(20)} = -.20$, $\underline{p} = .383$), but a significant correlation was found between Letter Number Sequencing and semantic repeat reaction times ($\underline{r}_{(20)} = -.43$, $\underline{p} = .046$), suggesting that semantic but not episodic repeat trials remain activated in working memory.

Significant correlations were found between behavioral and electrophysiological data. In order to determine the electrophysiological analog to the behavioral switch cost, a difference wave was computed by subtracting the repeat average waveform from the switch average waveform for episodic and semantic trials for both younger and older adults. Mean amplitude of the difference waveform was computed along 400 ms intervals (t1: 200-600 ms; t2: 600-1000 ms) for the cue-locked waves and 200 ms intervals (t1: 400-600 ms; t2: 600-800 ms) for the target-locked waves. This was done to avoid response artifacts in the target-locked interval as the average response time fell in the latest interval (i.e., 800-1000 ms). Data from the six midline sites were reduced to three sites (frontal: average of FPz and Fz; Central: average of FCz, and Cz; Posterior: average of CPz and Pz). Each time/site variable was correlated with proportional switch costs. In general, a different pattern of correlations was found in the younger and older group. In the younger group, significant correlations tended to be found in the semantic condition whereas in the older group significant correlations were found in the episodic condition. In both groups correlations with behavioral switch costs were significant only in the cue-locked time intervals and not in target-locked intervals.

Younger Subjects. Table 4 (top panel) shows the correlation table between the cue-locked ERP difference wave and the semantic switch costs. There was a significant positive correlation (Figure 5; $r_{12} = .61$, $p < .05$) between the later interval (i.e., 600-1000 ms) of the central regions of the midline of the cue-locked difference ERP wave and switch costs in the semantic condition but not in the episodic condition (Table 5, top panel). As can be seen in Figure 3 (left side) for the posterior sites especially, the semantic repeat waveform is less negative than the semantic switch waveform in the early phases of the cue-target interval but, at around 800 ms the semantic repeat waveform crosses over and becomes more negative than the semantic switch waveform. This relationship suggests that the higher the negativity in the semantic repeat condition relative to the semantic switch condition, the larger the semantic switch cost will be (See Appendix C).

Older Subjects. Table 5 (bottom panel) shows the correlation table between the cue-locked ERP difference wave and the episodic switch costs. In comparison to the young adults, there was a significant negative correlation (Figure 6; $r_{10} = -.61$, $p < .05$) between the later interval (i.e., 600-1000 ms) of the central regions of the midline of the cue-locked difference ERP wave and switch costs in the episodic condition but not in the semantic condition (Table 4, bottom panel). This relationship suggests that the less negative the repeat condition relative to the switch condition the higher the episodic switch cost will be. It must be noted however, that this correlation is driven by two subjects with a higher switch cost compared to their peers. Without these two subjects, the correlation disappears.

Table 4

Correlations between semantic switch cost and Cue-locked ERP Switch – Repeat difference wave amplitude at selected composite sites for two time intervals

Young (n = 13)	1	2	3	4	5	6	7
1. Semantic Switch Cost	--	.23	.18	.13	.41	.61*	.45
2. Frontal 200-600 ms		--	.38	.16	.65*	.25	.14
3. Central 200-600 ms			--	.91*	.10	.65*	.65*
4. Posterior 200-600 ms				--	.10	.67*	.76*
5. Frontal 600-1000 ms					--	.51	.34
6. Central 600-1000 ms						--	.92*
7. Posterior 600-1000 ms							--

Old (n = 11)	1	2	3	4	5	6	7
1. Semantic Switch Cost	--	.34	.32	.05	.10	-.03	-.37
2. Frontal 200-600 ms		--	.86*	.56	.73*	.63*	.30
3. Central 200-600 ms			--	.84*	.64*	.76*	.54
4. Posterior 200-600 ms				--	.43	.62*	.64*
5. Frontal 600-1000 ms					--	.79*	.32
6. Central 600-1000 ms						--	.75*
7. Posterior 600-1000 ms							--

* _p_< .05

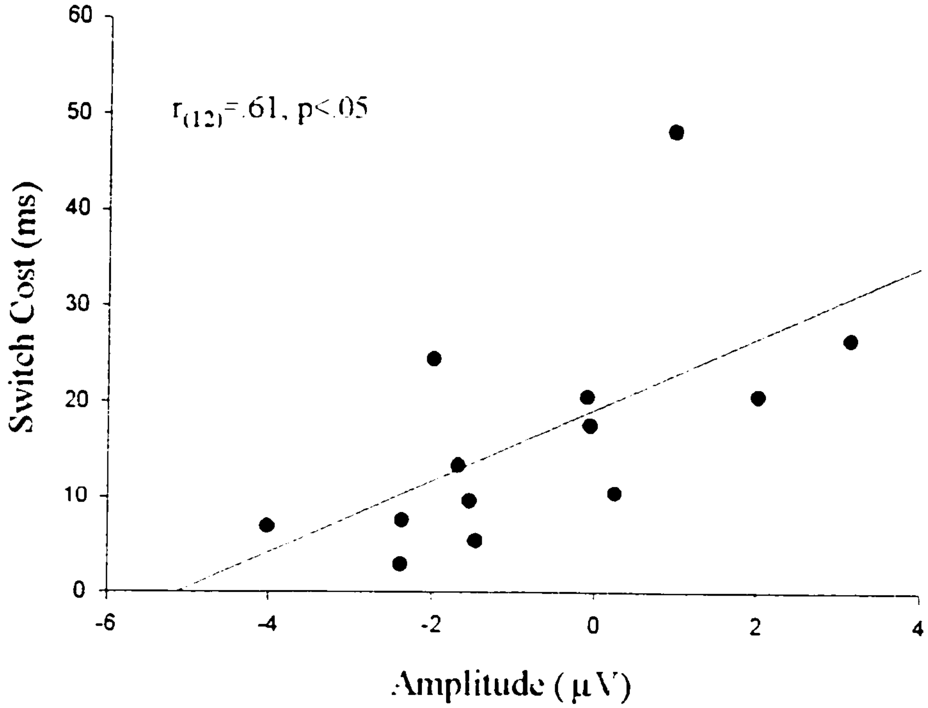

Figure 5. The relationship between cue-locked ERP Semantic Switch minus Repeat amplitude (Central sites, 600-1000 ms) and RT semantic switch cost in the younger group

Table 5

Correlations between episodic switch cost and Cue-locked ERP Switch – Repeat difference wave amplitude at selected composite sites for two time intervals

Young (n = 13)	1	2	3	4	5	6	7
1. Episodic Switch Cost	--	-.24	-.34	-.51	.06	-.03	-.25
2. Frontal 200-600 ms		--	.72*	.27	.65*	.55	.16
3. Central 200-600 ms			--	.81*	.63*	.84*	.69*
4. Posterior 200-600 ms				--	.33	.69*	.86*
5. Frontal 600-1000 ms					--	.76*	.48
6. Central 600-1000 ms						--	.83*
7. Posterior 600-1000 ms							--

Old (n = 11)	1	2	3	4	5	6	7
1. Episodic Switch Cost	--	-.55	-.54	-.52	-.61*	-.26	-.10
2. Frontal 200-600 ms		--	.80*	.60	.38	.20	-.11
3. Central 200-600 ms			--	.89*	.60	.51	.22
4. Posterior 200-600 ms				--	.73*	.51	.40
5. Frontal 600-1000 ms					--	.59	.53
6. Central 600-1000 ms						--	.91*
7. Posterior 600-1000 ms							--

