Evidence for the Transient Nature of a Neural System Supporting Goal-directed Action

Disruption of a neural system supporting goal-directed action gives rise to lapses of intention in healthy individuals and disorganized behavior in patients with prefrontal lesions. Evidence from behavioral studies indicates that the occurrence of lapses in selective attention, working memory and prospective memory tasks is transient in nature. In the current study, we used event-related brain potentials to demonstrate that lapses are associated with a slow wave over the frontal region that begins well before stimulus onset and lasts for several hundred milliseconds. The magnitude of this slow wave was modulated by task demands, indicating that attentional processes can be flexibly allocated in the service of goal-directed action. Together these experiments indicate that lapses result from a transient inability to bring to bear the goals of the individual upon the action selection system.

Introduction

In the course of our daily experience we sometimes find that our current goals and immediate actions become dissociated (Reason, 1979), a condition known as goal-neglect (Duncan et al., 1996). Generally, the outcome of these lapses of intention is quite innocuous, such as putting salt instead of sugar into our morning coffee. However, at other times the performance of an unintended action may have important consequences (Norman, 1981). While lapses are a part of everyone’s daily life, little is known about the neural events that give rise to these curious happenings.

Behavioral work has demonstrated that lapses are preceded by a gradual increase in response latency on correct trials (West, 1999), indicating that goal-neglect may result from the waxing and waning of intention-based control over action. Lapses also tend to occur in isolation, lasting only a single trial, and are relatively constant in number throughout the course of task performance (West, 1999). Together these findings indicate that the neural system supporting goal-directed action fluctuates in efficiency over time and that these fluctuations are an inherent property of this system.

The neural system supporting goal-directed action is also known to be sensitive to the contextual demands of a given situation. Lapses are more frequent when dominant response tendencies are only occasionally inconsistent with task demands. Conversely, the frequency of lapses decreases when dominant response tendencies are generally in conflict with task demands (West and Baylis, 1998; West, 1999). These data indicate that attention can be flexibly allocated to increase the efficiency of goal-directed action when dominant behavioral tendencies are in frequent competition with the goals of the individual.

The neurocognitive architecture supporting the integration of action and intention is not well understood. The right prefrontal cortex has been proposed to be part of an attentional network supporting sustained attention (Posner and Peterson, 1990; Stuss et al., 1995) that is necessary for maintaining goal-directed action. This proposal is supported by neuroimaging data demonstrating that the right prefrontal cortex is active during sustained attention (Pardo et al., 1991), selective attention (Benich et al., 1993) and memory retrieval (Duzel et al., 1999) tasks requiring goal-directed action. For instance, increased regional cerebral blood flow in the right fronto-polar cortex is only observed when competing sources of information are present in the Stroop task (Bench et al., 1993). Also, insult to the prefrontal cortex reduces the ability to maintain a high level of sustained attention (Manly et al., 1999) and increases the susceptibility of the individual to lapses of intention or goal-neglect (Duncan et al., 1996; Vendrell et al., 1995). These findings are all consistent with the idea that the right fronto-polar region supports the maintenance of a goal-directed attentional set in the face of competing environmental demands.

The aim of this study was to evaluate the extent to which transient fluctuations in the goal-directed action system give rise to goal-neglect resulting in intrusion errors within the Stroop task. We also explore whether inhibitory control and output monitoring processes that support goal-directed action are disrupted during lapses of intention. Given that error-related slowing of response latency is observed in the Stroop task for intrusion errors (West, 1999), one would expect those processes related to output monitoring to be intact during lapses. In the current study a neural index of error-related monitoring processes was obtained by considering the Ne/Pe complex of the event-related brain potential (ERP) (Falkenstein et al., 1990). The amplitude of the Ne wave is sensitive to the force of the errant response, the probability of error-correction, and response latency on trials following an error (Gehring et al., 1993). These findings suggest that the Ne wave indexed processes associated with the realization that task performance has deviated from the intended action of the individual. The P500 was taken as an index of inhibitory control processes (West and Alain, 1999). Previous work has demonstrated that this modulation is sensitive to the presence of competing information in the Stroop task (Rebai et al., 1997; West and Alain, 1999) and has led to the suggestion that the P500 reflects processes supporting inhibitory control.

