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## Modulations among the alerting, orienting and executive control networks

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**Abstract** This paper reports a series of experiments that were carried out in order to study the attentional system. Three networks make up this system, and each of them specializes in particular processes. The executive control network specializes in control processes, such as conflict resolution or detection of errors; the orienting network directs the processing system to the source of input and enhances its processing; the alerting network prepares the system for a fast response by maintaining an adequate level of activation in the cognitive system. Recently, Fan and collaborators [J Cogn Neurosci 14(3):340–347, 2002] designed a task to measure the efficiency of each network. We modified Fan's task to test the influences among the networks. We found that the executive control network is inhibited by the alerting network, whereas the orienting network raises the efficiency of the executive control network (Experiment 1). We also found that the alerting network influences the orienting network by speeding up its time course function (Experiment 2). Results were replicated in a third experiment, proving the effects to be stable over time, participants and experimental context, and to be potentially important as a tool for neuropsychological assessment.

**Keywords** Attentional networks · Exogenous orienting · Flanker task · Phasic alerting

### Introduction

Several authors have argued that the attentional function is carried out by three different attentional networks

that work in concert under everyday conditions and are independent of the systems related to perception and action<sup>1</sup>. These networks were named the anterior or executive control network, the posterior or orienting network and the alerting network (Posner and Boies 1971; Posner and Petersen 1990).

The executive control network is thought to be active when the cognitive system faces situations that involve planning, making a decision, detecting an error, giving a novel response or overcoming habitual actions (Norman and Shallice 1986). The Orienting Network selectively allocates attention to a potentially relevant area of the visual field and/or object, and it enhances its perceptual processing<sup>2</sup>. The alerting network prepares the system for fast reactions by means of a change in the internal state.

The three attentional networks have been studied under behavioral, neuropsychological and functional perspectives (Posner and Fan 2005; Posner and Petersen 1990 for reviews). Even neurotransmitter and gene studies have been carried out to further differentiate them (Fan et al. 2001; Fossella et al. 2002).

The executive control network is thought to be located in the anterior areas of the frontal cortex. More specifically, neuroimaging studies have found activity in the anterior cingulate cortex and the lateral prefrontal cortex to be associated with this network (Casey et al. 2000; Duncan and Owen 2000; Posner and Fan 2005). Some of the tasks used to measure attentional executive control are those dealing with conflict, handling novelty, and detecting errors (Posner and DiGirolamo 1998),

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<sup>1</sup>However, it is worth mentioning that dissenting views reject the thought of attention as a system independent of those used for the processing of input and planning of responses (see Allport 1993; Rizzolatti et al. 2002 for elaborations on this point of view).

<sup>2</sup>Even though the orienting network is not exclusively concerned with visual information, but with input coming from any sense, for the sake of simplicity we only mention the studies concerning visual orienting since it is the most relevant to our tasks. See Spence and Driver (2005) for a review on crossmodal spatial orienting or Correa et al. (2004) for temporal orienting.

such as stroop-like tasks or flanker tasks. Recent studies have shown that the areas involved in these tasks are similar, although not identical (Fan et al. 2003; Casey et al. 2000). The structure of the frontal lobe provides the ideal setting for executive control of actions since it has numerous connections with different parts of the brain where it may exert its control. In particular, the anterior cingulate cortex and the dorsolateral prefrontal cortex seem to be an important part of this network (Berger and Posner 2000). The connections of these areas with more lateral frontal areas may be related to working memory processes and the connections with more posterior parts of the brain may exert control over visual orienting areas (Posner and Raichle 1994).

The orienting network is thought to be implemented in the posterior parietal lobe, the superior colliculus and the pulvinar nucleus of the thalamus (Posner and Raichle 1994). Finer studies have associated each of these anatomical areas with one of three different operations involved in the orienting mechanism (Posner and Cohen 1987). The posterior parietal lobe has been associated with the disengagement of attention. The superior colliculus is related to the movement of attention to a different location (Sapir et al. 2002), and the thalamus is thought to enhance stimulus processing at the new location (LaBerge 2000). The thalamus is connected with virtually every area of the cortex (Jones 1985), which makes it a good candidate for such an enhancement function. Some see it as a biological amplifier of neuron firing (LaBerge 2000). More recent studies point to the role of parietal and frontal areas, including the intraparietal sulcus, the middle frontal gyrus and the right temporo-parietal junction, in the orienting and reorienting of attention (Thiel et al. 2004).

Studies of the brain areas sustaining the alerting network point to much more diffuse locations. This network is in charge of maintaining an adequate level of activation in the cognitive system. Two types of alertness have been described based on the tasks used to measure them. Tonic alertness or vigilance refers to a sustained activation over a period of time, whereas phasic alertness is related to the nonspecific activation experienced when a warning signal is presented prior to the target. Vigilance is usually measured with tasks where participants have to attend to a location over a period of time and detect infrequent targets. Phasic alertness is studied by measuring the influence on reaction time (RT) of a signal that only provides temporal information. Most studies agree on the role of the frontal and parietal regions of the right hemisphere on alerting [see Posner and Petersen (1990) for a review], although brain stem areas such as the reticular formation also seem to be important (Sturm and Willmes 2001). Likewise, some studies have pointed to a possible implication of the same brain areas on both types of alertness (Marrocco and Davidson 1999; Sturm and Willmes 2001).

Although separate anatomical substrates point to the independence of the three attentional networks, research has also been carried out to study the interactions

between them. However, the way they influence each other is still not clear. Neuroimaging studies have found that when participants are involved in alerting tasks, an enhancement in right hemisphere activation is observed, as well as a reduction in the signal coming from frontal areas such as the anterior cingulate cortex (Cohen et al. 1988). These patterns of brain activity have been interpreted as an inhibition of the anterior network by the alerting network. A shutdown of the control activity would be positive when the system has to concentrate on the detection of external signals. This phenomenon was termed “clearing of consciousness” (Posner 1994).

