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Inhibitory Mechanisms of Attentional Networks: Spatial and Semantic Inhibitory Processing

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Four experiments assessed the relationships between the orienting and the executive networks of visual attention. Experiment 1 showed spatial inhibition of return (IOR) with target words. Experiment 2 showed a type of semantic inhibition that mimicked spatial IOR. Reaction times to targets preceded by 2 consecutively presented words, the prime and the intervening stimulus, were longer when the target and prime were related than when they were unrelated. Experiment 3 combined spatial and semantic inhibition in a lexical-decision task. Spatial IOR was observed with both related and unrelated targets, but semantic inhibition was observed only when target words were presented in uncued locations. A similar interaction between IOR and positive semantic priming was observed when the intervening stimulus was not presented (Experiment 4). Implications for the relationships between the 2 attentional networks are discussed.

Recently, the study of attention has seen considerable progress through the convergence of different sources of evidence (see Posner & Petersen, 1990, for a review). For instance, knowledge is now available concerning the loci of brain activities when participants perform attentional tasks. Some sources provide topographic maps of neural activity, such as positron emission tomography (PET; Petersen, Fox, Posner, Mintun, & Raichle, 1988; Posner, Petersen, Fox, & Raichle, 1988) and recordings of localized event-related potentials (Compton, Grossenbacher, Posner, & Tucker, 1991; Curran, Tucker, Kutas, & Posner, 1993; Kellenbach & Michie, 1996). Others provide information about particular parts of the brain involved by recording at a lower scale (e.g., single cells; Moran & Desimone, 1985). Still others take advantage of patients with brain injuries to give a functional role to larger brain areas (Posner, Inhoff, Friedrich, & Cohen, 1987; Posner, Walker, Friedrich, & Rafal, 1984). This cognitive neuroscience approach has made it possible to view attention as a neural system for the control of mental processing, similar in many aspects to other neural systems. According to this account, attention involves a complex of networks that perform highly specific computations, and these networks can be specified anatomically in terms of the brain areas involved.

The issue of how many attentional networks there are is still a matter of debate. However, the results of recent cognitive–anatomical studies of attention have suggested at least three such networks (Posner & Petersen, 1990): the posterior attention network (PAN), the anterior attention network (AAN), and the alerting network. In this research we further explored the interrelationships between the first two.

The PAN

Briefly, the PAN includes the posterior parietal lobe, areas of the thalamus, and the superior colliculus (LaBerge, 1990; Posner, 1988; Posner & Petersen, 1990). Each area is supposed to be involved in specific computations related to visual orienting. For instance, imagine a simple detection task in which a cue signals the most likely location of a target. Participants will respond to the target appearing at the cued location more rapidly and more accurately than if the target is presented at an uncued location. That improvement in efficiency is found even when participants do not move their eyes to the cued location (Posner, 1980). The benefit of current cuing is produced at the cost of slowing responses to targets at incorrectly specified locations.

It has been proposed that, for people to perform such a simple detection task, three simple operations are necessary (Posner, 1988; Posner et al., 1987): *disengage* attention from its current focus, *move* attention to the cued location, and *engage* attention to the target appearing in that location (however, see Cohen, Romero, Servan-Schreiber, & Farah, 1994, and Humphreys, Olson, Romani, & Riddoch, 1996, for alternative accounts and simulations). Different areas of the PAN are held to be involved in each particular operation: The posterior parietal lobe is thought to be involved in the disengage operation; thalamic areas are involved in the

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engage operation; and midbrain areas (i.e., the superior colliculus) are involved in the move operation.

In addition to orienting to cued locations, operations are also required to prevent attention returning to previously cued locations. Evidence for such operations comes from the phenomenon known as *inhibition of return* (IOR), in which reaction times (RTs) are slowed when targets are presented to a cued location after a relatively long interval. IOR is associated with the prior programming of an eye movement to the target location, and, consistent with differences in the strength of connections into the superior colliculus, IOR is stronger in the temporal than in the nasal hemifield (Rafal, Calabresi, Brennan, & Sciolto, 1989; Rafal, Henik, & Smith, 1991). These latter results suggest that IOR is associated with the colliculus in the PAN.

This brief review indicates that our ability to search and to respond to target stimuli depends on a balance between the activation of stimuli at currently attended locations and the inhibition of stimuli at unattended and previously attended locations.

The AAN

The AAN is thought to involve activation of both the dorsolateral prefrontal and midline frontal areas including the anterior cingulate cortex and the supplementary motor area. PET studies have shown that both the anterior cingulate cortex and the supplementary motor area activate when participants perform linguistic tasks in which high-level processing (e.g., semantic access) is involved (Petersen et al., 1988). For instance, Fuentes, Carmona, Agis, and Catena (1994; see also Posner, Sandson, Dhawan, & Shulman, 1989) used a dual-task paradigm in which participants performed both a shadowing task and a lexical-decision task to target stimuli presented at fixation. Targets were preceded by two primes, one in the fovea and the other in the parafovea. The critical results showed that shadowing, a task that PET studies have suggested taps the AAN (i.e., Petersen et al., 1988), reduced semantic priming from foveal primes but did not have any effect on semantic priming from parafoveal primes. This suggests that this network has a relevant role in attention-dependent word processing.

Similar to the PAN, the AAN also appears to operate by means of facilitatory and inhibitory processes. For instance, in lexical-decision tasks (on which participants indicate whether a letter string is a real word), a prime word such as *dog* typically facilitates responses to a subsequent semantically related target word such as *cat* (Meyer & Schvaneveldt, 1971). This facilitatory semantic priming effect seems to be the product of two mechanisms. One mechanism reflects the participant's intentions, strategies, or both and so is attention dependent; the other mechanism reflects the operation of automatic encoding (Fuentes et al., 1994; Neely, 1977; Posner et al., 1989; Ratcliff & McKoon, 1988). The attention-dependent mechanism appears to depend on expectations about the target based on the prime, although the explanations of semantic priming are still controversial (for different views, see McNamara, 1992, 1994; McKoon & Ratcliff, 1992; Ratcliff & McKoon, 1994). Attentional (expectation-based) priming usually occurs with long prime–target intervals (Fuentes & Tudela, 1992; Neely, 1977). When the expectation is correct, target responses are facilitated; however, when the expectation is incorrect, target responses are inhibited (Neely, 1977). Such attention-based facilitatory and inhibitory processes in language tasks may arise from activity within the AAN (see Nakagawa, 1991).