We propose that lapses of intention result from the transient disruption of a goal-directed action system supported by the right prefrontal cortex. Given this hypothesis we expected to observe a transient shift in neural activity (i.e. a slow wave) over the frontal region beginning well before stimulus onset that would differentiate trials wherein a lapse occurred from trials wherein a goal-directed response was made. If fluctuations in the efficiency of the goal-directed action system disrupt processes supporting inhibitory control, the P500 was expected to be attenuated for intrusion errors relative to correct incongruent trials.
of these blocks contained 96 trials and five contained 144 trials. In all blocks of trials there were equal numbers of congruent, neutral and incongruent stimuli. In blocks with 96 trials 25% of the stimuli required word identification, while in blocks with 144 trials 50% of the stimuli required word identification. The manipulation of the proportion of word identification trials was unsuccessful at modulating the ERPs elicited in this study and, therefore, is not considered further.

Stimuli were presented for 400 ms and were then replaced with a blank screen until a response was made. The screen was then blank for another 1000 ms at which time the next stimulus was presented. Stimuli subtended between 1.37° and 3.11° by 1.00° of visual angle when viewed from 46 cm.

**Electrophysiological Recording and Analysis**

The EEG (bandpass 0.05–50 Hz) was recorded continuously from 47 electrodes at a sampling rate of 250 Hz. Trials contaminated by excessive eye or movement artifacts, peak-to-peak deflections over 200 µV, were rejected before averaging. Eye movements and blinks not removed by the artifact rejection criteria were corrected for each individual average using an ocular source components approach (Lins et al., 1993) through the Brain Electrical Source Analysis software (version 2; M. Scherg and P. Berg, Munich). ERP epochs included a 200 ms baseline. The epoch of the slow wave included –2200 to 2000 ms around stimulus onset, the epoch of the P500 wave (correct incongruent – congruent; intrusion error – congruent) included –200 to 1500 ms around stimulus onset, and the epoch of the Ne/Pe complex (intrusion error – correct incongruent) included –400 to 400 ms around the response. An 8 Hz low-pass filter was applied to the averaged ERPs. The slow wave differentiating intrusion errors from correct responses was quantified as the mean voltage between –1000 and 0 ms and was evaluated in an ANOVA including electrode positions (Fp1, Nz, Fp2, F3, Fz, F4, C3, Cz, C4). The P500 was quantified as the mean voltage between 450 and 550 ms and was evaluated in an ANOVA including the electrodes (F11 and F12). The Ne/Pe complex was quantified as the peak negative voltage between 50 and 150 ms and the peak positive voltage between 100 and 500 ms at the Cz electrode. When appropriate the degrees of freedom for the analyses of the ERP data were adjusted using the Greenhouse-Geisser correction (Geisser and Greenhouse, 1958).

**Results and Discussion**

Individuals committed between 10 and 55 intrusion errors across the task (mean = 22.25, SD = 6.21). A slow wave that began well before stimulus onset was observed differentiating the ERPs elicited by intrusion errors from those elicited by correct trials regardless of the type of stimulus (see Fig. 1). This finding was confirmed in an ANOVA including the factors condition (intrusion errors, correct incongruent, word reading trials), region (polar, frontal, central), and laterality (left, right, central) where the condition × region interaction was significant [F(4,40) = 8.94, P < 0.005, ε = 0.36]. The slow wave reversed polarity from the fronto-polar region to the fronto-central region. This scalp topography is compatible with the activity of a neural generator(s) located within the polar or dorsolateral region of the prefrontal cortex. A finding consistent with those of several neuroimaging studies revealing activation of the anterior frontal cortex during performance of the Stroop and other response competition tasks (Bench et al., 1993; Taylor et al., 1994). The slow wave differentiated intrusion errors from correct responses on incongruent trials and word identification trials. This indicates that the effect was independent of the properties of the stimulus, since the stimuli were identical for intrusion errors and correct incongruent trials, and the nature of the response, since the same information determined a response for intrusion errors and word identification trials.