The alerting network could also influence the orienting network. The alerting network has been associated with a specific neurotransmitter (norepinephrine) that is produced in the locus coeruleus. At the same time, this nucleus has especially strong connections with the posterior areas involved in the orienting of attention (Morrison and Foote 1986; Posner 1978), suggesting that the alerting network could produce a faster orienting to the stimulus. However, it would not influence the rate of build-up of the information about the stimulus identity. Behavioral studies have found no influence between the two networks (Fernandez-Duque and Posner 1997) while neuropharmacological tests found the opposite pattern of results. Neurotransmitter suppressant associated with each network produced a reduced disengagement time and a reduced validity effect (Clark et al. 1989).

Recent behavioral studies have found some evidence of a possible influence of the orienting network on the executive control network (Funes and Lupiáñez 2003). A reduction of spatial stroop was found when the conflicting stimulus appeared at the cued location. In this study, a spatial stroop task combined with visual orienting cues and auditory alerting cues was used to measure the three attentional networks. Participants were asked to discriminate the direction of an arrow. The location and direction of the arrow could be congruent (an arrow pointing leftwards located on the left side of the screen) or incongruent (an arrow pointing leftwards located on the right side of the screen). A peripheral spatial cue could appear either at the location of the subsequent target (cued trials) or at the opposite location (uncued trials). The proportion of cued and uncued trials was kept the same, so that no strategic processes were induced by it. Also, an alerting sound was used on half of the trials. The authors found the significant main effects for each of the three variables as well as two significant interactions. The spatial stroop effect was larger under conditions of high alertness. It was also smaller for cued trials than for uncued trials.

Recently Fan and collaborators (Fan et al. 2002) developed a task to measure the efficiency of each network. The Attentional Network Test (ANT) is based on the combination of a cued RT task (Posner 1980) and a flanker paradigm (Eriksen and Eriksen 1974). The logic of this test is to measure the efficiency of the orienting and alerting networks by means of the cueing task

through different types of visual signals, and the efficiency of the executive control network by means of the flanker task.

The ANT requires participants to discriminate the direction of an arrow flanked by two arrows on each side. The flankers can point to the same direction as the target arrow (*congruent condition*) or to the opposite one (*incongruent condition*). In a *neutral condition*, the target is flanked by horizontal lines. The stimulus can appear either above or below a fixation point, and is preceded by a cue. There are four types of cue: a *central cue* (asterisk) that appears at fixation point, a *double cue* that simultaneously signals the two possible locations of the target, a *spatial cue* that appears at the location of the subsequent target, or by a blank screen showing only the fixation point (*no cue condition*). These four levels of cuing provide an index for the orienting effect and another index for the alerting effect. The authors computed the efficiency score of the orienting network by subtracting trials with *spatial cue* from trials with a *central cue*. The role of the alerting network was measured by subtracting trials with *double cue* from trials with *no cue*. The executive control network was measured by means of the congruency variable, as the subtraction of congruent trials from incongruent trials.

Participants' performance on the ANT showed that a reliable index of each network could be easily obtained with a task short and simple enough to be suitable for adults and children. Nevertheless, apart from the expected main effects, authors found an unpredicted but significant interaction between the two variables being measured (cueing and conflict). Due to the design of their task, the interaction could not be interpreted, since alerting and orienting were measured with the same variable. Therefore it was not clear whether the conflict (congruency variable) was modulated by orienting or by alerting.

We had several goals in this study. The most important one was to provide a task useful not only for measuring the functioning of each attentional network, but also for studying the interactions among them. Once this goal was achieved, we had two more specific goals. First, we wanted to further study the interaction between congruency and cueing found by Fan and collaborators (2002) in order to learn whether the interaction was due to an influence from the alerting network, the orienting network, or both of them on the executive control network. Second, we wanted to learn more about the possible relationship between the alerting and orienting network.

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## Experiment 1

Following the additive factor logic (Sternberg 1969), we modified the ANT (Fan et al. 2002). An alerting sound was introduced and two of the four levels of the original cueing variable were eliminated in order to be able to

separately measure alerting and orienting. Thus, no central cue or double cue trials were presented. Further changes were introduced on the spatial cue, which was unpredictable of target location in our experiments, whereas it was 100% predictive in the original study. Predictive cues are thought to exert their function through the combined activation of the orienting network and the executive control network, since they imply the generation of an expectation that would give rise to an endogenous orienting system (Eimer 2000). On the other hand, nonpredictive cues only index the influence of the orienting system, since no interpretation or strategic processes are involved in their processing. Following the design proposed by Fernandez-Duque and Posner (1997, Experiment 3), we presented an alerting signal (Auditory Signal) 400 ms prior to the orienting signal (Visual Cue), and followed this by the target stimulus.

## Methods

### Subjects

Twenty-four psychology students of the University of Granada took part in this experiment for course credit. They all reported normal or corrected-to-normal vision and were naïve to the purpose of the experiment. Their age ranged from 19 to 25, and 19 of them were females. This and the following experiments were performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. All the participants gave their informed consent prior to their inclusion in the study.