* $p < .05$

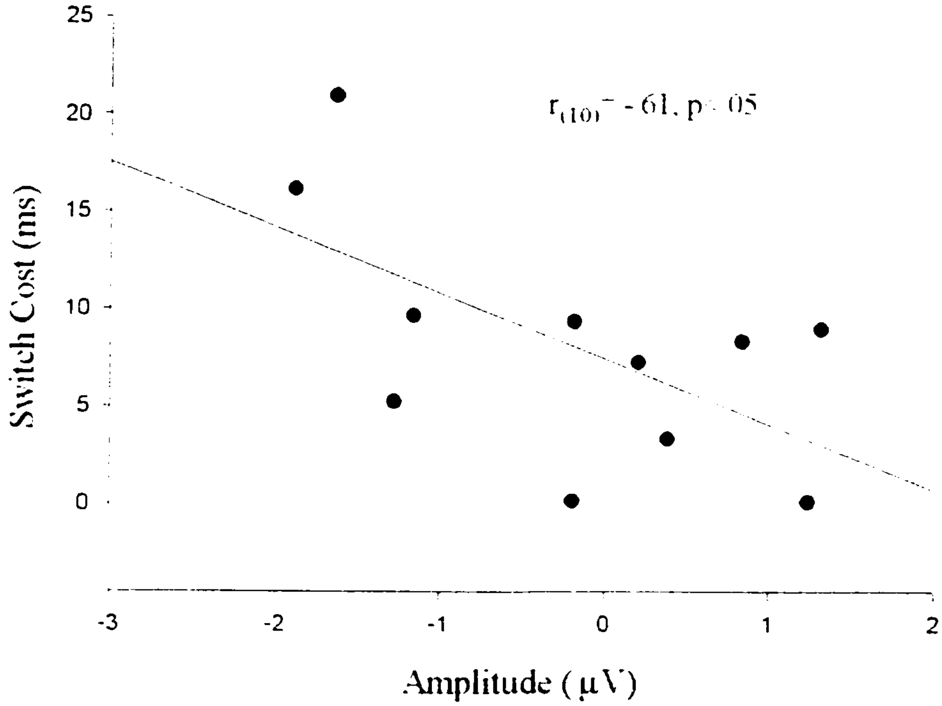

Figure 6. The relationship between cue-locked ERP Episodic Switch minus Repeat amplitude (Frontal sites, 600-1000 ms) and RT episodic switch cost in the older group.

Table 6

Correlations between semantic switch cost and Target-locked ERP Switch – Repeat difference wave amplitude at selected composite sites for two time intervals

Young (n = 13)	1	2	3	4	5	6	7
1. Semantic Switch Cost	--	-.41	-.44	-.34	-.22	-.50	-.27
2. Frontal 400-600 ms		--	.88*	.77*	.60*	.61*	.46
3. Central 400-600 ms			--	.96*	.54	.80*	.72*
4. Posterior 400-600 ms				--	.46	.83*	.84*
5. Frontal 600-800 ms					--	.66	.34
6. Central 600-800 ms						--	.90*
7. Posterior 600-800 ms							--
Old (n = 11)	1	2	3	4	5	6	7
1. Semantic Switch Cost	--	-.11	.06	.12	-.15	-.10	-.11
2. Frontal 400-600 ms		--	.81*	.71*	.91*	.87*	.80*
3. Central 400-600 ms			--	.96*	.62*	.89*	.87*
4. Posterior 400-600 ms				--	.52	.84*	.88*
5. Frontal 600-800 ms					--	.84*	.75*
6. Central 600-800 ms						--	.96*
7. Posterior 600-800 ms							--

* $p < .05$

Table 7

Correlations between episodic switch cost and Target-locked ERP Switch – Repeat difference wave amplitude at selected composite sites for two time intervals

Young (n = 13)	1	2	3	4	5	6	7
1. Episodic Switch Cost	--	-.25	-.22	.12	-.32	-.35	-.08
2. Frontal 400-600 ms		--	.78*	.56*	.42	.55*	.48
3. Central 400-600 ms			--	.85*	.37	.76*	.79*
4. Posterior 400-600 ms				--	.26	.60*	.82*
5. Frontal 600-800 ms					--	.82*	.64*
6. Central 600-800 ms						--	.89*
7. Posterior 600-800 ms							--
Old (n = 11)	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1. Episodic Switch Cost	--	.55	.47	.25	.46	.29	.12
2. Frontal 400-600 ms		--	.89*	.75*	.98*	.87*	.73*
3. Central 400-600 ms			--	.92*	.86*	.92*	.92*
4. Posterior 400-600 ms				--	.76*	.92*	.92*
5. Frontal 600-800 ms					--	.92*	.81*
6. Central 600-800 ms						--	.96*
7. Posterior 600-800 ms							--

* p< .05

Discussion

The goal of the study was to examine age and task difficulty effects on behavioral and electrophysiological measures of task-switching. Since episodic retrieval demands are higher than semantic retrieval demands, younger subjects were expected to show higher switch costs on episodic tasks than semantic tasks (Mayr & Kliegl, 2000) and since episodic retrieval demands were assumed to be higher for older adults compared to younger adults, it was hypothesized that although semantic switch costs should be comparable between the two groups, episodic switch costs should be significantly higher in the older group compared to their younger counterparts.

To review, there were two major findings. First, there were no age-related differences in switch cost magnitudes for either semantic or episodic tasks. Second, electrophysiological data for the young group showed a facilitation for the semantic repeat task relative to all other tasks, suggesting that semantic and episodic tasks were processed differently by the system.

Behavioral Data

As expected, switch trials were slower than repeat trials, giving rise to a reliable switch cost in both young and older adults and for both episodic and semantic tasks. Episodic trials were on the whole slower than semantic trials, suggesting that participants, both young and older, found the episodic tasks more difficult to perform. Further support for the increased difficulty of episodic tasks came from the significantly higher number of errors committed by participants (although accuracy was still high), both young and old, on episodic trials compared to semantic trials.

One result that was unexpected was the absence of an age effect on general reaction times. This was unexpected since cognitive slowing is a hallmark of the cognitive aging literature (Salthouse, 1996) and the older participants were predicted to perform more slowly than their younger counterparts. Older and younger participants performed similarly with respect to both error and reaction time measures. This equivalent performance may be due to the stringent accuracy and learning performance inclusion criteria that led to a highly selected group of older adults.

The performance of the elderly group on neuropsychological tests supports this notion. Although the older group had significantly fewer years of education (although still highly educated), they scored similarly to younger adults on the Vocabulary subtest of the WAIS III (Wechsler, 1997). This subtest has been found to be very stable throughout an individual adult life and it is the subtest that correlates most strongly with Full Scale IQ (Kaufman & Lichtenberger, 1999). There is some controversy in the literature as to whether scores on the Vocabulary subtest of the Wechsler batteries decline with age or not. On the one hand, longitudinal studies show a slight improvement in scores with every successive decade until the early 80s (Schaie, 1997). On the other hand, cross-sectional studies tend to show a marked decline in scores from middle to old age (Kaufman, Reynolds, & McLean, 1989). The difference between the two is probably due to a cohort effect. Since the methodology used in this study more closely resembles a cross-sectional design, the fact that the two groups did not differ on the raw scores of the Vocabulary subtest of the WAIS III suggests that the older group was high functioning.

Further evidence that the elderly group was comprised of high functioning individuals comes from the fact that the two groups did not differ on the Stroop Task and the Trail Making Task. The interference trial of the Stroop Task has been shown to be particularly sensitive to age effects (Daigneault, Braun, and Whitaker, 1992) and normative studies on the Trail Making Task indicate that performance decreases significantly with age (Stuss, Stethen, & Poirier, 1987). One study that did not find this age difference compared a group of elderly with significant more years of formal education than their younger counterparts (Boll & Reitan, 1973).

Given the known effects of age on these tests' performance, the older group was expected to perform significantly more poorly on these two tests. The fact that the two groups' performance on these two tests was not significantly different reinforces the idea that the older group was made up of high functioning individuals. The composition of the older group was probably not due to a random selection error. The difficulty of the task probably acted as a selection criterion. In other words, it is possible that, given the stringent criteria outlined in the method section, an elderly participant was likely to be a highly functioning individual to be able to participate in this experiment.

Another reason that may explain the two groups' similar behavioral performance may have to do with the instructions given to the subject during the learning to criterion phase. Because of the poor results obtained by elderly pilot subjects on the episodic associations when no instructions were given, all subjects were explicitly asked to make a mental image of the arbitrary association. There is evidence that providing ample time and encoding strategies to young and older adults greatly reduces age-related differences in both memory encoding and retrieval performances (Treat & Reese, 1976). In other words, it is possible that the explicit instructions given to all subjects may have leveled the playing field and contributed to the good performance of the elderly group.