Interrelationships Between the PAN and the AAN

The two attentional networks we are discussing can be viewed as (a) independent modules, with separate effects on behavior, or (b) interdependent modules of a common attentional network working in an interactive way.

Note that the notion of independence does not mean that both networks cannot operate when the participant performs a specific task. As Posner (1988) pointed out, reading is a good example of an activity in which both spatial orienting and semantic encoding of words would be involved, so that both networks must play a relevant role. However, it is unclear whether the control mechanisms for the two components operate separately.

One approach to understanding the interrelationships between the AAN and the PAN is to assess the pattern of interference when participants perform tasks tapping the different attentional networks. Following additive factors logic (Sternberg, 1969), an interaction between the attentional effects associated with each network would suggest an interrelationship between the two attentional networks. In contrast, additive effects would favor the hypothesis that there are separate control mechanisms.

In recent research using such a strategy, interesting insights about the relation between the different attentional networks have emerged. For instance, Posner et al. (1987) had a group of patients with parietal lobe damage perform either a single visual orienting task or two tasks: visual orienting (the primary task) plus a language task (the secondary task). In the visual task, participants had to detect an asterisk (the target) that could appear either on the cued side or on the uncued side. In the language task, participants had either to count backward from a three-digit number or to search for the phoneme *p* in a list of auditory words. They found that in the dual-task condition, the secondary language task reduced the advantage for valid (correctly cued) compared with invalid (incorrectly cued) trials (the validity effect; see Posner, 1980) in the visual orienting task. That is, attending to linguistic stimuli interfered with the network that shifts visual attention. Posner et al. (1987) suggested that there must be a common network that is involved in both visuospatial attention and attention to language. Because patients with parietal damage did not show a specific deficit (a greater disadvantage for contralateral targets on invalid trials) when they were engaged in the language task, the authors concluded that that common network could not be the posterior parietal lobe. In contrast, they argued that this common network was the AAN because (a) the parietal lobe is connected anatomically to the cortical areas constituting the AAN (areas of the lateral prefrontal cortex and the medial frontal cortex, such as the supplementary motor area) and (b) PET studies have revealed that the medial frontal areas are activated in tasks involving attention to language (Petersen et al., 1988) and in visual tasks involving overt eye movements (Fox, Fox, & Raichle, 1985).

Posner et al. (1987) further proposed that the PAN and AAN could be thought of as being organized in a hierarchical network. Thus, because moving attention requires the previous disengaging of attention, midbrain areas involved in the "move" operation should be controlled by parietal areas involved in the "disengage" operation. Also, because the orientating of visual attention is affected by a language task depending on the AAN, the PAN must, as a whole, be controlled by the AAN. Posner et al. suggested that in dual-task conditions the AAN can interrupt (or delay) the action of the PAN.

The Present Research

The aim of the present research was to further investigate the relationships between the PAN and the AAN by determining whether inhibitory processes dependent on the PAN, and both facilitatory and inhibitory processes dependent on the AAN, are related to each other, as would follow if the two networks are interdependent.

In the present experiments, we combined a spatial inhibitory effect (spatial IOR) thought to tap the PAN with a semantic inhibitory procedure (we call this "semantic inhibition") that may tap the AAN. The starting point is as follows: If inhibitory processes in the PAN and the AAN are part of a common attentional network, spatial IOR and semantic inhibition must interact. The pattern of that interaction would help elucidate the nature of the relationship between the attentional networks. Note that this additive factors approach differs from that used by others to isolate attention networks (Nakagawa, 1991; Posner et al., 1987; see also Fuentes et al., 1994, and Posner et al., 1989, for a similar approach). These researchers used a dual-task paradigm in which each task was thought to tap a different attention network. In the present research, we combined two procedures into a single task. However, both the dual-task approach and the present approach assume that if two effects thought to tap a different attention network (either measured by different tasks or by different procedures in a single task) interact with each other, they must share anatomical areas of a common attention network. As Posner et al. (1989) pointed out, a major contribution of cognitive science has been the development of methods to isolate internal operations rather than entire tasks (p. 51). These operations can be accessed by asking participants to perform several tasks (Posner et al., 1987) or by combining procedures in a single task (the present study).

Experiments 1 and 2 were aimed at showing spatial IOR and semantic inhibition, respectively. Experiment 3 combined both procedures into a single task to test for interactions between the two effects. Experiment 4 extended the results of Experiment 3 to semantic facilitation instead of semantic inhibition.

Experiment 1

In this experiment we used a modified version of the IOR procedure (Maylor, 1985; Posner & Cohen, 1984). We presented two words: one (the prime) inside the box that served as a peripheral cue and the other (the intervening stimulus) inside the box that served as the central cue. Participants made a simple RT (detection response) to the target word, which could be presented either at the cued or at the uncued location (see Figure 1). The aim of Experiment 1 was simply to test whether the typical IOR effect would occur under these presentation conditions. Words were used here to enable the procedure to be combined with that in Experiments 2, 3, and 4. Nonwords were not included because semantic effects in Experiments 2, 3, and 4 were expected to be found with words but not with nonwords.

Two important features of this experiment should be noted: First, participants were told to perform a simple detection task in which the semantic nature of the target was irrelevant. Second, the prime–target intervals used (950 and 1,250 ms) were long enough to minimize the effects of automatic semantic priming (see Neely, 1977). Note that the main purpose of the present research was to observe the pattern of interference between two components of a task in which each component is supposed to tap a different attentional network. To tap the AAN, only attentional (expectation-dependent) priming should occur in the appropriate conditions (Experiment 2).

Method

Participants. Twenty undergraduates from the University of Almería participated. The participants received course credits for their participation, and all of them had normal or corrected-to-normal vision.

Materials and apparatus. The words DOG (PERRO) and HAND (MANO) served as prime stimuli, and the words BREAD (PAN) and SEA (MAR) were selected as intervening stimuli. The words *cat* (*gato*) and *finger* (*dedo*) served as target stimuli. In each trial, both the prime words and the intervening words were printed in uppercase, whereas the target was in lowercase. Every letter subtended an average 0.48° × 0.38° of visual angle in 40-column text mode at the viewing distance of 60 cm. Three boxes arranged horizontally were also used as stimuli for cuing purposes. The boxes subtended viewing angles of 5.4° × 1.3° when seen from the viewing distance of 60 cm. The inner sides of the two peripheral boxes were each located 4.9° of visual angle from fixation. All stimuli were presented on the color monitor (video graphics array card) of an IBM-compatible computer, and participants' responses were recorded by means of the computer keyboard.