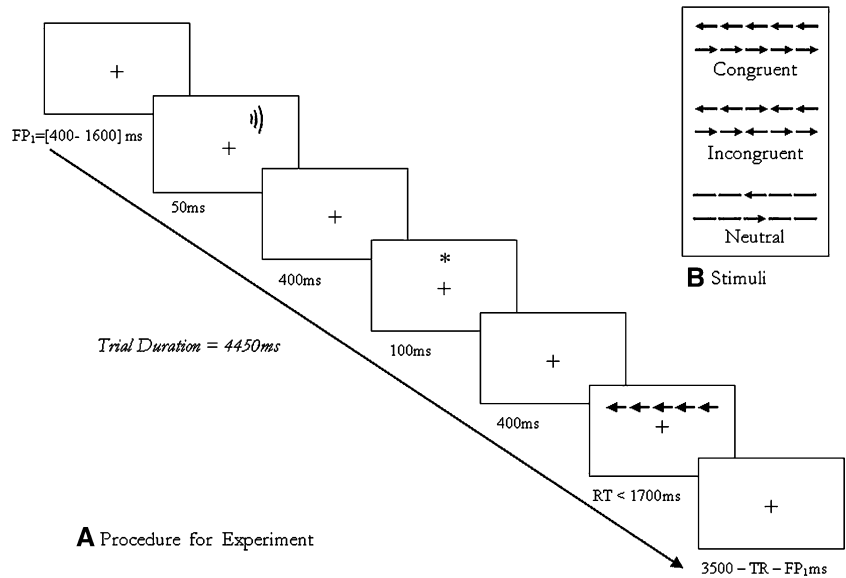
### Apparatus

A Pentium III computer with a 15-inch color screen monitor, running E-Prime software (Schneider et al. 2002) was used for programming, presentation of stimuli, and timing operations. Responses were collected through the keyboard of the computer and a headphone set was used to deliver an alerting signal.

### Stimuli

The stimulus used for the orienting signal was an asterisk presented at the same location as the target ( $0.6^\circ$  of visual angle above or below fixation point). For the alerting signal, a 2000 Hz and 50 ms sound was used. The target display was made up of a target arrow that could point either to the left or to the right, and four flankers that could be just plain black lines or arrows pointing either left or right. The length of the arrows (or lines for the neutral condition) was  $0.55^\circ$ , and they were  $0.06^\circ$  away from each other.

**Fig. 1** Experiment 1. Procedure: **A** is an example of the procedure, and **B** represents the stimuli used in this experiment



### Procedure

Participants were seated approximately 53 cm from the computer screen, and were instructed to respond to the direction of the target stimulus by pressing one of two possible keys in the keyboard. Feedback regarding accuracy was given during the practice block, but not during the experimental blocks. Participants could rest between blocks. The mapping of hand-response was always compatible (a rightward arrow was to be responded to with the right hand and a leftward arrow with the left hand).

The sequence of events for each trial is shown in Fig. 1. A fixation point (a plus sign) of variable duration (400–1600 ms) was presented at the beginning of each trial. This was followed by the 50 ms alerting signal in only half of the trials. After a 450 ms stimulus onset asynchrony (SOA), an orienting cue was presented for 100 ms above or below fixation point on 2/3 of the trials. After another 500 ms SOA, the target and flankers were presented either on the same or opposite locations of the previous orienting cue. They were present on the screen for 1700 ms or until the participant gave a response. After the response was given, the fixation point that had been present during the whole trial was kept for a variable duration dependent on the duration of the initial fixation point and on the RT of the subject, so that every trial had the same duration (4450 ms). No stimulus was presented between trials. Consequently, participants did not know when a trial had finished and the next one had begun. This produced more uncertainty about when the signals were going to appear, and that increased their informative value.

### Design

The experiment had a 2 (Auditory Signal)  $\times$  3 (Visual Cue)  $\times$  3 (Congruency) factorial design. The Auditory

Signal had two levels: presence or absence of a 2000 Hz and 50 ms sound. The Visual Cue had three levels: no cue trials (no orienting cue was presented), cued trials (an orienting cue was presented at the same location as the subsequent target) and uncued trials (the orienting cue was presented, but at the location opposite the target)<sup>3</sup>. Congruency had three levels: neutral trials (the target was flanked by two lines on each side), congruent trials (the target was flanked by arrows pointing to the same direction), and incongruent trials (the flanker arrows pointed to the opposite direction to the target). The number of trials per level of each variable was kept constant. This is especially important in the case of the Visual Cue, since a larger proportion of cued trials would have made the cue predictive of target location. The practice block had 20 trials and was followed by three blocks of 144 trials each, so that there were eight trials per experimental condition in each block (24 trials per condition in the experiment). The trials were presented randomly within each block.

### Results

#### Reaction time analysis

Mean correct RTs after eliminating extreme values (RTs faster than 200 ms or slower than 1200 ms;<sup>4</sup> 1.8% of the total) were introduced into a 2 (Auditory Signal)  $\times$  3 (Visual Cue)  $\times$  3 (Congruency) repeated measures ANOVA (see Table 1 for mean RTs per experimental condition). The analysis showed significant main effects of the three variables. Trials with auditory signal were

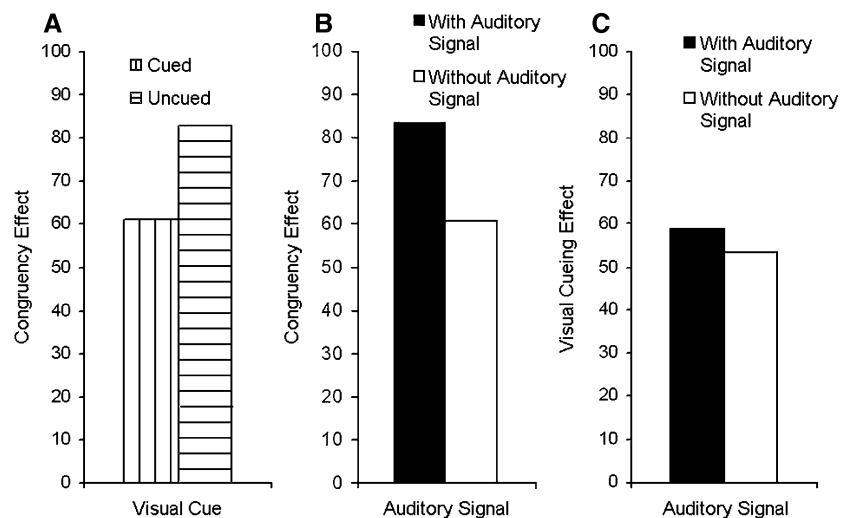
<sup>3</sup>We used this nomenclature instead of the usual “valid/invalid” one to emphasize the absence of contingency between the location of the cue and that of the target.

