

## Ambient Odors Influence the Amplitude and Time Course of Visual Distraction

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Behavioral performance was examined in a task of attentional capture by luminance under conditions of ambient odors (phenyl ethyl alcohol [PEA], olfactory stimulus, and allyl isothiocyanate [AIC], mixed olfactory/trigeminal stimulus). The AIC increased the amplitude and duration of capture, whereas the presence of PEA led capture to disappear. Furthermore, the PEA caused a general slowing in the speed of information processing. The amplitude and time course of capture were correlated to the irritating components of these odorants, whereas a control experiment showed that the general slowing caused by the PEA was correlated to a drop-off of the subjects' arousal level. These results suggest that ambient odors may exert differential influence of visual-attentional processes and that this influence may depend on the odor's properties.

*Keywords:* sensory systems, olfactory senses, visual psychophysics and behavior, visual attention, attentional capture

Vision enables one to apprehend the components and structure of the environment by selecting salient or behaviorally relevant information. However, the visual system has to attribute processing priority to some items over their neighbors because the human cognitive system is capacity limited. The assignment of processing priority partly depends on the salience of the visual image (Yantis & Jonides, 1984). In point of fact, salient objects can capture attention because they may reveal the presence of potentially threatening events to avoid, making their detection and coarse analysis critical for survival and behavioral adaptation. The mechanism subserving visual attentional capture could determine the biological significance of such events (Michael, Boucart, Godefroy, & Degreef, 2001; Vuilleumier & Schwartz, 2001) and would prepare the organism to adopt withdrawal behavior away from (or approach behavior toward) the related event.

Usually, in the real world, other kinds of stimuli coexist and interact with the visual images. For example, the view of an approaching bee is almost constantly accompanied by the hearing of its humming. The spatiotemporal proximity between images and sounds may exert a stronger attraction over attention and enhance processing efficiency (Kitagawa & Ichihara, 2002; Morein-Zamir, Soto-Faraco, & Kingstone, 2003). Cross-modal interactions have

also been found between vision and olfaction (Gilbert, Martin, & Kemp, 1996; Gottfried & Dolan, 2003; Kemp & Gilbert, 1997; Millot, Brand, & Morand, 2002; Zellner & Whitten, 1999) and olfactory stimuli have been reported to reliably influence visual attention (Ilmberger et al., 2001; Michael, Jacquot, Millot, & Brand, 2003; Millot et al., 2002; Spence, Kettenmann, Kobal, & McGlone, 2001). In a recent study, we showed that ambient odors could modulate the responsiveness of the attentional system to visual stimuli (Michael et al., 2003). In particular, a mixed olfactory/trigeminal stimulus, the allyl isothiocyanate (AIC; mustard oil), triggered larger effects of visual attentional capture (i.e., larger effects of a visual distractor on response time [RT]) than did the absence of ambient odor, whereas a pure olfactory stimulus, the phenyl ethyl alcohol (PEA; a roselike odor) abolished attentional capture. It was proposed that this effect revealed modifications in the processing of visual abrupt events that would concern the event's subjective salience not its perceptual features. Yet, no data are available on the temporal extent of this effect. Attentional capture is characterized not only by the amplitude of reactions toward threatening, noxious, or interesting events but also by the duration of these reactions: Important environmental changes are more likely to trigger larger and long-lasting effects than are other, less important events or objects. These events may also challenge intentional, goal-driven processing of a target by giving rise to robust, long-lasting interference (Michael, Kleitz, Sellal, Hirsch, & Marescaux, 2001). Yantis and Jonides (1990) and Theeuwes (1995) showed that under specific conditions, visual attentional capture by irrelevant items could be reduced over time. For instance, Theeuwes (1995) asked participants to ignore a distractor that could suddenly appear somewhere in space at varying temporal intervals following the appearance of a target to identify. The author reported that the distractor invoked strong capture effects (i.e., longer RTs) when presented at the same time as (or immediately after) the target. However, these effects dropped off pro-

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We thank Samy Barkat, Olivier Koenig, Jean-Pierre Royet, and Nathalie Bedoin for their "last-minute" assistance, a precious help for the control experiment.