Procedure. Participants sat approximately 60 cm from the computer and the experimenter explained the task verbally to them. Figure 1 shows the sequence of events and exposure durations used in this experiment. Each trial began with a fixation point (an asterisk) presented in the middle of the screen for 500 ms. Three white boxes then replaced the asterisk and were presented for 1,000 ms. Then, one of the peripheral boxes changed to red for 300 ms. This served as a cue to attract attention to the periphery. The peripheral box also contained the prime word. The boxes were then all presented in white again, for 200 ms, followed by the central changing again to red (the central cue) for 300 ms. The central box contained the intervening word. The target was subsequently

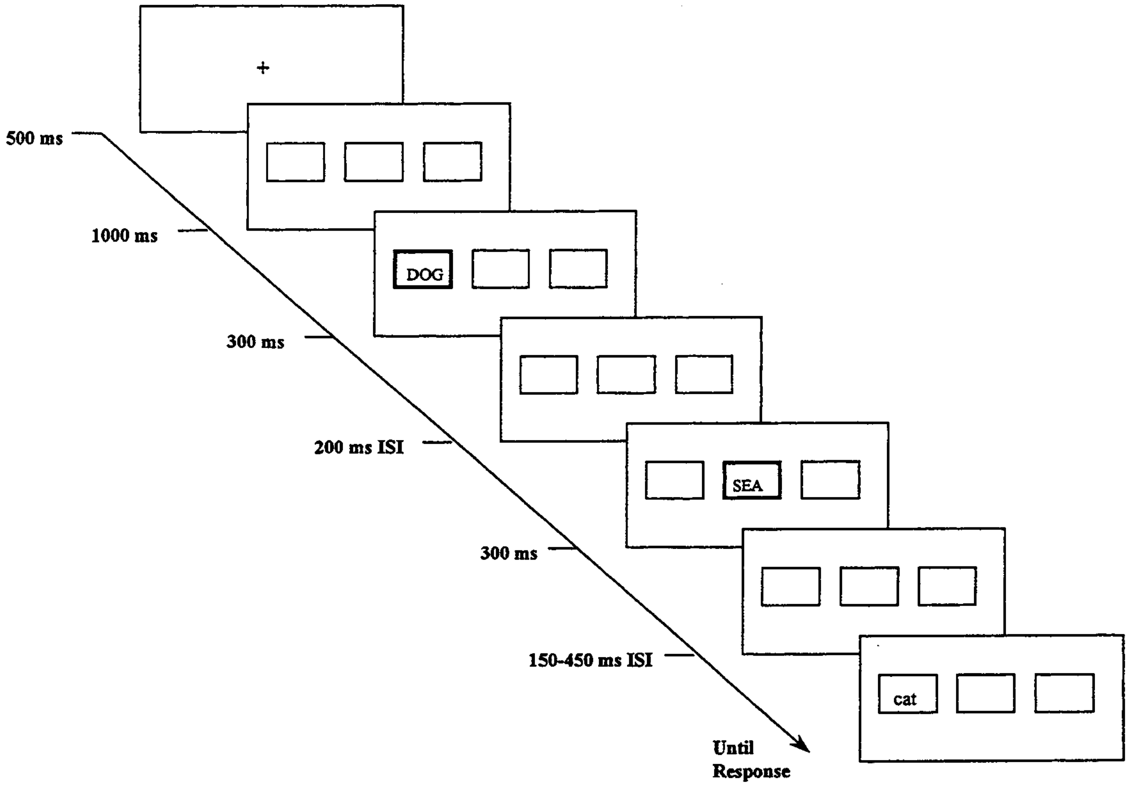

Figure 1. Sequence of events and exposure durations of stimuli in each trial. In Experiment 1 the stimulus onset asynchrony (SOA) was either 950 or 1,250 ms. In Experiments 2, 3, and 4 the prime–target SOA was 950 ms. In Experiment 2 the primes were presented inside the central box and the intervening item could be either a word or three Xs. In Experiment 4 the intervening item was not presented. ISI = interstimulus interval.

presented an equal number of times either at the cued location or at the uncued location within the left or the right peripheral box. The target could also be related to the prime on half the trials and unrelated on the other half. The prime–target stimulus onset asynchrony (SOA) was either 950 or 1,250 ms. The target remained on until the participant responded. These SOA values have proved appropriate to observe IOR in healthy adults, patients with neurological problems (Fuentes, Langley, Overmier, Bastin de Jong, & Prod'Homme, 1998), and those with psychosis (Fuentes & Santiago, 1999). Participants were informed about the sequence of events in each trial. They were told to pay attention to the changes taking place on the monitor screen but just to push the space bar from the keyboard as soon as they *detected* the target.

The following conditions were included: (a) cued-related, the target appeared at the cued location and was related to the prime word (e.g., DOG–cat); (b) uncued-related, the target appeared at the uncued location and was related to the prime word; (c) cued-unrelated, the target appeared at the cued location and was not related to the prime word (e.g., DOG–finger); and (d) uncued-unrelated, the target appeared at the uncued location and was not related to the prime word. Participants were run in three blocks of 64 trials (the first block for practice).

Results

Table 1 shows the mean of median RTs and standard deviations from Experiment 1. Mean RTs were submitted to a 2 × 2 × 2 repeated measures analysis of variance (ANOVA) with target location (cued, uncued), relatedness (related, unrelated), and prime–target SOAs (950 and 1,250 ms) as within-subjects factors.

The main effect of location was reliable, $F(1, 19) = 26.59$, $MSE = 2{,}219$, $p < .001$. That is, RTs for target detection were longer when the target was presented at the cued location than when it appeared at the uncued location (322 vs. 284 ms; the spatial IOR effect). The main effect of SOA was also reliable, $F(1, 19) = 42.66$, $MSE = 2{,}785$, $p <$

Table 1
Mean of Median Reaction Times and Standard Deviations as a Function of SOA, Target Location, and Relatedness in Experiment 1

Target location	950-ms SOA				1,250-ms SOA			
	Cued		Uncued		Cued		Uncued	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Relatedness								
Related	350	99	308	83	290	89	258	87
Unrelated	352	93	312	86	297	106	258	88

Note. SOA = stimulus onset asynchrony.

.001, indicating that the short interval produced longer latencies than the long interval (330 vs. 276 ms). However, neither the main effect of relatedness nor any of the interactions reached statistical significance (*F*s < 1).