<sup>4</sup>The same criteria were used for all the experiments.

**Table 1** Mean RT (ms) and percentage of errors (between parenthesis) for each experiment and experimental condition

| Experiment   | SOA | Congruency  | No auditory signal |           |           | Auditory signal |           |           |
|--------------|-----|-------------|--------------------|-----------|-----------|-----------------|-----------|-----------|
|              |     |             | Nocue              | Cued      | Uncued    | Nocue           | Cued      | Uncued    |
| Experiment 1 | 500 | Neutral     | 569 (1.2)          | 496 (0.9) | 540 (1.2) | 530 (1.2)       | 485 (0.5) | 537 (1.7) |
|              |     | Congruent   | 572 (1.0)          | 499 (0.7) | 550 (1.6) | 522 (0.5)       | 491 (0.7) | 538 (0.3) |
|              |     | Incongruent | 633 (3.5)          | 562 (2.6) | 627 (3.9) | 606 (2.3)       | 550 (2.1) | 627 (4.2) |
| Experiment 2 | 100 | Congruent   | 577 (0.7)          | 546 (0.5) | 572 (0.8) | 540 (0.3)       | 519 (0.0) | 557 (0.4) |
|              |     | Incongruent | 645 (2.6)          | 614 (3.3) | 657 (5.3) | 625 (2.9)       | 599 (2.9) | 656 (6.2) |
| Experiment 3 | 500 | Congruent   | 574 (0.0)          | 521 (0.5) | 560 (0.7) | 541 (0.4)       | 510 (0.4) | 546 (0.4) |
|              |     | Incongruent | 640 (3.5)          | 596 (3.3) | 651 (6.0) | 618 (4.3)       | 583 (2.3) | 645 (6.5) |
|              | 100 | Congruent   | 576 (0.7)          | 536 (0.3) | 554 (1.5) | 531 (0.8)       | 511 (0.7) | 548 (0.5) |
|              |     | Incongruent | 632 (4.1)          | 610 (2.8) | 637 (4.9) | 610 (4.5)       | 590 (3.8) | 646 (6.7) |

**Fig. 2** Experiment 1. Results: **A** graphic representation of the interaction between Congruency and Visual Cue. The *y-axis* represents the congruency effect in ms (incongruent trials minus congruent trials); **B** graphic representation of the interaction between Congruency and Auditory Signal. The *y-axis* represents the congruency effect in ms; **C** graphic representation of the interaction between Visual Cue and Auditory Signal. The *y-axis* represents the orienting effect in ms (uncued trials minus cued trials)



faster than those without it ( $F_{(1,23)} = 38.68$ ;  $p < 0.0001$ ). The main effect of the Visual Cue ( $F_{(2,46)} = 120.09$ ;  $p < 0.0001$ ) indicated that when the target was presented in the same location as the cue, participants were faster than when no cue was presented or when it was presented on the opposite location, as shown by planned comparisons,  $F_{(1,23)} = 275.30$ ;  $p < 0.0001$ , and  $F_{(1,23)} = 188.61$ ;  $p < 0.0001$ , respectively (there was no difference between the last two conditions  $F_{(1,23)} < 1$ ). Congruency was also statistically significant ( $F_{(2,46)} = 162.67$ ;  $p < 0.0001$ ), and a further analysis showed that this was due to faster RTs in trials where congruent or neutral flankers were presented than in those where incongruent flankers were used ( $p < 0.0005$ ). No differences were found between congruent and neutral trials ( $p = 0.89$ ).

Regarding the interactions, for the purpose of this study the relevant comparisons are the ones carried out without the neutral conditions of Visual Cue and Congruency. Since no cue trials were the ones where no visual orienting could be measured (visual orienting control condition) and neutral trials were the ones where no congruency could be measured (congruency control condition), no interaction between the variables could

actually be measured here. Therefore, these are the results reported in the experiments<sup>5</sup>. The interaction between Visual Cue and Congruency was significant ( $F_{(1,23)} = 14.72$ ;  $p < 0.001$ ). The congruency effect was significantly larger for uncued trials than for cued ones (see Fig. 2A).

The interaction between the Auditory Signal and Congruency variables was also significant ( $F_{(1,23)} = 4.28$ ;  $p < 0.05$ ). A subsequent analysis was carried out under conditions of no orienting (no cue level only) to ensure that the results were not contaminated by those trials where spatial orienting was also involved. This new analysis suggested an even clearer significant interaction between Auditory Signal and Congruency ( $F_{(1,23)} = 10.26$ ;  $p < 0.005$ ) in the sense of a greater Congruency effect when an Auditory Signal had been previously presented than when it had not (see Fig. 2B)<sup>6</sup>.

<sup>5</sup>The results of the interactions including all the levels of the variables were: Visual Cue  $\times$  Congruency:  $F_{(4,92)} = 6.31$ ;  $p < 0.001$ ; Auditory Signal  $\times$  Congruency:  $F_{(2,46)} = 2.60$ ;  $p = 0.08$ ; Auditory Signal  $\times$  Visual Cue:  $F_{(2,46)} = 39.26$ ;  $p < 0.0001$ .

<sup>6</sup>This is easily explained by arguing that visual cues already produce some alerting, thus reducing the net effect produced by an auditory cue (Fernandez-Duque and Posner 1997).