The only measure the two groups differed on is the WAIS III, Letter Number Sequencing task (LNS; Wechsler, 1997). LNS is thought to be a sensitive measure of working memory because subjects have to keep the auditorily received letters and digits "on-line" and sort them in ascending order. The requirement of simultaneous storage and manipulation of information make the LNS a sensitive measure of working memory. Working memory is also a function that has been highlighted as one of the most important executive functions to be selectively affected by normal aging (Baddeley, 1986). The fact that the working memory difference between the two groups did not seem to impact the older group's behavioral performance may be due to the choice of experimental design. By providing the participant with information about the upcoming trial, the cued design minimizes working memory demands.

Contrary to our expectations, not only did the two groups not differ on RT measures, but they also did not differ on switch cost magnitude for both semantic and episodic tasks. It was hypothesized that given that older adults have been shown to have difficulties on episodic tasks, and given the high experimental demands, they would be disproportionately slowed – relative to their younger counterparts – on episodic switch trials but not on episodic repeat trials or on semantic trials. However, the results showed that older adults were not disproportionately slowed on episodic switch trials compared to younger adults. In fact, the pattern of reaction times on the four conditions was similar in the two groups. Again, this may be due to the highly selected group of older adults. On the other hand, the lack of age effects on switch cost magnitudes may not be due to the high functioning status of the elderly participants only.

Given the known age-related decline in executive functions, the fact that this elderly group showed almost identical switch costs as their younger counterparts suggests that either cued task-switching requires little executive processes, or that the executive processes involved in task switching are spared in older adults. Previous studies have shown that, given enough practice (Kramer et al., 1999; Kray & Lindenberger, 2000), or by providing external cues (Kray, Li & Lindenberger, in press) older adults' switch costs are equivalent to their younger counterparts. Studies comparing frontal lobe patients and normal controls have shown no difference in specific switch costs (Keele & Rafal, in press; Mecklinger, von Cramon, Springer, & von Cramon, 1999), suggesting that switch costs, as measured in the current experiment, are not necessarily a frontal phenomenon and are therefore relatively spared in older adults.

The most interesting and counterintuitive result of the experiment was that for both groups, the episodic switch cost was smaller than the semantic switch cost. Based on previous experiments (Mayr & Kliegl, 2000), we expected episodic switch costs to be larger than semantic switch costs. This prediction was based on the premise that the task rules necessary to perform a task need to be retrieved from long-term memory. The task rules needed to be retrieved refer largely to the stimulus-response mappings relevant to each task and, in addition to those, episodic tasks but not semantic tasks, also require the activation of an arbirtary episodic context. This extra requirement should make episodic tasks more difficult to activate than semantic tasks, and switching to an episodic task more time consuming than switching to a semantic task. The time it takes to perform a new task less the time it takes to repeat a task (i.e., the switch cost) is thought to reflect the processes necessary to deactivate the previous task, shift to the new task and activate it. Assuming that repeating a task does not require deactivating and then reactivating it, the more time it takes to retrieve the task rules from long-term memory, the larger the switch cost will be.

The assumption that performing a new task requires extra processes compared to repeating a just performed task may not hold up in some instances. Because the switch cost is made up of the switch and the repeat components, a small switch cost may be due to fast switch trials, to slow repeat trials, or both. Although comparisons with other experiments should be taken with caution because of methodological differences, Mayr and Kliegl (2000; experiment 2) reported, in a cued design where subjects had to switch between four tasks, episodic switch reaction times roughly 15% slower than semantic switch reaction times, which in turn were roughly 30% slower than episodic repeat trials. In this experiment, although young subjects' episodic switch trials were roughly 8% slower than semantic switch trials, episodic repeat trials were identical to semantic switch trials. In other words, in the current experiment, there was little performance difference between the episodic repeat condition and the two switch conditions, suggesting that the smaller episodic switch cost were due to a relatively slow episodic repeat condition.

There could be at least three reasons that could account for the relatively slow episodic repeat trials. First, because this was a cued task, and switch and repeat trials were interspersed randomly, there was an advantage in adopting a neutral preparatory stance since the subject does not know if the next trial is a switch or a repeat one. Second, switching to a new task requires more resources than repeating a just performed task. This difficulty is enhanced by the fact that in this experiment participants must switch between four tasks. It is possible that under these circumstances the system will adopt a more conservative strategy whereby the last used task is suppressed immediately after it is carried out in order to be better positioned for a possible switch to another task. Third, because 80% of trials are switches, the suppression of the last used task is further encouraged because the next trial is likely to be a switch.

In summary, because of the considerable task demands imposed on the participant as well as the relative frequency of switch and repeat trials in this experiment, it is possible that the participants could not benefit from repeated trials to the same extent as in a more traditional two-tasks switching design. The likely reason is that the repeated task has to be reactivated. As plausible as this account seems to be in explaining the relatively small switch costs obtained in this experiment it does not account for the fact that episodic switch costs were significantly smaller than semantic switch costs. The difference between semantic and episodic switch costs suggests that the system processes the two types of tasks in a different way.

One way to account for this difference is to hypothesize that when a task is deactivated, the system inhibits it so that it does not interfere with current tasks. It is possible that, the more complex a task, the stronger it must be inhibited. Tentative evidence for this account comes from a recent experiment by Mayr and Kliegl (2000). Because episodic task-sets are more difficult to activate, they may need to be inhibited more strongly than semantic tasks once they have been used. In the event of a repeat trial, episodic task-sets would have to overcome stronger inhibition than semantic task-sets resulting in slower episodic repeat trials and smaller episodic switch costs. Because a semantic task is relatively easy, the system does not need to inhibit it very much. When it is cued again immediately, it will be primed in the system and its re-establishment facilitated. On the other hand, the episodic task is more complex and therefore when no longer needed, it will be strongly inhibited. When it is immediately re-cued, it may actually be more difficult to re-prepare for it than to prepare for a new task.

Another possible explanation for the fact that episodic repeat trials appear to be reactivated whereas semantic repeat trials do not, is that semantic tasks are kept in working memory but episodic tasks cannot be held in working memory because they are too demanding. Instead of invoking the need to actively inhibit the difficult task, this hypothesis takes the opposite approach and proposes that the easier task can be actively maintained in the system but not the difficult one. Because estimates of working memory were measured in this experiment (i.e., performance on Letter Number Sequencing) it was possible to test this hypothesis by correlating working memory with both semantic and episodic repeat reaction times while covarying the age factor since, as was discussed above, working memory is significantly affected by age. If indeed semantic repeat trials can be kept in working memory, but not episodic repeat trials, then individual variability in working memory performance will be correlated with individual variability in semantic repeat reaction times but not episodic repeat reaction times. This is in fact what was found. No significant correlation was found between working memory and episodic repeat reaction time, but a significant correlation was found between working memory and semantic repeat reaction times. Although the present data cannot validate one hypothesis rather than the other, it remains that episodic repeat trials appear to require reactivation whereas semantic repeat trials appear to be facilitated. The ERP data reviewed next provides support for this account.

ERP Data

In general, significant ERP results were found for the younger group. As expected, cue-locked activity was characterized by CNV-like general negative sloping waveforms observed at central and parietal sites. When one stimulus (the warning, or signal stimulus) always precedes (or is contingently related to) another (the imperative stimulus), a negative potential is observed between the two stimuli. The CNV has been related to cortical priming and can be considered an index of preparation for the target stimulus (Walter, Cooper, Aldridge, McCallum & Winter, 1964).