Discussion

Experiment 1 showed spatial IOR. Latencies were longer when the target appeared at the cued location than when it appeared at the uncued location. This result is consistent with the contention that IOR is a general effect that is independent of the kind of stimuli participants are told to respond to (here occurring with words, whereas simple light onsets have been used in the majority of previous studies).

Note that no semantic priming was observed. This null effect is consistent with spatial IOR occurring by means of a PAN, which is indifferent to word meaning.

Experiment 2

In this experiment we sought to show an inhibitory semantic effect that would mimic in the semantic domain the kind of inhibitory processing that we obtained in the spatial domain in Experiment 1. Conditions were similar to those of Experiment 1, but a baseline control condition in which the intervening stimulus was three Xs was also included. Neutral warning signals (XXX) have been used frequently in previous studies of priming (e.g., Neely, 1977; Posner & Snyder, 1975). These signals provide temporal information about the onsets of target stimuli, matched to that provided by related and unrelated prime words. Other authors have noted that such neutral signals do not carry the information load of related and unrelated prime words (Jonides & Mack, 1984) and so may fail to provide an appropriate baseline in all respects. We used the neutral warning signal here to equate for the temporal properties of the displays to ensure that any switch of attention away from the meaning of the prime was not due to the occurrence of a signal for a forthcoming event. Also, contrary to Experiment 1, we presented the prime word in the central box instead of in one of the peripheral boxes because we were interested only in the semantic effect of the word rather than effects attributable to whether its location validly cued that of the target, as in Experiment 1. Finally, because only two spatial locations were used in the spatial procedure, we chose a small set of prime–target pairs in the present semantic procedure.

Method

Participants. Twenty-two undergraduates from the University of Almería were tested. The participants received course credit for their participation. All had normal or corrected-to-normal vision and none had participated in Experiment 1.

Materials and apparatus. The equipment used in this experiment was the same as that used in the previous experiment. The words DOG (PERRO) and HAND (MANO) served as primes; the words BREAD (PAN) and SEA (MAR) or three Xs served as intervening stimuli; and the words *finger* (*dedo*) and *cat* (*gato*) and the nonwords *dode* and *cato* served as targets. Thus, target nonwords were formed either changing a single letter or swapping two letters from the target words. The same three boxes of Experiment 1 were also used in this experiment.

Procedure. The procedure was similar to that used in Experiment 1, with the following important modifications: (a) The prime word was presented inside the central box (no peripheral cue was presented). The box color changed to red to make the stimulus conditions of this experiment comparable to those used in Experiments 1, 3, and 4. (b) The intervening stimulus could be either a word (from a different category of that of both prime and target) or three Xs (the neutral baseline). Thus, the prime words were followed an equal number of times by an intervening word and by the string of Xs. (c) Targets could appear inside the left or the right box. (d) The target could be either a word or a pronounceable nonword, and participants were told to make lexical-decision responses on targets. On half the trials, primes were followed by a target word and by a target nonword on the other half. Thus, primes were presented twice as frequently as the target words; when the target was a word, the prime was related to it 50% of the time. (e) Only the short prime–target interval of Experiment 1 (950-ms SOA) was used.

As in Experiment 1, participants were informed about the sequence of events in each trial. They were told to pay attention to all changes taking place on the monitor screen but just to respond *word* by pressing a key with their dominant hands and *nonword* by pressing a key with the nondominant hands when the targets were presented. The *M* and *C* keys from the computer keyboard were chosen for response purposes. Participants were run in three blocks of 64 trials (the first block was for practice).

Results

The means of median RTs, standard deviations, and percentage of errors are presented in Table 2. Because target location (left or right) did not exert any reliable effect, we collapsed the data from this factor. Separate analyses were conducted for target words and target nonwords. Because target nonwords were generated from target words, the same relatedness conditions were considered in both analyses, and this was true for this and for the remaining experiments. Thus, a target nonword that followed the prime word related to the target word from which the nonword was generated was taken as a related condition in the target nonword analysis.

Table 2

Mean of Median Reaction Times, Standard Deviations, and Percentage of Errors as a Function of Relatedness and Intervening Stimulus Type for Target Words and Target Nonwords in Experiment 2

	Intervening stimulus					
	Word			XXX		
Target	*M*	*SD*	PE	*M*	*SD*	PE
Words						
Related	659	66	2.8	650	59	3.1
Unrelated	640	56	3.7	657	70	3.7
Nonwords						
Related	684	58	3.4	682	58	2.8
Unrelated	679	48	3.7	688	60	4.8

Note. PE = percentage of error.

The mean correct RTs were submitted to a 2 × 2 repeated measures ANOVA with relatedness (related, unrelated) and intervening stimulus type (word, XXX) as within-subjects factors. The analysis of target nonwords did not produce any reliable effect ($Fs < 1$).

For target words, the main effect of both relatedness and intervening stimulus type failed to reach statistical significance ($Fs \leq 1.27$). However, the Relatedness × Intervening Stimulus Type interaction proved reliable, $F(1, 21) = 5.49$, $MSE = 668, p < .05$. The analysis of the simple main effects showed that RTs were reliably longer with related than with unrelated targets when the intervening stimulus was a word (semantic inhibition), $F(1, 21) = 10.05$, $MSE = 400$, $p < .01$. There were no differences when the intervening stimulus was a string of Xs ($F < 1$). Error rate analyses did not show any reliable result ($Fs < 1$).

Discussion

The results of Experiment 2 are important because they show, in the semantic domain, an inhibitory effect similar to that observed in the spatial domain. Note that the prime word in the semantic domain was supposed to have the same role as the peripheral cue in the spatial domain, that is, to "precue" (to prime) the semantic content of the target (equivalent to the location of the target in the spatial domain). In contrast, the intervening word was never related to either the prime or the target, and it was included to mimic in the semantic domain the role of the central cue in the spatial domain, that is, to remove attention from a previously attended prime word (the cued location in the spatial domain). Thus, because the target was never presented at the central location in the spatial task the target was never related to the intervening word in the semantic task. This is important because we sought to determine whether the AAN would behave in the semantic domain as the PAN does in the spatial domain. Consistent with this proposal, as in the spatial task, inhibition was observed when attention was first withdrawn from the prime word "space," to be allocated to the intervening word space for the intervening word, and then returned again to the word space for the previous prime (when targets were related to the prime). This is consistent with Posner's (1978) suggestion that attention can be oriented not only to events occurring in the sensory domain but also to representations in the semantic domain.