The interaction between Auditory Signal and Visual Cue was not significant ( $F_{(1,23)}=2.02$ ;  $p=0.17$ ). This was interpreted as an absence of mutual influence between the alerting and orienting Networks (see Fig. 2C).

### Accuracy analysis

The percentage of incorrect answers was analyzed by means of a 2 (Auditory Signal)  $\times$  3 (Visual Cue)  $\times$  3 (Congruency) repeated measures ANOVA. Table 1 shows the percentage of errors per experimental condition. Only the main effects for Visual Cue and Congruency were significant ( $F_{(2,46)}=3.77$ ;  $p<0.05$  and  $F_{(2,46)}=9.44$ ;  $p<0.0005$ , respectively). The pattern of errors for the Visual Cueing was similar to that of RT. Regarding Congruency, congruent trials were less error-prone than incongruent trials ( $p<0.001$ ), whereas neutral trials were not different from congruent trials ( $p=0.84$ ). The main effect of Auditory Signal was not significant ( $F_{(1,23)}=1.12$ ;  $p=0.3003$ ). None of the interactions were significant.

### Discussion

By modifying Fan's ANT task (Fan et al. 2002), we have created a task that can measure the interactions among the three attentional networks, allowing us to explore our specific hypothesis regarding these interactions. The first goal of this experiment was to study the causes of the interaction found by Fan and collaborators (2002). We found an interaction between Auditory Signal and Congruency. Under conditions of high alerting, the congruency effect of the flanker arrows was larger than under low alerting conditions. Also, the interaction between Visual Cue and Congruency was significant. When the location of the target was cued, the congruency effect was smaller than when the opposite location was cued. Thus, using one variable for each attentional network, we have found that both Auditory Signal and Visual Cue exert an influence on the Congruency variable.

The second goal of this study was to verify a previous hypothesis of a possible interaction between the alerting and orienting Networks (Posner 1978), but we did not find it here. This absence of interaction could be due to two different reasons: either the orienting and alerting networks do not interact (Fernandez-Duque and Posner 1997), or the method we used was not sensitive enough. The fact that previous studies had found an interaction (Clark et al. 1989) made us think that the second possibility was more plausible. Assuming that the alerting network exerts an influence on the orienting network, this influence could be to either increase or speed up the orienting of attention (see below and Fig. 4). Posner (1978) proposed the former. Given the fact that the function of orienting reaches an asymptote at a specific moment in time (Posner and Cohen 1984; Müller and Findlay 1988; Müller and Rabbitt 1989; Lupiáñez et al. 1997), we thought that the auditory signal might have an

effect on this function, but this effect was already gone by the time we measured it. To study whether this hypothesis was correct, we designed Experiment 2, where the interval between the onset of the Visual Cue and the onset of the target stimulus (SOA) was manipulated.

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## Experiment 2

This experiment had two goals. On the one hand, we were interested in replicating the interactions obtained in our first experiment. On the other hand, we wanted to test the hypothesis of a possible influence of the alerting network on the orienting network via a speeding up of its function. To do so, the temporal course of the orienting effect was studied by manipulating the SOA between the spatial cue and the target at two levels. We kept the SOA at 500 ms and set the second SOA to 100. Previous findings in our laboratory (Funes and Lupiáñez 2003) had pointed to an absence of interaction using a SOA of 250 ms, so we thought that the influence of the Auditory Signal on the Visual Cue may happen even earlier than that.

### Methods

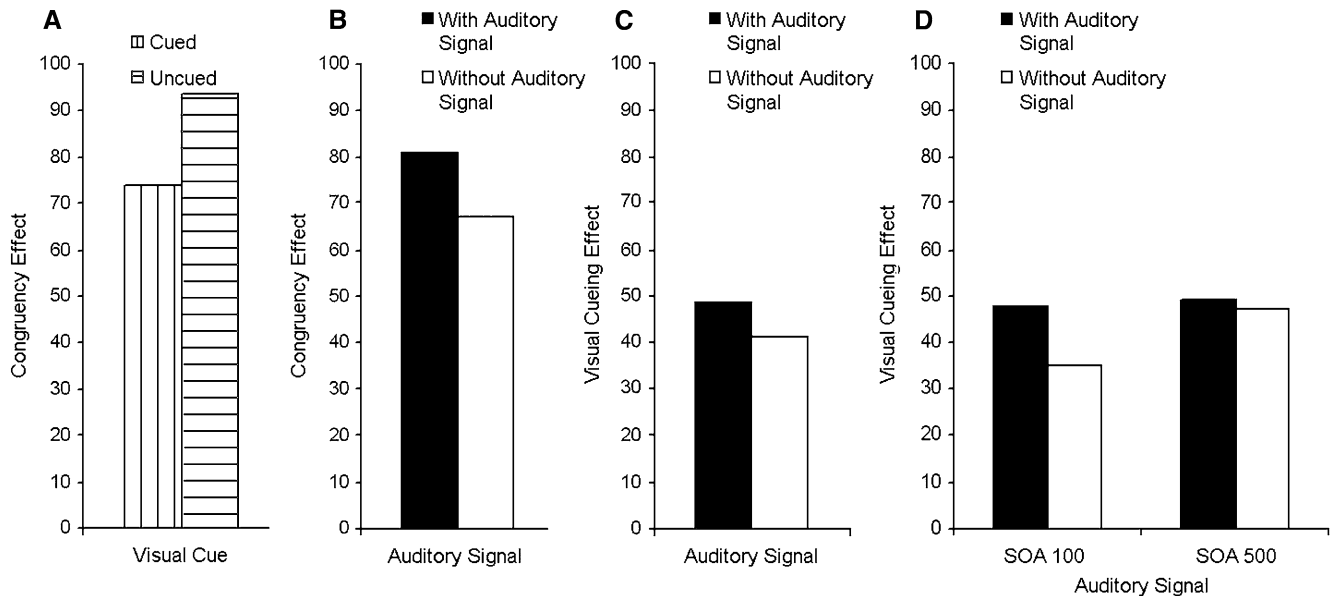
#### Subjects

Forty-eight students of psychology took part in this study for course credit and they were naïve to the purpose of the experiment. Ten of them were males, they all reported normal or corrected-to-normal vision, and their age ranged from 19 to 24. None of them had participated in the previous experiment.