In the context of this experiment, the late negativity may reflect preparatory activity in anticipation of the to-be-performed task. An important feature of the cue-locked waveforms, in both younger and older adults was the absence of negativity at frontal sites. This stands in contrast to previous studies (Lorist, Klein, Nieuwenhuis, De Jong, Mulder, & Meijman, 2000; Phillips, Poulsen & Segalowitz, 2000; Poulsen, Luu, Tucker, Speiser, Segalowitz, Phillips, & Davey, 2001) which observed preparatory negativity at frontal sites. The most plausible explanation for this difference is that this study is the only one that used an explicitly cued design as opposed to a color or spatial cue. This may have minimized working memory demands because subjects do not have to keep track of what the upcoming trial will be. Interestingly, this methodological difference suggests that frontal preparatory negativity observed in other studies may be due to working memory demands. It also reinforces the idea, mentioned above, that the processes associated with a cued task-switching design may not be predominantly frontally mediated.

Another prominent effect observed in the young group's cue-locked waveforms is a strong divergence between the semantic repeat waveform and the other three conditions' waveforms between 400 and 800 ms after the presentation of the cue. This effect was pervasive across all areas of the scalp but was most accentuated in the central and centro-parietal midline sites (see Figure 3, left column). Whereas in response to three of the four conditions the waveform shows a clear negative deflection, the negativity is reduced following the repetition of a semantic cue until about 800 ms after cue presentation.

The timing and topography of the divergence suggests that this phenomenon may be related to the N400 component of the human evoked potential. The N400 is a component sensitive to semantic priming that was first described by Kutas and Hillyard (1980). Participants were shown sentences that varied in word endings. The final word was either semantically deviant (e.g., He spread the warm bread with *socks*"), semantically correct but physically deviant (e.g., "It was his first day at WORK"), or was neither semantically nor physically deviant (e.g., "She put on her high heeled shoes"). A large negative deflection with a latency of about 400 ms after stimulus onset was observed in response to semantically deviant sentences but not for the physically deviant sentences and the normal sentences. Studies using word pairs, where a prime-unrelated target will evoke an N400 whereas a prime-related target will not, have shown that the N400 reflects processes that are semantic in nature (for a review, see Kutas & Van Petten, 1988). Furthermore, the processes associated with the N400 are sensitive to priming caused by automatic spreading of activation. N400 amplitude varies inversely with semantic priming; that is, a word will elicit an N400 to the extent that it is not primed in the system (Osterhout & Holcomb, 1995).

Thus, in the present experiment, the absence of the N400 to repeated semantic task cues may suggest that the task-set is primed in the system. Because switch trials are not primed, they could produce an N400. A reduced N400 amplitude would be expected in response to repeat trials because the task-set had recently been activated in the system.

The present results showed that the reduced N400 occurred only following the repetition of a semantic cue. Interestingly, following the repetition of an episodic cue, the waveform showed an N400 component as large as on switch trials. This suggests that, even though it had been just performed, the repeated episodic task was not primed in the system. This result supports the hypothesis raised above – during the discussion of the behavioral data – that episodic and semantic tasks are processed differently by the system. Either because episodic tasks are more difficult to activate than semantic tasks and may be more forcefully inhibited when no longer needed, or because episodic tasks are too demanding to be maintained in working memory. When evoked again on the following trial, they are not facilitated and must be reactivated, requiring the same amount of resources necessary to activate a new task.

Further evidence in favor of the reactivation hypothesis comes from a recent fMRI study (DiGirolamo, Kramer, et al., 2001), investigating the neural substrates involved during task-switching in both young and older adults. Results showed that young adults recruited different brain areas during switch and repeat trials whereas older adults recruited similar areas for both switch and non-switch trials. It is possible that the reason older adults required more cognitive resources to perform repeat trials was because the task-set had to be reactivated. In the context of the current experiment, young adults may have been faced with the same increased cognitive demands as the older adults when performing the challenging episodic tasks. As a result, brain activation would be more similar for episodic switch and repeat trials than for semantic switch and repeat trials since the processes required to perform episodic switch and repeat trials would be similar (i.e., both the switch and repeat tasks are deactivated and then reactivated). Visual inspection (Figure 3; left column) shows that, episodic switch and repeat waveforms are quite similar whereas the semantic switch and repeat waveforms appear quite different from each other.

In summary, the ERP and behavioral data combined provide evidence that episodic and semantic tasks were not processed in the same way, at least in the young group. Because of the demands of the experiment, subjects may have been encouraged to deactivate the just performed task. The cue-locked waveforms suggest that episodic tasks were either inhibited more strongly than semantic tasks or not maintained in working memory as easily as semantic tasks. Either way, the lack of facilitation is reflected by the presence of the N400 in response to the repetition of episodic cues suggesting that episodic repeat trials were not primed in the system. The facilitation associated with semantic tasks is reflected in the absence of N400 following the repeat of semantic trials.

It is reasonable to hypothesize that the extent to which a task-set is facilitated in the system will determine performance on the trial. In order to test this hypothesis a difference wave was computed by subtracting the repeat wave from the switch wave for both the semantic and episodic conditions. Average waveform amplitudes were then correlated with the switch costs. A significant positive correlation was found between the semantic switch cost and the 600-1000 ms interval of the semantic difference wave over the central midline sites in younger adults only (Table 4, top panel; Figure 5).

To understand this result, one must keep in mind that the switch cost is made up of two measures, the switch and the repeat trials. A large switch cost may reflect slow performance on the switch trial or facilitated performance on the repeat trial. It is reasonable to assume that, in the context of this experiment, switch cost magnitude is driven, at least in part, by performance on repeat trials. Higher switch costs, and presumably faster semantic repeat reaction times (i.e., semantic repeat facilitation) were correlated with late difference wave's amplitude. In other words, the extent to which the semantic repeat wave became more negative than the switch wave at the later stages of the waveform actually predicted switch cost magnitude across subjects. The same relationship was not found for episodic tasks in the young group, where RT performance was slow and switch costs were relatively small. It is possible that task rules must be retrieved from long-term memory whenever an episodic task is performed, regardless of whether or not it had been repeated.

Target-locked activity

Consistent with previous studies, target-locked results show a positivity between 400 and 800 ms following target presentation most prominent at the parietal midline site. This P300-like positivity is enhanced for repeat trials relative to switch trials. Although the interaction between task and switch condition missed conventional levels of significance, visual inspection of the waveform, shows that the positivity to semantic repeats is enhanced relative to semantic switch trials.

The P300 has been interpreted as an index of resource allocation (Ullsperger et al., 2001), stimulus evaluation and working memory updating (Donchin & Coles, 1988). In more general terms, whereas the CNV could be interpreted as an index of cognitive preparation, the P300 reflects stimulus identification and stimulus-response mapping (Hohnsbein, Falkenstein, & Hoormann, 1998). The P300 like component observed in this study could be explained in two ways. First, because task repetitions made up only 20% of total number of trials, this positivity may be due to a P300 response to the infrequency of the task condition. However, this interpretation may need to be tempered for three reasons. First, in the present experiment, it was the task repetition that was infrequent and not any of the 16 target words or of the four task-sets as such. The experimental design ensured that all target words and task-sets occurred in the same frequency. Second, in a recent study Kray, Li, and Lindenberger (submitted) found no effect of switch frequency on both specific and general switch costs, suggesting that switch frequency does not modulate RT switch cost processes. Third, semantic repeats occurred as frequently as episodic repeats, yet they elicited a larger positivity (although not statistically significant), suggesting that the P300 reflects another phenomenon.

Previous experiments (Lorist et al., 2000; Phillips, 2001; Poulsen et al., 2001; Ullsperger, Freude, Dehoff, & Erdmann, 2001) have shown an enhanced P300 to repeat trials relative to switch trials. This increased positivity has been interpreted as an index of resource allocation (Ullsperger et al., 2001). A larger positivity may suggest that targets are processed more easily and extensively on semantic repeat trials than on episodic repeat and switch trials.