A full spatial analogy here would suggest that attention is some form of internal spotlight, or site of preactivation, within a semantically defined word space. A shift in attention to the location of an unrelated, intervening word would then delay activation to a subsequent target. However, why should RTs then be slower when the initial prime item is related to the target relative to when it is unrelated? In both cases, the intervening word (unrelated to either prime) would shift attention from the location of the target. The slowed RTs, following related primes, suggest that there is some additional residual bias against attending to the meaning of a previously attended word. For example, when attention is consciously withdrawn from the meaning of one word (and set to the meaning of the intervening word), there may be some inhibition of the prime word's representation in the semantic space. Slow RTs result when targets are related to primes. In the neutral condition, attention may be withdrawn from word space altogether because of the nonlexical nature of the stimuli. The time to reallocate attention to the word space when the target is presented may slow RTs relative to when an intervening word is used following an unrelated prime. In this last instance, attention will remain in the word space and there will be no bias against the representation of the subsequent target.

The inhibitory effect found here with an unrelated intervening word contrasts with other studies in which either no semantic effect was observed (Dannenbring & Briand, 1982; Gough, Alford, & Holley-Wilcox, 1981) or positive semantic priming was found (for reviews, see Davelaar & Coltheart, 1975; Masson, 1991). However, an important difference in the present experiment is that in those studies, the prime–target SOA value was short (e.g., Masson, 1991, referred to a study in which he used a prime–target SOA of 234 ms), presumably involving automatic semantic priming (see Posner & Snyder, 1975). In this experiment we used a long prime–target SOA (950 ms), which is thought to involve attentional processing. Posner and Snyder (1975) showed that both facilitation and inhibition may be observed if semantic priming is attention dependent, a result that has been confirmed several times in the literature (e.g., Fuentes & Tudela, 1992; Neely, 1977). A second important difference is that priming researchers usually use a large set of words as primes and targets to measure semantic priming. In contrast, in the present study, we used a small set of stimuli that repeated across trials. Under these circumstances, representations of all stimuli might reach a high level of activation. Inhibition may be limited to such situations (see Dark, Vochatzer, & Van Voorhis, 1996, for a similar view). Thus, the long prime–target SOA, and the small set of stimuli used in the present study, might be crucial for the semantic inhibition effect observed here. In Experiment 3 we assessed whether this attention-dependent semantic inhibition effect and spatial IOR would interact.

Experiment 3

In Experiment 3 we combined the two procedures used in the previous experiments into one single task. We expected the two effects, IOR and semantic inhibition, to interact if they are mediated by a common attentional network.

The procedure used in the present experiment replicated that of Experiment 1, but lexical decisions on targets, instead of detection responses as in Experiment 1, were now required. The new procedure allowed us to measure semantic effects from prime words presented at either cued or uncued locations (see Figure 1) and the typical spatial effects (spatial IOR). The nature of any interaction could help us understand how both attention networks are organized within the overall attentional system.

Method

Participants. Twenty-five undergraduates from the University of Almería participated. The participants received course credit for their participation. All of them had normal or corrected-to-normal vision, and none had participated in the previous experiments.

Materials and apparatus. The stimuli and equipment were the same as those used in the previous experiment, except that the intervening stimulus was always a word.

Procedure. The same procedure as in Experiment 2 was used, except that, as in Experiment 1, one of the peripheral boxes changed to red instead of the central one. Also, as in Experiment 1, the prime word was presented inside the peripheral box that changed its color. The intervening stimulus was always a word. Targets were presented an equal number of times at the cued location and at the uncued location, and at each location half the stimuli were words and half were nonwords. The prime–target SOA was 950 ms. Participants were informed about the task as in previous experiments. They were told to pay attention to all changes occurring on the screen but to make lexical responses only on targets.

The main experimental conditions were cued-related, cued-unrelated, uncued-related, and uncued-unrelated. As in Experiment 2, these conditions were also used for analyzing the data from target nonwords. Participants were run in three blocks of 64 trials (the first block was for practice).

Results

The means of the median RTs, standard deviations, and percentages of error are shown in Table 3. Separate analyses were conducted for target words and nonwords. The mean correct RTs were submitted to a 2 × 2 repeated measures ANOVA, with target location (cued, uncued) and relatedness (related, unrelated) as within-subjects factors.

The main effect of target location was reliable, $F(1, 24) = 62.84$, $MSE = 2{,}240$, $p < .001$, but the main effect of relatedness was only marginally reliable, $F(1, 24) = 3.98$, $MSE = 554$, $p < .06$. In general, RTs were longer with targets appearing at cued than at uncued locations (706 vs. 630 ms), that is, we observed spatial IOR. Also, related target words produced longer RTs than unrelated target words (673 vs. 663 ms), that is, there was a semantic inhibition effect. However, the most interesting result was that location reliably interacted with relatedness, $F(1, 24) = 4.53$, $MSE = 759$, $p < .05$. The analysis of the simple main effects showed that related targets produced longer RTs than did unrelated targets (i.e., there was a semantic inhibition effect), but this was true only for target words appearing at uncued locations (641 vs. 620 ms), $F(1, 24) = 8.44$, $MSE = 661$, $p < .01$. When target words were presented at cued locations, the effect of condition vanished (704 vs. 707 ms, $F < 1$).

Table 3

Mean of Median Reaction Times, Standard Deviations, and Percentage of Errors as a Function of Target Location and Relatedness for Target Words and Target Nonwords in Experiments 3 and 4

	Target location					
	Cued			Uncued		
Target	*M*	*SD*	PE	*M*	*SD*	PE
	Experiment 3					
Words						
Related	704	102	1.3	641	102	2.0
Unrelated	706	100	2.3	620	95	2.5
Nonwords						
Related	737	82	4.0	657	74	2.3
Unrelated	738	85	3.0	666	82	3.3
	Experiment 4					
Words						
Related	832	85	1.5	754	66	2.1
Unrelated	823	75	1.3	773	74	2.0
Nonwords						
Related	847	92	2.0	779	85	2.3
Unrelated	838	83	1.9	773	71	1.7

Note. PE = percentage of error.

For target nonwords there was a reliable main effect of target location, $F(1, 24) = 56.87$, $MSE = 2{,}545$, $p < .001$. Target nonwords presented at cued locations produced longer RTs than at uncued locations (738 vs. 661 ms). The main effect of relatedness and the Location × Relatedness interaction were not reliable ($Fs \leq 1.28$). The error rate analyses did not produce any reliable effects.