Relative to congruent trials, the correct incongruent trials and intrusion errors elicited a P500 wave (see Fig. 2a). This finding was confirmed in an ANOVA including the factors condition

**Experiment 1**

Individuals performed a variation of the Stroop task (Stroop, 1935; MacLeod, 1991) while ERPs were recorded from the scalp. The Stroop task required individuals to identify the color of words when color and word information was congruent (e.g. the word RED printed in red) or incongruent (e.g. the word RED printed in blue), or to identify the name of a word. Lapses were operationally defined as intrusion errors where individuals responded with the word, the prepotent response, when the task required naming the color, the goal-directed response.

**Materials and Methods**

Subjects

Twelve individuals (6 females) 24–31 years of age participated in the study. All participants reported normal or corrected to normal visual acuity. Data from one male participant was not considered in the analysis as he committed only two intrusion errors over the course of the task.

**Experimental Procedure**

The Stroop task consisted of congruent (e.g. RED in red), neutral (e.g. XXX in red), incongruent (e.g. RED in blue) and word identification trials (e.g. RED in light gray). When the stimulus was red, blue, green or yellow in color, individuals were instructed to press a key as quickly as possible identifying the color of the stimulus (v-red, b-blue, n-green, m-yellow). In comparison, when the stimulus was presented in light gray, individuals were instructed to press a key identifying the name of the stimulus. Color and word identification trials were randomly intermixed within a block of trials. Ten blocks of trials were presented during the experiment, five
(congruent, correct incongruent, intrusion error) and laterality, where the main effect of condition was significant \([F(2,20) = 5.88, \ P < 0.02, \ \varepsilon = 0.70]\). The P500 wave was reliable for both correct incongruent trials \([F(1,10) = 6.40]\) and intrusion errors \([F(1,10) = 10.72]\), and the amplitude of this wave did not differ for these types of trials \((F < 1)\). These findings are consistent with those of Carter et al. (Carter et al., 1998), where increased activation of the anterior cingulate was observed for trials where response competition was present regardless of whether or not a correct response was elicited.

A Ne/Pe complex was associated with intrusion errors (see Fig. 2b). Analysis of the Ne/Pe complex at the midline central electrode (Cz) revealed that both the Ne wave \([\mu = -2.90, \ P < 0.02]\) and the Pe wave \([\mu = 3.28, P < 0.01]\) were significantly different from zero. This finding is consistent with behavioral data demonstrating error-related slowing for intrusion errors, and supports the idea that output monitoring processes are intact during lapses of intention.

The findings of experiment 1 reveal that lapses of intention result from the transient disruption of a neural system supporting goal-directed action and not a failure of inhibitory control processes. These findings are consistent with the idea that lapses of intention result from an inability of the individual to bring to bear intention upon the action selection system. This proposal echoes the clinical observation that individuals suffering from damage to the frontal cortex are often fully able to express their goals and quite aware that their behavior is inconsistent with these goals, but are unable to resolve the inconsistency between action and intention (Stuss and Benson, 1984; Jahanshahi and Frith, 1998).

**Experiment 2**

Experiment 2 served two purposes. First, we sought to replicate the slow wave associated with intrusion errors observed in experiment 1. Second, we sought to explore the influence of variations in task context on the amplitude of the slow wave. This manipulation was motivated by research demonstrating that the frequency of lapses is modulated by task demands (Duncan et al., 1996; West, 1999). If the allocation of attention to the goal-directed action system is modulated by contextual demands, the amplitude of the slow wave should be greatest when there is generally minimal conflict between the goals of the individual and candidate actions. Conversely, the slow wave should be reduced in amplitude when there is generally a high degree of conflict between the goals of the individual and candidate actions.

**Materials and Methods**

**Subjects**

Twelve individuals (6 females) 19–30 years of age participated in the study. All participants reported normal or corrected to normal visual acuity. Data from one female participant was not considered in the analysis as she committed only one intrusion error in the mostly incongruent condition of the task. Three of the subjects for this experiment had participated in experiment 1.