Older group ERPs

The goal of this experiment was to examine age differences in task switching. Having found no significant behavioral differences, it was reasonable to expect that, although older adults perform at the same level as their younger counterparts, differences would become apparent in their electrophysiological recordings. In general, the waveforms derived from the older group present the same general morphology as the younger group with a strong negative going cue-locked wave at central and parietal sites and a strong positivity observed at parietal sites between 400 and 800 ms in the target-locked waveforms. However, no significant differences between the four conditions were found in the older group. This may be due to the relatively small sample size and increased inter and intra-individual variability present in the older group. Perhaps due to the considerable task demands imposed by the design, ERP data tended to be more variable and artifact prone for the older group. Another explanation may come from a recent fMRI study by DiGirolamo, Kramer, et al. (2001). Results showed that young adults activated different areas for switch and repeat trials but older adults tended to activate the same regions on both switch and repeat trials. In other words, the lack of significant ERP differences in the older group may not be a power problem but may reflect the fact that older adults tend to recruit more similar brain areas for both switch and repeat conditions than their younger counterparts.

A significant negative correlation was found between the episodic switch cost and the 600-1000 ms interval of the episodic difference wave over the frontal midline sites in older adults only (Table 5 bottom panel). However, when attempting to interpret this association, it became clear that the correlation was due to two subjects who showed relatively higher episodic switch costs. Unfortunately, their ERP waveforms did not show the usual gradually sloping negativity and amplitudes were unusually. When the two subjects are removed, the correlation disappears (see Figure 6). Many researchers have noted increased age-related inter- and intra-subject variability (Li, Aggen, Nesselroade, & Baltes, 2001). Some have hypothesized that increased adrenergic system dysfunction, may be one possible cause of decreased performance consistency in older adults (Li & Lindenberger, 1999). Whereas increased variability in performance has in the past been considered an experimental challenge in aging research, some researchers are now proposing that it should be the object of study rather than an obstacle that should be controlled for. Although the present study was not designed to measure intra-individual performance variability, this phenomenon may at least in part account for the increased variability observed in the elderly ERP data.

Limitations

Due to the demanding nature of the task, several subjects were excluded from the study during the learning-to-criterion phase. This created two problems. First, the elderly sample may not be representative of the wider population so that any age related results should be taken with caution because the current sample was probably not representative of the elderly population. Second, the sample of older participants was small. Therefore it is not possible to say whether the lack of effects in the older group was due to the small sample size or to a true lack of effect.

As mentioned above, the data presented here were part of a larger study examining backward inhibition. Because repeat trials were only 20% of switch trials, the results may have been affected in ways that were not considered in the above discussion.

Further, because of design constraints, two control conditions that may have been relevant to these reported results were not included. First, it would have been interesting to compare performance on a repeat trial that followed another repeat trial (i.e., a run of three identical tasks) to performance on a simple repeat trial. This is true especially for the episodic tasks. The presence of such a baseline condition could have shed more light on the mechanisms that contribute to task facilitation discussed above. Second, due to time constraints (the present study was already very long for the elderly participants) data were not collected on homogeneous blocks (i.e., blocks where the participant has to choose between the dimensions of only one task). Again, inclusion of homogeneous blocks would have provided a baseline condition against which the repeat trials on the heterogeneous blocks (i.e., the experimental blocks in this experiment where subjects had to switch between tasks) could have been compared.

However, some of these questions could be answered by a study (Phillips, Goffaux, Pushkar, & Sinai, 2002) in the same laboratory as the authors, where young and old adults were required to switch between three semantic tasks. The study was designed to include homogeneous blocks and more than two consecutive repetition of the same task, thus providing the control conditions missing in the present study's design.

Relation to models of task-switching

Although the above discussion does not allow for conclusive contributions to the veracity of proposed task-switching models, certain hypotheses and inferences can be made based on the data collected in this study.

In general, the current data support Rogers and Monsell (1995) dual process account of task-set reconfiguration whereby endogenous executive processes allow the participant to partially reconfigure the cognitive system ahead of the upcoming target, and post stimulus processes that are necessary to complete the reconfiguration.

It is apparent from the cue-locked data that the subject can and does prepare for the next trial as evidenced from the preparatory negativity leading to the target. However, one might ask what exactly can a subject do to prepare for the upcoming target. According to Mayr and Kliegl (2000), much of what a participant can do to prepare for the upcoming target is to retrieve the task rules from long-term memory. Although appealing at first, this hypothesis becomes problematic when one considers exactly what these task-rules are. According to Mayr and Kliegl (2000) task rules are the stimulus-response mappings relevant to a specific task. For example, if the subject is presented with the cue "size" the task-rules that can be retrieved will be: "if the target is large then press the left key and if the target is small then press the right key". Providing the explicit stimulus-response mappings to the participant reduced the switch cost dramatically (Mayr & Kliegl, 2000; Experiment 3). The authors reasoned that because the task rules are provided exogenously, they do not need to be retrieved from long-term memory. The problem is that the task-rules for an episodic task (e.g., if target red press left, if target yellow press right) are not more difficult than for a semantic task (e.g., if target large press left, if target small press right). Therefore, any difference in the magnitude of switch costs between episodic and semantic tasks cannot be due to the retrieval of task rules only.

It is more likely that the endogenous act of task-set reconfiguration prior to the target described by Rogers and Monsell (1995) consists of a general priming of the cortex containing the task set. At the physiological level this priming may take the form of reduced inhibition, or decreased polarization of the network axons' dendrites. This account is more in line with Rubinstein's et al. (2001) goal shifting phase, whereby the previous task set is deactivated and the focus is shifted to the new task set.

Implications for task-switching, aging, and executive functions

The current study is consistent with the literature's general finding that when external cues are provided, specific switch costs are not affected by age (Kray, Li & Lindenberger, in press; Kray & Lindenberger, 2000; Kramer et al., 1999). This suggests that the processes that contribute to specific switch costs probably do not involve frontal cortex areas. This proposal is supported by studies that show no specific switch cost difference between frontal patients and controls (Keele & Rafal, in press; Mecklinger, D. von Cramon, Springer, & M. von Cramon, 1999). Yet, it is difficult to explain how the cognitive system could organize the different sub-processes needed to successfully alternate between two tasks without the involvement of executive processes.

The notion that executive functions require the involvement of frontal cortex areas is widely held and supported by clinical and experimental data (Stuss & Alexander, 2000). However, the possibility that non-frontal areas may be involved in the control of behavior has not been explored. The fact that, although requiring executive functions, task switching does not appear to recruit frontal lobe areas raises the possibility that executive functions may involve more posterior association cortices.

This possibility, albeit speculative, would contribute to the growing evidence that suggests that executive control functions are not the result of a unitary process but the result of processing in several interconnected but independent subsystems (Jonides & Smith, 1997).

Future directions

As mentioned above, the data collected in this study support Rogers and Monsell's (1995) proposal that the process of task-set reconfiguration requires the presentation of the target to complete the process. Evidence for a post-stimulus process comes from the observation that a residual switch cost remains even when ample time is given for advanced preparation. Because in this, and previous experiments (Lorist et al., 2000; Phillips et al., 2001; Poulsen et al., 2001; Ullsperger, Freude, Dehoff, & Erdmann, 2001) the P300 to repeat trials is larger than to switch trials it is possible that the P300 is in some way related to the presumed post-stimulus process. This could be verified in future experiments by comparing the P300 to trials that allow for a long time to prepare versus trials that allow a short time to prepare. If the difference in P300 amplitude between repeat and switch trials correlates with preparation time and/or residual switch cost, then a link would be made between P300 amplitude and the exogenous reconfiguration process described by Rogers and Monsell (1995).

In order to further explore the mechanisms that contributed to task facilitation, a study could be designed that would allow two baselines that were absent from this experiment. First, ERP data would be collected on homogeneous blocks for both episodic and semantic tasks. Second, runs of three and four consecutive repeat trials would be allowed in heterogeneous blocks in order to verify whether repeated presentation of a task set results in episodic task facilitation. Finally, equal occurrence of switch and repeat trials would be required. If participants behavioral performance can benefit from several episodic task repetitions, then the same facilitation observed in this study following the repetition of a semantic task would be observed.

The data presented here were part of a study that examined age differences in backward inhibition. As such, information was collected that related a current trial to one or two preceding tasks. Although no age differences were noted with regard to the current trial, it is possible that age differences will arise in relation to what kind of task (episodic vs. semantic) preceded the current trial.