#### Design and procedure

The design was the same as the previous experiment, except for the following. A new variable was introduced (SOA between Visual Cue and target) with two levels: 500 and 100 ms. In order to be able to introduce the short SOA (100 ms), the duration of the Visual Cue was shortened to 50 ms to prevent the target from appearing immediately after the cue. Also, the neutral condition of the Congruency variable was eliminated since it was not providing any information (similar performance to the congruent condition) and was making the task longer and more tedious. After these modifications, the experiment had a 2 (Auditory Signal)  $\times$  3 (Visual Cue)  $\times$  2 (Congruency)  $\times$  2 (SOA) within-participant design. Since there were two different SOAs between the Visual Cue and the target stimulus, the final duration of each trial could be either 4050 or 4450 ms.

Again, participants performed a practice block of 20 trials. Four experimental blocks of 96 trials each followed the practice. The number of trials per experimental condition was lowered to 16 to prevent the task from being too long.



**Fig. 3** Experiment 2. Results: **A** graphic representation of the interaction between Congruency and Visual Cue. The *y-axis* represents the congruency effect in ms (incongruent trials minus congruent trials); **B** graphic representation of the interaction between Congruency and Auditory Signal. The *y-axis* represents the congruency effect in ms; **C** graphic representation of the

interaction between Visual Cue and Auditory Signal for collapsed levels of SOA. The *y-axis* represents the orienting effect in ms (uncued trials minus cued trials); **D** graphic representation of the interaction between Visual Cue and Auditory Signal for each level of SOA. The *y-axis* represents the orienting effect in ms

## Results

### Reaction time analysis

Trials with extreme RT values (0.3%) were excluded from the analysis. The 2 (Auditory Signal)  $\times$  3 (Visual Cue)  $\times$  2 (Congruency)  $\times$  2 (SOA) repeated measures ANOVA yielded a significant main effect for each variable,  $F_{(1,47)} = 79.44$ ;  $p < 0.0001$ ,  $F_{(2,94)} = 188.68$ ;  $p < 0.0001$ ,  $F_{(1,47)} = 331.53$ ;  $p < 0.0001$  and  $F_{(1,47)} = 38.57$ ;  $p < 0.0001$ , respectively (see Table 1).

As a replica of the previous experiment, we were expecting to find significant interactions for Visual Cue  $\times$  Congruency as well as for Auditory Signal  $\times$  Congruency<sup>7</sup>. The Visual Cue  $\times$  Congruency interaction was significant ( $F_{(1,47)} = 27.23$ ;  $p < 0.0001$ ). The same pattern found in Experiment 1 was seen here (See Fig. 3A). The Auditory Signal  $\times$  Congruency interaction was also significant ( $F_{(1,23)} = 12.43$ ;  $p < 0.005$ ). Again, the same pattern of results was found (see Fig. 3B).

The interaction between Auditory Signal and Visual Cue was now significant ( $F_{(1,47)} = 6.23$ ;  $p < 0.05$ ). As it is

apparent from Fig. 3C, this interaction consisted of a larger visual cueing effect under alerting conditions.

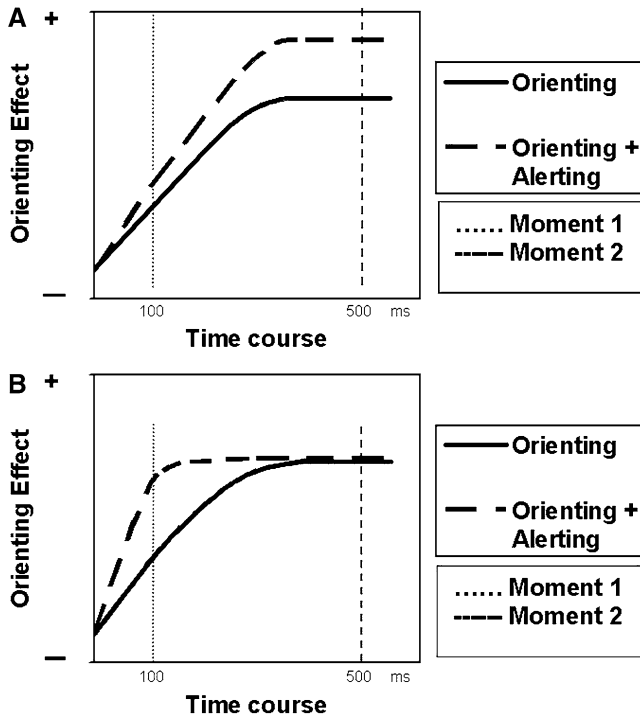
After finding that the results replicated those of the first experiment (except from the last interaction that was not significant in Experiment 1), we analyzed the variables concerned with the SOA manipulation. The three way interaction between Auditory Signal, Visual Cue and SOA approached significance:  $F_{(1,47)} = 2.93$ ;  $p = 0.0935$  (only cued and uncued levels of visual cueing were included). More interestingly, when a separate ANOVA (again excluding no cue trials) was performed on each level of SOA, we found a significant Auditory Signal  $\times$  Visual Cue interaction for the short SOA level (100 ms) ( $F_{(1,47)} = 8.09$ ;  $p < 0.01$ ) and no effect for the long SOA level (500 ms) ( $F < 1$ ), thus replicating the results of Experiment 1, with a long SOA.