In an additional analysis we compared the size of the IOR effects in Experiment 1 versus Experiment 3. This comparison was important because it addressed differences between IOR in detection versus discrimination tasks (Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997). The IOR effect size was computed as follows: First, we calculated the average RTs for the related and unrelated cued conditions and for related and unrelated uncued conditions in each experiment (only the target words from Experiment 3 entered into the computations because only target words were used in Experiment 1). The IOR effect sizes were then calculated for each participant from each experiment by subtracting the average RTs at the cued location from the average RTs at the uncued location. Each difference was then divided by the average RT at the uncued location. The resulting scores were submitted to a one-way ANOVA with task type (detection in Experiment 1 vs. lexical decision in Experiment 3) as a between-subjects factor. The dependent variable was the effect size. The results show a reliable effect of task type, $F(1, 43) = 6.83$, $MSE = 3{,}224$, $p < .025$. The effect size of IOR in the lexical-decision task was greater than in the detection task (38 vs. 21).

Discussion

Three aspects of the present results deserve comment. First, the fact that spatial IOR occurred when participants were told to make lexical responses on targets suggests that the spatial attributes of stimuli (e.g., location detection) are not the only ones that are affected by inhibition (see Lupiáñez et al., 1997). This is consistent with other studies that have shown that IOR affects stimulus processing when (a) responses are based on color (Law, Pratt, & Abrams, 1995); (b) judgments are made of the temporal order in which two targets are presented (Gibson & Egeth, 1994); and (c) when Eriksen-type interference from a precued flanker is measured on central targets (Fuentes, Vivas, & Humphreys, 1999). Thus, attentional orienting seems not only to facilitate both the detection and discrimination of targets (Posner, Snyder, & Davidson, 1980) but also to hamper target processing when IOR conditions are met (Fuentes et al., 1999; Gibson & Egeth, 1994; Law et al., 1995).

Second, previously, semantic inhibition has been observed when expectations based on primes are not met by later targets (cf. Neely, 1977). Such expectation-based inhibition may be considered to be a product of the AAN. However, the procedure used here suggests that there is an inhibitory component depending on the AAN that functionally mimics that of the PAN inhibitory component because it arises after attention has been withdrawn from the semantic "space" of a once-attended word (semantic inhibition). This confirms Posner's (1978) suggestion that the orienting network may be thought of as a model network, so that similar components in the spatial domain may also be found in the attention within the semantic domain.

Third, semantic inhibition and spatial IOR interacted. Semantic inhibition occurred only when targets were at uncued locations; it did not occur when targets appeared at cued (spatially inhibited) locations. This is consistent with semantic inhibition and IOR reflecting two interdependent components of a common attentional network that seem to work in an interactive way (Posner et al., 1987). (The way in which these components of the attentional network are related to each other is discussed further in the General Discussion section.)

Experiment 4

On the basis of the results of the previous experiments, we concluded that semantic inhibition is a product of an attentional mechanism that modulates semantic processing from primes. We attributed this semantic inhibition effect to the operation of an AAN. In the present experiment, we wanted to test two other hypotheses: (a) If the inhibitory effect observed in Experiment 3, when targets were presented at uncued locations, were due to the intervening word, removing this word should produce semantic facilitation instead of inhibition because attention should be maintained on semantic information derived from the prime (cf. Neely, 1977). (b) If the interaction between spatial IOR and semantic inhibition we found in Experiment 3 were due to a PAN affecting the functioning of the AAN, a similar interaction should occur in this experiment in which semantic facilitation is now expected. In other words, we expected attention-dependent semantic facilitation when targets are presented at uncued locations. When targets are presented at cued locations, the semantic effect should vanish.

Experiment 4 replicated the conditions of Experiment 3, except that the intervening stimulus was not presented. We also increased the number of prime–target pairs to four, so that there were four target words and four target nonwords.

Method

Participants. Twenty-four undergraduates from the University of Almería participated. The participants received course credit for their participation. All had normal or corrected-to-normal vision, and none had participated in the previous experiments.

Procedure. The procedure was similar to that used in Experiment 3, except that the intervening stimulus was not presented. Also, in contrast to the previous experiments, we used four prime–target pairs for the semantic effect. The words DOG (PERRO), HAND (MANO), SEA (MAR), and BREAD (PAN) served as primes, and the words *cat* (*gato*), *finger* (*dedo*), *river* (*rio*), and *wine* (*vino*) served as target words. Target nonwords were formed from target words by changing a letter or swapping two letters. In half the trials, the target was a word and a nonword in the other half. The main experimental conditions were cued-related, cued-unrelated, uncued-related, and uncued-unrelated. As in Experiments 2 and 3, only the short prime–target interval was used (950 ms). Participants were informed about the task as in previous experiments. They were told to pay attention to all changes occurring on the screen but to make lexical responses only on targets. Participants were run in two blocks of 192 trials preceded by a block of 64 trials for practice.

Results

Table 3 shows the mean of median RTs, standard deviations, and percentage of errors of this experiment. Separate analyses were conducted for target words and nonwords. The mean correct RTs were submitted to a 2 × 2 repeated measures ANOVA with target location (cued, uncued), and relatedness (related, unrelated) as within-subjects factors.

For target words the main effect of target location was reliable, $F(1, 23) = 61.55$, $MSE = 1{,}611$, $p < .001$. In general, RTs were longer with targets appearing at cued than at uncued locations (828 vs. 763 ms), that is, we observed spatial IOR. The main effect of relatedness was not reliable ($F < 1$), but, importantly, we observed a reliable Location × Relatedness interaction, $F(1, 23) = 13.88$, $MSE = 327$, $p < .01$. The analysis of the simple main effects showed that related targets produced shorter RTs than unrelated targets (semantic facilitation) but that that was only true for target words appearing at uncued locations (754 vs. 773 ms), $F(1, 23) = 6.44$, $MSE = 636$, $p < .025$. When target words were presented at cued locations, the effect disappeared (832 vs. 823 ms), $F(1, 23) = 1.29$, $MSE = 759$, $p > .25$.

For target nonwords there was a reliable main effect of target location, $F(1, 23) = 55.55$, $MSE = 1{,}908$, $p < .001$. Target nonwords presented at cued locations produced longer RTs than at uncued locations (842 vs. 776 ms). The main effect of relatedness and the Location × Relatedness interaction were not reliable. Error rate analyses did not produce any reliable effects.