Conclusions

The goal of this study was to examine age differences in task switching when task difficulty was manipulated. The major findings of the experiment were that 1) both behavioral and electrophysiological measures suggest that age has little or no influence on specific task-switch costs, suggesting that more posterior regions may contribute significantly to these processes. 2) Evidence from both behavioral and electrophysiological measures indicate that episodic and semantic tasks were processed differently from each other. Whereas the repetition of semantic tasks benefited from cognitive facilitation, the repetition of episodic tasks appeared to be processed similarly to switch trials. Two possible mechanisms that could account for the lack of facilitation following the repetition of an episodic task were discussed. First, it is possible that episodic tasks were inhibited more strongly than semantic tasks because more difficult task-sets had to be more strongly inhibited than easier task-sets when no longer needed. Second, it is possible that episodic tasks were more difficult to keep in working memory than semantic tasks. In both cases, results suggest that, contrary to semantic tasks, episodic repeat tasks had to be re-activated, leading to smaller episodic than semantic switch costs.

In the broader context, this finding cautions against the interpretation of switch costs as an index of executive functions. The assumption that the repeat condition can be considered a baseline against which the switch trial can be compared may need to be nuanced. The results in the present experiment suggest that, under certain conditions, repeat trials should not be considered the baseline condition.

Further research is needed to explore the boundary conditions that underpin task-set facilitation.

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Appendix A

Health Screening Questionnaire

Interviewer: ____________________ Date: ________________
Vacation Plans:

____

History Questionnaire

In this research, we need to know whether there are factors, in addition to the ones we are studying, that may be affecting the results. Your answers to a few short questions will aid us in this effort. All answers will be kept strictly confidential. Thank you for your help.

Demographics

- Name:
- Phone Number: Source:
- Date of Birth: Age:
- Gender:
- Handedness:

Language

- Place of Birth:
- Languages Spoken:
- Primary Language/Language of Choice:
- Language at home: At Work:
- Language of Education:
- When did you first learn English?
- When did you become fluent in it?
- *Interviewer's subjective rating of subject's fluency (1-5, where one is least fluent) and comments:*

- Education - how many years including kindergarten? (finished -- primary school, highschool, college, university?)
- Have you ever skipped or repeated a grade? Why?

- Occupation - Present:
  - Past:

(What would you consider to be/to have been your primary occupation?)

Medical History

- Do you have now, or have you had in the past -

  - Visual problems: Nearsighted / Farsighted
    Glasses / Contact lenses
    Cataract: Left / Right
    Colour blind: NO / YES

- Trouble hearing: NO / YES
Hearing Aid: Left / Right

- Have you ever been unconscious, had a head injury or had blackouts? NO / YES
  Cause:
  Duration:
  Treatment:
  Outcome:

- Have you been seriously ill or hospitalized in the past 6 months? NO / YES
  Duration:
  Cause:

If Yes - <u>Treatment</u>: With what? Since when? Current status?

Do you have now, or have you had in the past -

• Stroke	NO / YES	When?	Transient ischemic attack?
• Heart disease	NO / YES	Nature (MI, angina, narrowing of arteries)	
• High blood pressure	NO / YES	Controlled?	
• High Cholesterol	NO / YES		
• Bypass surgery	NO / YES		
• Surgery	NO / YES	Nature:	
• Seizures	NO / YES	Age Onset: Cause:	Freq: Treatment:
• Epilepsy	NO / YES		
• Diabetes	NO / YES	Type I / Type II	Age Onset:
Insulin dependent?	NO / YES	Treatment:	
• Thyroid disease	NO / YES		
• Frequent headaches	NO / YES	Tension / migraine	
• Dizziness	NO / YES		
• Trouble walking/unsteadiness	NO / YES		

- Serious illness (e.g. liver disease) NO / YES

- Neurological disorders NO / YES

- Exposure to toxic chemicals
  (that you know of)? NO / YES

- Depression NO / YES
- Anxiety NO / YES
- (Other) psychological difficulties? NO / YES

Medication

Type	Reason for consumtion	Age/Duration of consumption/Dose

Hormone replacement? / Steroids?

Alcohol, Tobacco, Drug Consumption (1 drink = 1 beer, 1 glass of wine, 1 oz of liquor) - Current/Past

	Amount (per day/week/month/year)		
	Present	Past	Age of Consumption
Alcohol			
Tobacco			if Yes: packs/day (exclude if 20 pack-years)
Drug use			

Present Problems - Are you currently troubled by any of the following?

- Concentration / Attention problems NO / YES Nature:

- Memory problems NO / YES Nature:

- Difficulties finding words NO / YES Nature:

What is your **general state of health** (1-5, where 1 is poor and 5 is excellent)? 1 2 3 4 5

Address for correspondence:

Appendix B

Consent Form

Jewish General Hospital
Department of Clinical Neurosciences
Age Differences in Task Switching:
Electrophysiological Indices of
Backward Inhibition.

Consent Form for the Jewish General Hospital Study of Age Differences in Task Switching: Electrophysiological Indices of Background Inhibition.

Purpose of the Study:

I have been informed that the purpose of this research is to study the effect of age on attention. Electrical brain responses will be measured during a simple word classification task (i.e., deciding whether a noun is large or small). This study is being conducted under the supervision of Dr. Natalie Phillips, Dept. of Psychology, Concordia University, and the Dept. of Neurology, Lady Davis Institute/Jewish General Hospital.

Details of the Study:

The study will take place in the Psychophysiology laboratory of Dr. Phillips in the Department of Neurology, Jewish General Hospital. The electroencephalogram (EEG) is a recording of electrical brain activity measured at the scalp (similar to a EKG recording of heart activity). To record EEG, a nylon cap containing small sensors (electrodes) will be placed on my head. To obtain proper recordings, the scalp area underneath each sensor will be lightly rubbed with electrolytic gel using a blunted needle. The gel resembles a facial scrub and is used to clean the skin surface.

The study will be conducted in a small testing room. I will be seated in a comfortable chair in front of a computer monitor. I understand that the task I will be asked to accomplish consists of classifying words that will appear on the screen by responding on a keypad. I am aware that my responses will be timed and that my electrical brain activity will be recorded. I have also been informed that I will have to learn some word-attribute associations prior to the testing session and that I will be asked the meaning of some words at the end of the computer task.

This study will take approximately 4 hours. I understand that I will not be required to complete any tasks other than those mentioned above and that no deception is involved. I have been informed that certain demographic information (age, sex, education, health status) will be recorded. I understand that this study is not a medical test. It is for research purposes only and it is not diagnostic, meaning that it will not yield any results about my health. I understand that my individual results will not be provided to me; however, I will be informed of the general findings of the study. In the unlikely event that any potentially significant abnormality in my EEG is observed, this information will be forwarded to my family physician with my permission.

Jewish General Hospital
Department of Clinical Neurosciences
Age Differences in Task Switching:
Electrophysiological Indices of
Backward Inhibition.

Disadvantages and Risks of Participating in the Study:

EEG testing is a painless and non-invasive (using no foreign substances like medications, tubes, or needle injections) procedure. Nevertheless, while the scalp is being prepared for recording, some people may experience a mild and temporary discomfort where the skin is being rubbed. It is also possible that I will find it boring or frustrating to look at the information on the computer screen. However, I will be given frequent breaks whenever required to avoid this. I understand that, in the *unlikely* event that any finding of possible clinical significance is made and communicated to my physician, it may be recommended that I have additional testing which would not have taken place if I had not participated in this study.

Advantages to Participating in the Study:

The researchers hope to learn more about age-related differences in the brain processes involved when one is required to switch between various tasks. Although this will not benefit me directly, this research could add to our scientific of the brain processes involved in attention. In addition, I will gain knowledge about how psychological research is conducted.

I will receive 20$ in exchange for my participation in this study.

Confidentiality:

I understand that my participation in this study is *confidential*, that is, the researcher will know but will not disclose my identity in any published report or scientific communication. My records will not be identified by name; instead a subject code will be used. If the present study is published, only group results will be mentioned, insuring my confidentiality as a participant in this experiment.

Withdrawal from the Study:

I understand that my participation in this study is voluntary and, if I agree to participate, I may withdraw my consent and discontinue participation *at any time* without negative effects.