**Experimental Procedure**

The Stoop task utilized in the experiment included congruent, neutral and incongruent trials. The proportion of congruent and incongruent trials was varied across the task. For half of the task 66% of the trials were congruent, 17% neutral and 17% incongruent; for the other half of the task these probabilities for congruent and incongruent trials were reversed. Performance of the mostly congruent and mostly incongruent blocks of trials was counterbalanced across participants, with half performing the mostly congruent blocks of trials, then the mostly incongruent blocks of trials, and half performing the mostly incongruent trials, then the mostly congruent trials. There was a total of 1440 trials across the task. Stimulus duration and visual angle were identical to those used in experiment 1. The response to stimulus interval was reduced from 1000 to 500 ms in experiment 2.

**Electrophysiological Recording and Analysis**

The recording parameters were the same as those used in experiment 1. For this experiment the epoch of the slow wave included –800 to 800 ms around stimulus onset and the amplitude of the slow wave was measured from –400 to 0 ms. The epoch for the slow wave was reduced in experiment 2 to compensate for the decrease in the response to stimulus interval from 1000 ms in experiment 1 to 500 ms in experiment 2.

**Results and Discussion**

Intrusion errors were more likely in the mostly congruent condition \((mean = 10.91)\) than the mostly incongruent condition \((mean = 7.27; t(10) = 2.09, P < 0.03)\). The amplitude of the slow wave elicited by intrusion errors was greater in the mostly congruent condition than in the mostly incongruent condition (see Fig. 3). This was confirmed in an ANOVA including the factors condition (correct incongruent, intrusion error), proportion of congruent-incongruent trials, region and laterality, where the interaction of condition, proportion of congruent--incongruent trials and latality was significant \([F(2,20) = 4.15, P < 0.04, \ \varepsilon = 0.72]\). These findings are consistent with the idea that attention can be flexibly allocated to the goal-directed action system to meet the contextual demands of a given situation.

**General Discussion**

Both experiments demonstrate that lapses of intention result from the transient disruption of a neural system supporting goal-directed action, reflected in a slow wave that began well before stimulus onset. The disruption of this system had a relatively specific influence on the information processing system, as neural indices of inhibitory control (P500) and error monitoring (Ne/Pe) were intact during the lapse. These findings are consistent with recent work in the area of memory retrieval where the prefrontal cortex has been found to implement both
task-related processes (i.e. retrieval mode) that support information processing over a number of stimuli, and item-related processes responsive to characteristics of a given stimulus (Duzel et al., 1999). The findings of the current experiments indicate that lapses of intention result from an inability to bring to bear the goals of the individual on the action selection system, a task-related effect, and not a failure of inhibitory control processes on a given trial, an item-related effect.

The results of experiment 2 reveal that the amplitude of the slow wave was modulated by the task demands. The slow wave was greatly attenuated in the mostly incongruent condition and was similar in amplitude to that observed in experiment 1 in the mostly congruent condition. These findings indicate that attentional processing is dynamically allocated to meet changing task demands in support of the goal-directed action system (Duncan et al., 1996; West, 1999).

It has been widely assumed that damage to the prefrontal cortex gives rise a general impairment in goal-directed action (Jahanshani and Frith, 1998). However, based upon the transient nature of the neural system supporting goal-directed action observed in the current study, we propose that an increase in the frequency or magnitude of fluctuations in the efficiency of this system, and not necessarily a global disruption, gives rise to deficits in goal-directed action. This hypothesis is consistent with recent findings indicating that age-related increases in lapses of intention resulted from an increase in the frequency of goal-neglect (West, 1999), and that the magnitude of impairments in goal-directed action varies widely from day to day following traumatic brain injury (Stuss et al., 1994).

In summary, the current experiments demonstrate that lapses of intention are associated with a transient change in neural activity over the frontal region that begins well before stimulus onset. This slow wave inverted polarity from the fronto-polar to the fronto-central region consistent with the activity of a neural generator in the polar or dorsolateral prefrontal cortex. A P500 wave was observed for the ERPs associated with both correct responses on incongruent trials and intrusion errors, suggesting that inhibitory control processes were unaffected by lapses of intention. Together, these findings indicate that lapses of intention result from an inability to bring to bear the goals of the individual on the action selection system and not a failure of inhibitory control.

Notes
This work was supported by a fellowship funded through grant RO1AG13845–01 to R.W.; and grants from the Natural Sciences and Engineering Research Council of Canada and a NARSAD Young Investigator Award to C.A.
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