As can be observed in panel D of Fig. 3, at the 100 ms SOA, the visual cueing effect was larger for the condition with an auditory signal (48 ms) than for that without it (34 ms). Furthermore, the visual cueing effect obtained at the short SOA with auditory signal was almost identical to that found for the long SOA level with or without auditory signal (48 ms for the short SOA vs. 48.5 and 47 ms for the long SOA with and without auditory signal, respectively).

### Accuracy analysis

The 2 (SOA)  $\times$  2 (Auditory Signal)  $\times$  3 (Visual Cue)  $\times$  2 (Congruency) ANOVA yielded significant effects for only two of the four variables. The main effects of SOA

<sup>7</sup>The results of the interactions, including all the levels of the variables, were: Visual Cue  $\times$  Congruency:  $F_{(2,94)} = 17.69$ ;  $p < 0.0001$ ; Auditory Signal  $\times$  Congruency does not change since the neutral level of the congruency variable was eliminated from the design; Auditory Signal  $\times$  Visual Cue:  $F_{(2,94)} = 20.92$ ;  $p < 0.0001$ ; SOA  $\times$  Auditory Signal  $\times$  Visual Cue:  $F_{(2,94)} = 1.45$ ;  $p < 0.24$ ; Auditory Signal  $\times$  Visual Cue (SOA 100):  $F_{(2,94)} = 9.6$ ;  $p < 0.0005$ ; Auditory Signal  $\times$  Visual Cue (SOA500):  $F_{(2,94)} = 9.47$ ;  $p < 0.0005$ .



**Fig. 4** Possible influences of the alerting network on the orienting network: **A** graphic representation of the hypothetical time course function of the orienting effect if an alerting signal produces an enhancement of orienting; **B** graphic representation of the hypothetical time course function of the orienting effect if an alerting signal produces a speeded-up orienting

and Auditory Signal were not statistically significant ( $F_{(1,47)} < 1$  and  $F_{(1,47)} < 1$ , respectively), while those of Visual Cue and Congruency were ( $F_{(2,94)} = 14.00$ ;  $p < 0.0001$ , and  $F_{(1,47)} = 28.63$ ;  $p < 0.0001$ ). Again, the pattern of errors for Visual Cue was similar to the one found in Experiment 1. In the case of Congruency, congruent trials produced fewer errors than incongruent ones. The interaction of Visual Cue  $\times$  Congruency was significant ( $F_{(2,94)} = 10.56$ ;  $p < 0.0001$ ), and it pointed to an increase in the congruency effect for uncued trials as shown by planned comparisons ( $F_{(1,47)} = 17.26$ ;  $p < 0.0005$ ). No differences were found for no cue and cued trials ( $F_{(1,47)} = 1.01$ ;  $p = 0.32$ ).

### Discussion

One of the aims of this experiment was to replicate the results of Experiment 1. The presence of the interactions between Auditory Signal and Congruency as well as the interaction between the Visual Cue and Congruency showed that the influences among the different attentional networks are stable.

The most important aim of the experiment was to study the time course of the orienting function to test whether an alerting sound would exert an influence at any time. We found an interaction between the Alerting Signal and the Visual Cue. When a visual cue is presented

under conditions of high alertness, it is more effective than under conditions of low alertness. However, this effectiveness is only present for short intervals. When more time is allowed (long SOA), the system is able to effectively orient to the target independent of the presence or absence of an alerting signal.

Given the importance of these results (it is the first time, to our knowledge, that an interaction pointing in this direction has been shown; see, for example, Fernandez-Duque and Posner 1997), we wanted to ensure that the results were not a spurious finding. Therefore, we carried out a third experiment to replicate the findings in a different context (only short SOA). This was done because previous results have shown that temporal context can have an influence on cueing effects (Cheal and Chastain 2002; Milliken et al. 2003). Therefore, it is important that all the effects observed in the short SOA conditions are replicated when only that SOA is manipulated, thus having a fixed cue-target SOA. Also, since this task will be potentially interesting for clinical use in neuropsychological assessment, we thought it would be a good way to ensure its utility in order to demonstrate the replicability of the results with a shorter version in which only the short SOA was used. In this new experiment all of the results replicated those observed at the short SOA in Experiment 2<sup>8</sup>.

### General discussion

The aim of the experiments reported in this paper was to independently measure the three networks and study their interactions (Experiments 1 and 2), and to confirm the results found in these two experiments under different conditions (see footnote 8). The pattern of results reliably obtained across the three experiments seems to show the achievement of this goal.

The results obtained in Experiment 1 shed light on the first main question we sought to answer. We wanted to study whether the interaction found by Fan et al. (2002) was due to a modulation of the alerting network on the executive control network, a relation between the orienting network and the executive control network, or both. The interaction found in the original study (Fan et al. 2002) between the Cueing and Congruency variables consisted of a larger congruency effect for the *center cue* and *double cue* conditions compared to the effects of the *no cue* and *spatial cue* conditions. This pattern of results could be interpreted according to the previously hypothesized “clearing of consciousness”

<sup>8</sup>Again all the main effects, as well as the interactions, pointed in the same direction as the previous findings. Mean RT and error rates per condition can be found in Table 1. Main effects: Auditory Signal:  $F_{(1,24)} = 29.66$ ;  $p < 0.0001$ ; Visual Cue:  $F_{(2,48)} = 50.69$ ;  $p < 0.0001$  and Congruency:  $F_{(1,24)} = 129.74$ ;  $p < 0.0001$ . Interactions: Visual Cue  $\times$  Congruency:  $F_{(1,24)} = 5.94$ ;  $p < 0.05$ ; Auditory Signal  $\times$  Congruency:  $F_{(1,24)} = 8.84$ ;  $p < 0.01$  and Auditory Signal  $\times$  Visual Cue:  $F_{(1,24)} = 17.36$ ;  $p < 0.0005$ . See Callejas et al. (2004) for an extended report of a similar study.



phenomenon (Posner 1994) as an influence of the alerting network on the executive control network: a larger congruency effect was found on the alerting conditions (*center cue and double cue*) compared to the control condition (*no cue*) or the spatial condition (*spatial cue*). However, Fan et al. (2002) proposed another explanation for this interaction. They pointed to an influence of the orienting network on the executive control network; the orienting of attention to the location where the target would be presented could help participants to concentrate on this area and ignore the incongruent flankers, thus producing a faster response than in those cases where the cue signals the location opposite to that of the target.