Jewish General Hospital
Department of Clinical Neurosciences
Age Differences in Task Switching:
Electrophysiological Indices of
Backward Inhibition.

Participant's/Patient's Rights:

I have been told and have fully discussed the purpose and procedure of this study and have had the opportunity to ask any questions.

The following is the name, address, and telephone number of the researcher whom I may contact for answers to questions about research or any injuries or adverse reactions that might occur:

Dr. Natalie Phillips (Ph.D.), Dept. of Psychology, Concordia University, 7141 Sherbrooke St. West, Montreal, PQ. H4B 1R6; tel: 848-2218.

The following is the name, address, and telephone number of the Hospital's Patient representative, who is not associated with this study and to whom I may address my concerns about my rights as a research participant:

Mrs. Lianne Brown, 3755 Côte Ste. Catherine Rd. Montreal, PQ. H3T 1E2; tel: 340-8222 ext 5833.

Signature:

I have been told the contents of this consent form, a copy of which I have received, and I have had the opportunity to ask questions. I agree to participate in this study. I do not give up any of my legal rights by signing this consent form.

Date	Signature of the Participant	Print Name
	Signature of Investigator	Print Name
	Signature of person explaining Informed Consent.	Print Name

Appendix C

Cue-locked Average ERP Waveforms for Subjects Y08 and Y12 for the Semantic Condition.

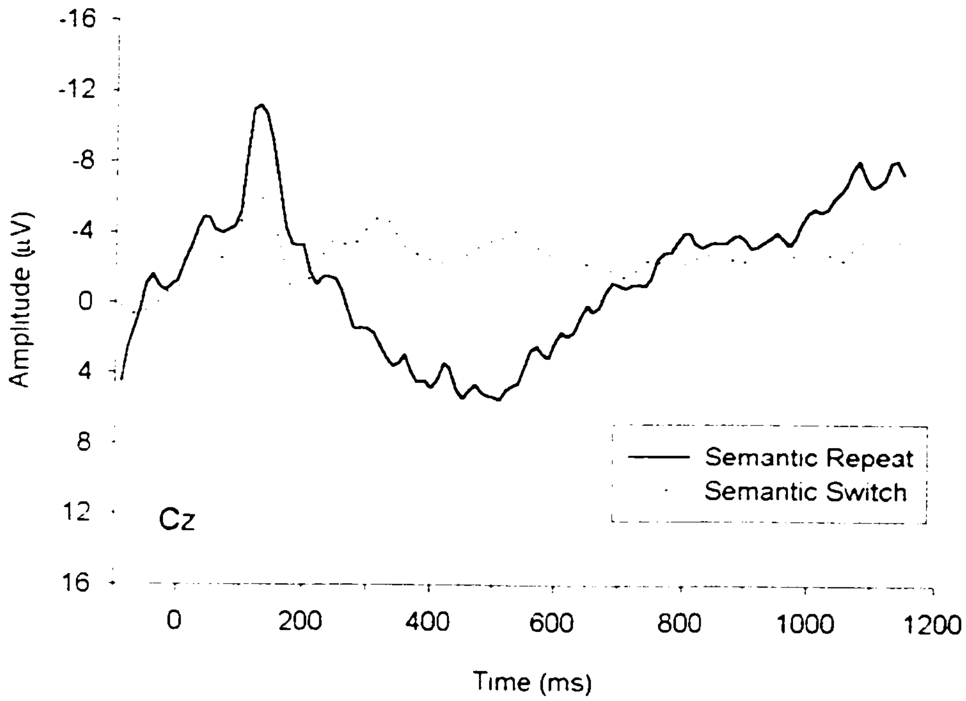

Figure C1. ERP average wafeforms for participant Y08 for semantic switch and repeat trials at the central midline site (Cz).

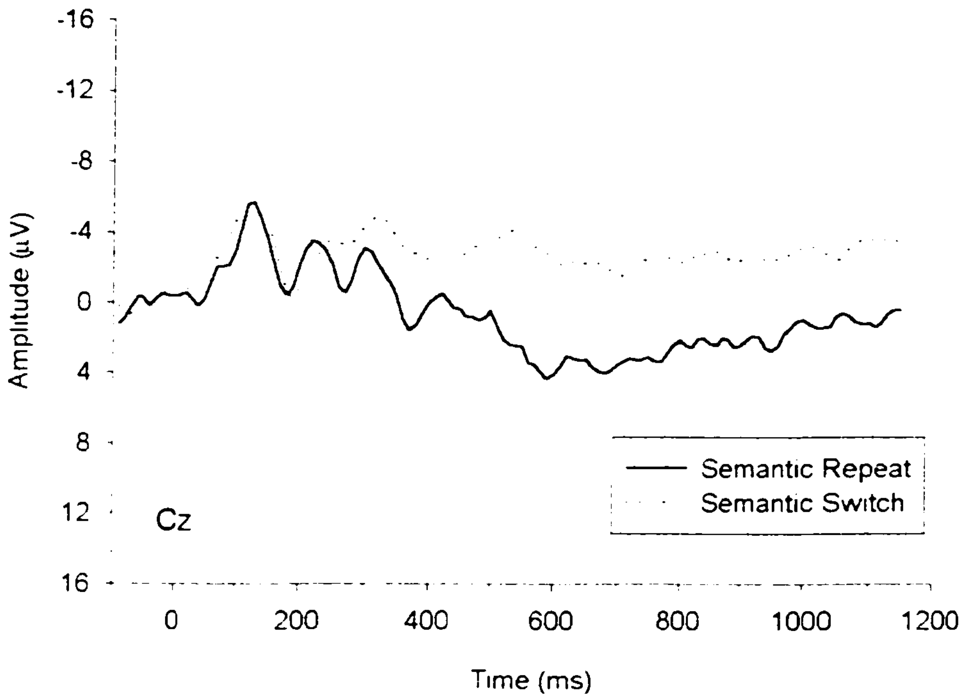

Figure C2 ERP average wafeforms for participant Y12 for semantic switch and repeat trials at the central midline site (Cz).

Appendix D

Cue-locked ERP Grand Average Waveforms at site CPz for the young and older group

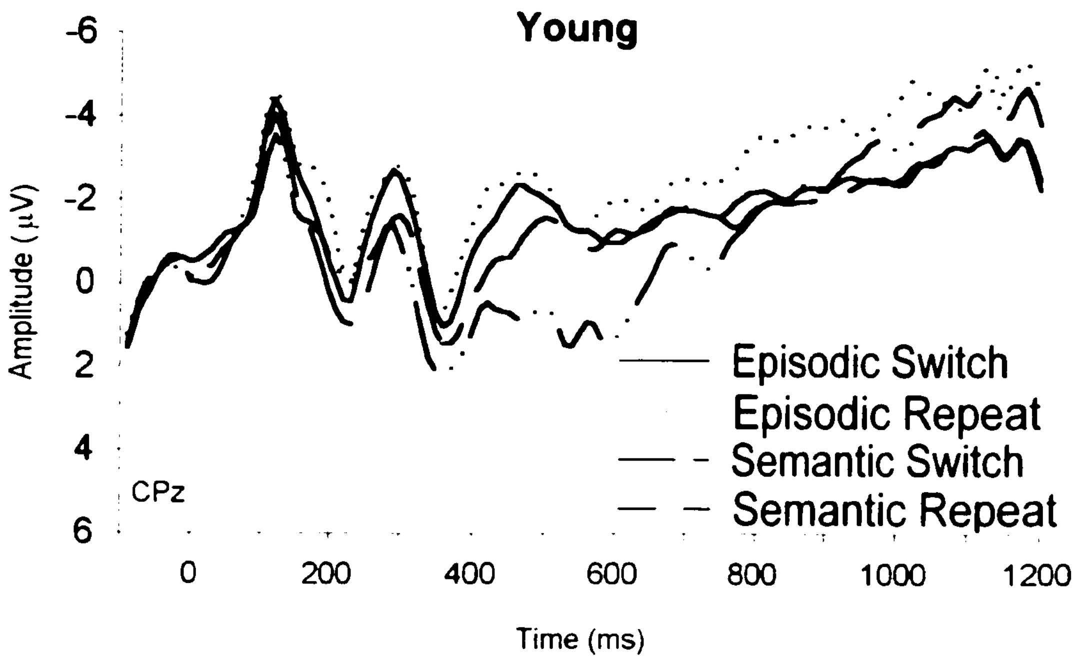

Figure D1. Cue-locked Average ERP grand average waveforms at site CPz for the young group.