Discussion

The results show that removing the intervening stimulus between the primes and targets produced semantic facilitation, as would be expected if attention then remained at the location of the prime in a semantically organized word space. Preactivation of this space, by attention, may spread to facilitate RTs to related target words. Taken together, the results of Experiments 2, 3, and 4 strongly suggest that the lexical nature of the intervening stimulus was crucial to the semantic inhibition effect found in Experiments 2 and 3;

the intervening word led to attention shifting from the semantics of the prime (and related targets). Removal of the intervening word reversed the effects because attention should not then shift. As before, we observed an interaction between spatial IOR and semantic facilitation. When targets occurred at inhibited locations, the semantic facilitation effect observed at uncued locations was eliminated. This suggests that the PAN affected the current action of the AAN, that is, inhibiting (Experiment 3) or facilitating (Experiment 4) semantic processing. Again, this supports the view of the PAN and the AAN as two interdependent networks that interact in their operation.

General Discussion

In the present research, we assessed the relationships between two putative attentional networks: the PAN and the AAN. Previous work has shown that both networks seem to be part of a common attentional system that exerts control functions on the spatial orienting of attention and on linguistic processing (Posner, 1988; Posner et al., 1987).

The results shown here are consistent with that contention and allow us to further suggest that the facilitatory and inhibitory components of the AAN and the inhibitory component of the PAN interact with each other. Experiment 1 showed spatial IOR, similar to in previous studies (Maylor, 1985; Posner & Cohen, 1984). Experiment 2 showed that a similar inhibitory effect was observed in the semantic domain, likely involving the AAN. Lexical decisions to targets were inhibited after attention had shifted from the "semantic space" of a first prime to that of an intervening word, and targets were related in meaning to the first prime. It appears that attentive shifts within a semantically organized word space lead to inhibition of the representations of previously attended words. Experiment 3 showed that, in a task in which both components operated, spatial IOR was observed but interacted with semantic inhibition; semantic inhibition vanished for targets appearing in inhibited (cued) locations. Finally, Experiment 4 showed that an interactive effect was also observed when semantic facilitation caused by the AAN was measured rather than inhibition.

IOR in Lexical Decisions

IOR is the mechanism that prevents visual attention from returning to already explored locations. Some researchers have assumed that IOR is independent of attention (Klein & Taylor, 1994) because effects emerge in tasks in which participants have to program an eye movement to predicted target locations. Consistent with that view is that covert orienting using a central cue produces IOR only if an eye movement is programmed in the signaled direction, even if the eye movement itself is subsequently canceled (Rafal et al., 1989). However, recent studies have shown that IOR may be observed not only in simple detection tasks but also in discrimination tasks and that effects found in both tasks may be dissociated. Thus, Lupiañez et al. (1997) found different temporal courses for IOR when participants were engaged in a detection task than when they were told to perform a discrimination task, with the former starting earlier than the latter.

A more plausible account of IOR is based on the multiple-component hypothesis of the phenomenon (Abrams & Dobkin, 1994). One component of IOR is observed mainly when participants are told to detect the target or when a choice response is based on location (Klein & Taylor, 1994). Experiment 1 showed an effect of this kind. The other component is involved in the processing of target stimuli and is observed when responses are based on target properties other than location (Experiments 3 and 4). This multicomponent view of IOR is further supported by the fact that in the present research the IOR effect was greater with lexical decisions than with detection responses, suggesting that inhibition affected target processing in a different way in each task. Fuentes et al. (1999) provided further evidence that IOR affected the access of activated representations of stimuli to their response mechanisms. They found that IOR reversed the standard flanker interference effect (cf. Eriksen & Eriksen, 1974). At inhibited locations, compatible distractors produced longer RTs than incompatible distractors. Fuentes et al. proposed that inhibited items are disconnected from their linked response (in their study, targets were classified as numbers or letters). RTs to targets from the same category as inhibited distractors are then slowed because that category is disconnected from the response. RTs are facilitated when the distractor is incompatible because the incongruent response (to the distractor) is then disconnected.

The lower level component of IOR seems to act as a filtering mechanism affecting early vision, perhaps being mediated by the superior colliculus and linked to the oculomotor system (Abrams & Dobkin, 1994; Rafal et al., 1989). This component predominates when detection responses or saccades are required by the task. The higher level component seems to affect a later processing of stimuli presented at inhibited locations and may more likely be mediated by cortical areas (Tipper, Weaver, Jerreat, & Burak, 1994). This component seems to predominate in discrimination tasks (Abrams & Dobkin, 1994; Fuentes et al., 1999; Lupiañez et al., 1997). We suggest that it is this higher level component of IOR that interacts with attention-dependent semantic processing within the AAN.

Semantic Inhibition and Inhibitory Processing

The semantic inhibition effect found here mimics that usually observed in spatial cuing experiments. It suggests that attention is not only oriented to space but that it is also oriented within the semantic network. An inspection of relevant attentional studies reveals that this is not the only case in which a clear analogy can be drawn between attention in different domains. Similar cognitive inhibition operations have been proposed when the selection of target stimuli from distractors is required (Tipper, 1985) and when participants are told to retrieve weakly activated codes from memory (see Dagenbach & Carr, 1994, for a review). These analogous effects also occur in a variety of tasks involving attentional orienting. Posner (1980) suggested that attention may be oriented to a location when either a peripheral cue or a central cue (e.g., an arrow pointing to a likely target location) is presented in advance of the target. The cue signals the most likely location where the target will subsequently be presented. Presenting the target in that location will produce faster detection responses, fewer errors, or both than presenting the target in the uncued location (a cue validity effect). Validity effects are also found in the semantic domain. When a word (the prime) precedes a related target, responses (naming, lexical decisions, target categorization) to that target will be faster and more accurate than if the prime and target are not related: Semantic priming occurs (see Neely, 1991, for a review). Participants may also orient their attention to a location different from that indicated by the cue when a central (endogenous) cue is used (Posner & Cohen, 1984). Similar effects have been observed in the semantic domain. Thus, Neely (1977) observed that participants were able to expect a target from a different category to that signaled by a prime (i.e., expecting a bird when the category *body* was presented as the prime stimulus) when they were instructed to do so. This led to activation of the expected category and inhibition of the learned category relations. The semantic inhibition in the present research provides an analog of spatial IOR in the semantic domain. All these similar attention-dependent effects are consistent with Posner's (1978) suggestion that the PAN may be a good model to study how other attentional networks operate.