These two hypotheses were difficult to assess with the procedure they used, because alerting and orienting were not independently manipulated. Also, a third hypothesis to explain the data could be offered. The interaction might be due to both types of influence—alerting and orienting networks—on the functioning of the executive control network.

We found an interaction between Auditory Signal and Congruency. Under conditions of high alerting, the congruency effect of the flanker arrows was larger than under low alerting conditions. Also, the interaction between Visual Cue and Congruency was significant. When the location of the target was cued, the congruency effect was smaller than when the opposite location was cued.

These results could be interpreted in the direction of a double cause for the Cueing and Congruency interaction found in the original experiment by Fan et al. (2002). It could be due to an enhancement of the effect of the flanker interference when an alerting cue was presented relative to the other conditions, or it could be due to the use of the spatial cues. On one hand, congruency was modulated by the auditory signal. A larger congruency effect was found when an auditory signal was presented than when it was absent. This is consistent with Posner's proposal (Posner 1994) that the alerting network influences the executive control network by inhibiting its functioning so that the organism can focus on giving a fast response rather than concentrating on control functions. On the other hand, the visual cue also influenced the congruency effect. When the cue was presented in the location opposite to that of the target, the participant had to reorient the focus of attention to a different location, and this would make the response longer. These cues allow the participant to direct attention to the target stimulus ahead of time, and this could potentially filter out some of the surrounding flanker information. This result is congruent with previous experiments run in our laboratory, where a related task (spatial Stroop) was used to measure the executive control network (Funes and Lupiáñez 2003; Funes et al. 2005).

The second aim of this study was to test whether the alerting and the orienting networks interact with each other or work in an independent manner. In Experiment 1 we did not find the interaction postulated by Posner

(1978). The results from the first experiment acquire a deeper meaning when taken together with those from the second experiment. Orienting towards a stimulus takes some time. The time course is dependent on different factors, such as the type of stimulus used (central versus peripheral cue) or the type of task to be performed (detection versus discrimination) (Müller and Rabbitt 1989; Lupiáñez et al. 1997). After an asymptote is reached, where the maximum amount of orienting takes place, the system shows a reversed effect where the cued location produces longer response times than the uncued location (inhibition of return)<sup>9</sup>. The alerting network could be influencing the orienting network in two possible ways: the alerting network may influence the orienting network by increasing its functioning (Hypothesis A) or by speeding it up (Hypothesis B). Figure 4 shows both hypotheses. If alerting influences orienting by increasing it (Hypothesis A), then we would expect the asymptote to be reached at the same moment in time, independently of the level of alertness, but it would be of greater size under alerting conditions (in other words a larger benefit of orienting towards the stimulus under conditions of high alertness). On the other hand, if alerting influences orienting by speeding it up (Hypothesis B), then we would expect the function to be of similar magnitude but reach the asymptote earlier in time (so that the benefits of orienting towards a stimulus would be seen at shorter SOAs).

The fact that the effect of an auditory signal on that of the visual cue was only found at the short SOA clearly points to a speeded-up orienting of attention under conditions of high alerting.

These results show that when a task is designed to study the influence of an alerting signal on the time course of the orienting function, the differences found tell us about crucial aspects of this function. The results we have obtained show that the orienting of attention reached an asymptote at around 500 ms (maybe even sooner: see Funes and Lupiáñez 2003), no matter whether an auditory signal has been previously presented or not. However, this asymptote can be reached much earlier (by 100 ms) under alerting conditions.

All the main effects and interactions were replicated in the third experiment, thus increasing the robustness of our findings. These results clearly favored the view that the alerting network influences the orienting network by speeding up the orienting process.

This experimental series have shed light on the ways in which our attentional system works and, more importantly, the way it functions in a coordinated way in order to produce an effective behavior. The executive control network is able to take advantage of the work done by the orienting network, and use the information provided by it to resolve a conflict situation sooner in

<sup>9</sup>Inhibition of return was not found in our studies. When a task is complex enough (such as our difficult discrimination task) IOR is not observed unless SOAs much longer than ours are used (Lupiáñez et al. 1997)

time. The alerting network helps the system to concentrate on the external events (when these are the important ones) by preventing the executive control network from taking part in the processing. Also, the orienting network is able to take advantage of the general activation provided by the alerting network to produce a faster orienting to the salient stimulus. It is clear then that, although the attentional networks may have some functional independence such that they can be measured independently (Fan et al. 2002), they are capable of modulating each other in order to produce a more adaptive behavior.

Future research might focus on studying the performances of different groups of patients with attentional deficits on this task. This could provide important information about the possible functional systems that have been damaged and also about the direction of a possible rehabilitation program. One example of this is the improvement of neglect patients' performance when an alerting signal is provided. When an event happens on the left side of the visual field, neglect patients are much slower to notice it, but if an alerting beep is presented right before the visual event, then the bias is reduced, even though the tone has no information about the location or direction of the event (Robertson et al. 1998). Nevertheless, there is still a great deal of study that needs to be done on the way and the circumstances that subtend these modulations, as well as on the reasons for these modulations to not occur on subjects with attentional deficits.

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