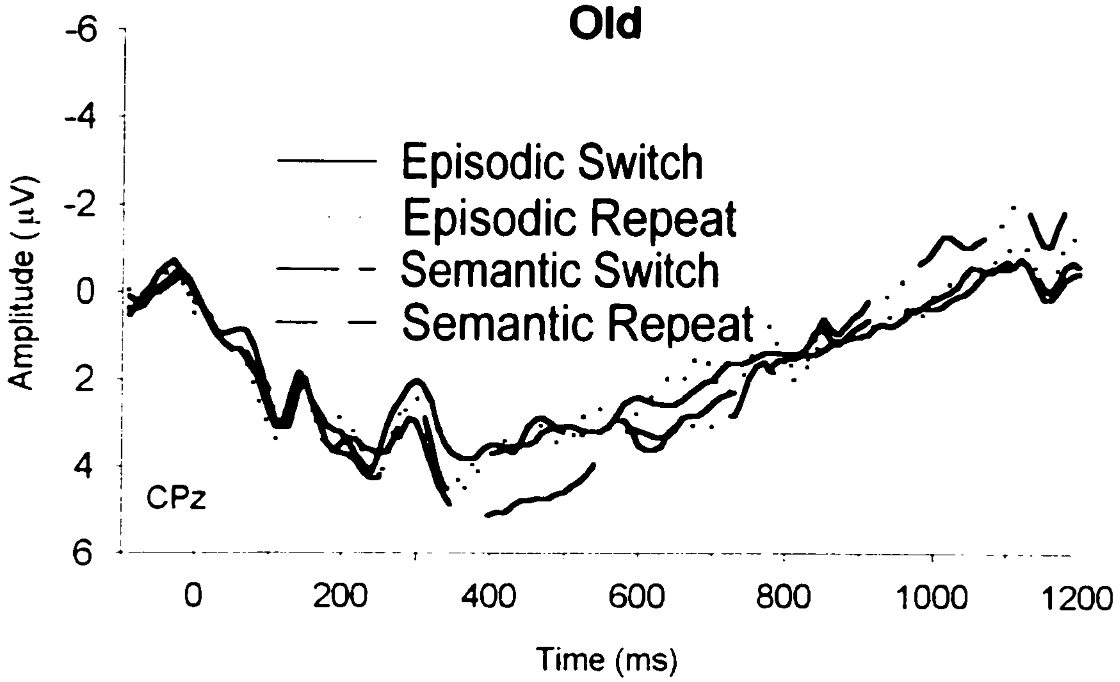

Figure D2. Cue-locked Average ERP grand average waveforms at site CPz for the older group.

Appendix E

Target-locked ERP Grand Average Waveforms at site CPz for the young and older group

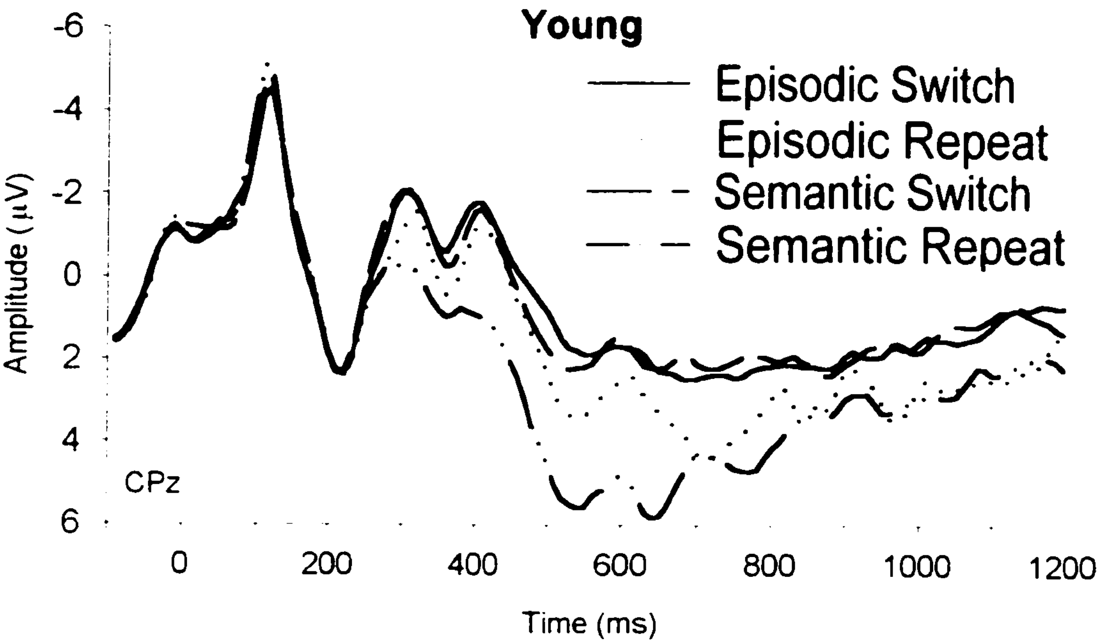

Figure E1. Target-locked Average ERP grand average waveforms at site CPz for the young group.

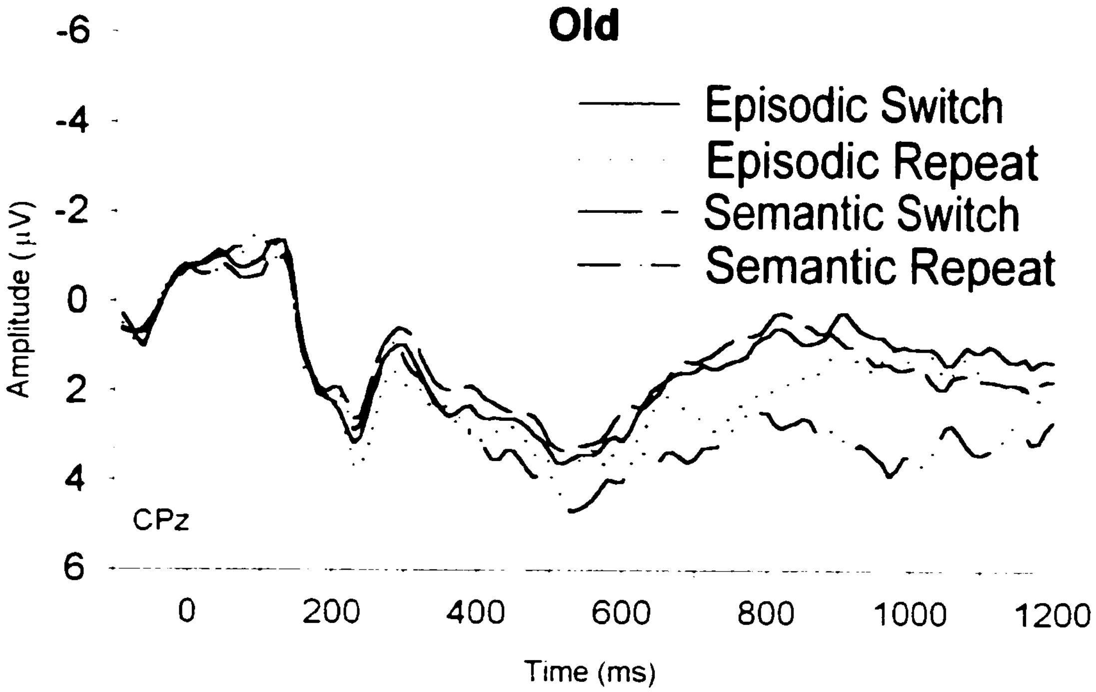

Figure E2. Target-locked Average ERP grand average waveforms at site CPz for the older group.