A major issue is to determine whether all these inhibitory effects involved in selective attention tasks may be accounted for considering a single underlying mechanism. For instance, Houghton and Tipper (1994) proposed a model of inhibitory mechanisms in which selection is thought to involve the interaction of internally activated target descriptions (the target field), with the representations of external stimuli being activated in the object field. Selection is achieved by means of a matching process (using match–mismatch detectors), with inputs being generated from both the object fields (i.e., from the target object and the distractor object) and the target field. When a target that matches its internal representation in the target field is presented, the match–mismatch detector further increases target properties in the object field by means of excitatory feedback, but this is at the expense of a concurrent inhibitory circuit, which also activates when a stimulus is presented. When a distractor is presented, the match–mismatch detector suppresses distractor activation in the object field. However, as soon as the exposure of the distractor ceases, the only circuit activated is the inhibitory one, producing an "inhibitory rebound" that renders distractor activation below baseline level, producing negative priming. An important property of the model is that the inhibitory rebound is proportional to the level of activation the to-be-ignored object reaches in the object field. This accounts for the increments in negative priming as a function of distractor intensity. More intense distractors produce a higher level of activation in the object field, which, in turn, would produce more interference with targets under certain circumstances and a greater inhibitory rebound when its activation finishes (Houghton, Tipper, Weaver, & Shore, 1996). Importantly, the model may account for other inhibitory effects that have appeared in the literature recently, such as when participants are told to retrieve weak semantic codes that may suffer from greater interference from well-learned semantic codes (Dagenbach & Carr, 1994).

Interestingly, Houghton and Tipper (1994) extended the scope of the model to other inhibitory mechanisms that occur when participants orient their attention to search for relevant targets. One of these mechanisms is IOR. We wanted to show here that the model could also account for the analog effect in the semantic domain, the semantic inhibition effect found here. In our experiments, the cue (the box changing to red, or the prime word) would activate its representation in the object field, and a template in the target field is then internally generated. In the absence of extra stimulation, that would be sufficient to produce facilitation (Experiment 4). However, if a second cue comes up before the target is presented (the central box changing to red, or the intervening word, as in Experiments 2 and 3), then activation of the previous cue ceases and a new target representation in the target field is created that would fit with the new cue in the object field. The activation of the previous cue will persist for a while, but it will now generate a mismatch from the match–mismatch generator. This brings about an inhibitory rebound in the representation of the cue producing IOR in the spatial domain and semantic inhibition in the semantic domain. We now propose that when both processes are taking place at the same time, different patterns of interference between the two may take place (see the next section).

Interrelationships Between the AAN and PAN

To understand how selective attention operates to control information processing, researchers need to understand the way in which attentional networks relate to one another. As indicated in the introduction, Posner et al. (1987; see also Posner, 1988) proposed that the AAN and PAN are organized hierarchically. They observed that orienting attention (associated with the PAN) was affected by a concurrent task associated with the AAN. They concluded that under certain circumstances, the action of the PAN could be affected by the AAN. Here, we found that semantic effects, thought to tap the AAN, were affected by IOR (associated with the PAN). In particular, once attention has been withdrawn from a location (because of IOR), attention is not sustained to semantic representations of targets that fall there (either to inhibit or to facilitate those representations). Note that this does not mean that words presented in inhibited locations fail to activate their semantic representations in the usual way. In fact, Fuentes et al. (1999) reported evidence for semantic activation from words presented under those conditions. Rather, the present evidence shows that attentional processing (dependent on the AAN) is not applied to semantic representations of words falling in locations subject to IOR.

There are important differences between the procedure followed by Posner et al. (1987) and that used here that might account for the differences observed in the relationships between the two attention networks. In the Posner et al. (1987) study, participants had to search for the presence of a determined phoneme in a list of auditory words or to count backward from a three-digit number (the secondary task). Concurrently, participants had to detect one visual target that could appear either at a valid or at a invalid location (the primary task). It seems possible that the secondary task required more attentional resources than the primary task. Thus, the secondary task, associated with the AAN, might have had priority in terms of attentional processing in their experiment, which affected the PAN by modulating the validity effect on the spatial task.

In a recent study, Fuentes et al. (1998) combined an IOR procedure with a semantic cuing procedure. Participants were presented with a target word that could appear either at a cued location or at an uncued location and had to report whether it was an exemplar of the category *animal* or an exemplar of the category *tree*. The peripheral box that was used as a spatial cue contained the prime (ANIMAL, TREE, or XXXX). Prime and target stimuli were presented within three conditions (valid, invalid, and neutral). The results showed that costs effect in the semantic domain increased when targets were presented at noninhibited (uncued) locations, compared with when they appeared at inhibited (cued) locations. This suggests an influence of the PAN on the AAN. However, their results showed that IOR was affected by cuing in the semantic domain, being greater for valid and invalid than for neutral targets. This suggests an influence of the AAN on the PAN. Attentional demands may be similar for the tasks of locating a target and maintaining the category of a prime until the target is presented; as a consequence, the AAN and PAN can affect one another. In the present research, participants did not have to maintain the prime word until the target was presented because their responses were based exclusively on lexical decisions on targets. Thus, the spatial task (locating the target) might have had priority in terms of attentional demands, and therefore visual orienting influenced the semantic effect associated with the AAN.

Our results leave open the argument concerning when processes such as rebound inhibition might come into play. Here we used small sets of primes and targets to mimic, as much as possible, the conditions typically used to study spatial cuing when only a few locations can be used. However, one consequence of this is that the representations of all the prime and target words could have been strongly activated in the experiment because the stimuli were repeated across trials. Under this circumstance, some form of attention-dependent inhibitory process may be used to suppress the activation of previously attended primes, when attention is switched to the meaning of an intervening word. It remains a moot point as to whether similar mechanisms are used in other circumstances, when stimuli are not repeated. Note, however, that a rebound-inhibition process would help prevent repetitions of responses in everyday life; damage to such a process could lead to perseverative behavior (see Forde & Humphreys, in press).

Taken together, our results support the view of two attentional networks acting in an interactive way. The AAN will interfere with the action of the PAN when processing demands are higher for the anterior task (Posner et al., 1987); the opposite will occur when detection of target location (i.e., the posterior task) has priority (the present research); and effects in both directions will occur when both tasks have similar priority in terms of attentional processing (Fuentes et al., 1998). Such interactions will enable coherent behavior to emerge across networks concerned with selecting different types of information for action (cf. Duncan, Humphreys, & Ward, 1997).

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