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gressively with the increment of the target-distractor interval. For distractors appearing at a distance of 5° of visual angle from the target, this effect was no more significant for intervals bigger than 100 ms. These results were attributed to the deployment of a focused state over time encompassing the target and blocking out irrelevant information (Theeuwes, 1995; Yantis & Jonides, 1990). The aim of the present study was to investigate the influence ambient odors exert on the time course of attentional capture. In our previous study (Michael et al., 2003) we reported that the irritating properties of a mixed olfactory/trigeminal stimulus could influence the amplitude of visual attentional capture. To establish whether the same stimulus can also alter the time course of attentional capture in a different manner than a second, nonirritating stimulus, we used two nontoxic ambient odors, the PEA and the AIC. Both stimuli have a pure olfactory component, but only the AIC is a trigeminal, irritating stimulus.

### Main Experiment

#### Materials and Method

**Subjects.** Forty-seven right-handed young female subjects (22 ± 1.3 years old) with normal or corrected-to-normal vision participated in a task of attentional capture by luminance under conditions of ambient odors. They were free of head colds or nasal allergies at the time of the test. Before the experiment took place, subjects were told that the purpose of the study was to investigate visual attention. After the session was completed, subjects were fully informed on the precise purpose of the study, that is, the visual attention/ambient odors interaction. The study was conducted in accordance with the declaration of Helsinki/Hong Kong.

**Ambient odors.** Three independent groups of subjects were created, and each group was assigned to one of the following odor sessions: no odor ( $n = 15$ ), PEA ( $n = 16$ ), or AIC ( $n = 16$ ). The room in which the task of visual attentional capture was performed was well ventilated prior to each odor session. For the two sessions in which odors were used, PEA (9 mL) or AIC (1.5 mL) was sprayed in the room. Subjects were informed that there could be odors present in the experimental room previously used by other researchers for studies on olfaction. This remark was made to all subjects in order to dissociate the presence of odors from the current research. At the end of the visual task, a visual analog psychophysical scale (a continuous line of 10 cm) was administered to subjects assigned to the PEA and AIC sessions. Subjects were asked to rate, by means of a mark, the perceived intensity of odors, hedonic valence (i.e., pleasantness), and irritation level.

**Task of visual attentional capture.** The experiment was conducted in a 5 m × 3 m × 3 m, dimly lit room. Subjects were installed in front of a computer monitor and had their chin posed on a chin rest placed at a distance of 30 cm from the screen. Each trial started with the presentation, for 300 ms, of a small white circle (i.e., target; 25cd/m<sup>2</sup>) on the center of the black screen. This target was flanked on the right and the left by two big gray circles (5cd/m<sup>2</sup>) located at an angular distance of 5.7°. Then, a gap appeared on either the upper or lower side of the target. Four conditions were tested: In the baseline condition, the display remained unchanged until response; in three distractor conditions, one of the big circles underwent a sudden increment in luminance (from 5cd/m<sup>2</sup> to 25cd/m<sup>2</sup>) just 50, 100, or 200 ms after the appearance of the target's gap and remained on the screen until response (see Figure 1). The side (left or right) of the luminance increment and the target-to-distractor temporal interval were random. The next trial started 1,000 ms after the response. Subjects were asked to focus their attention on the central item (i.e., target) and to indicate the gap position (up or down) as quickly as possible by pressing one of two predetermined, vertically arranged response buttons. They were also asked

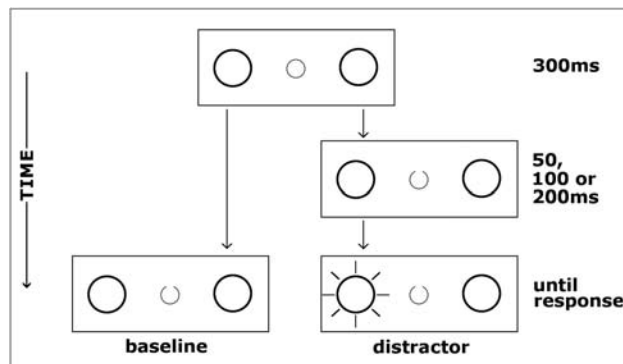


Figure 1. Example of trial events of each condition in the task of visual attentional capture by luminance. Each trial started with the presentation of a small central circle and two larger peripheral circles. Shortly after, a gap appeared on the central circle and was either followed, at different temporal intervals, by a sudden increment in luminance (distractor) or nothing (baseline). Subjects were asked to concentrate on the central circle and to indicate the gap position (up or down) as quickly as possible by pressing a predefined response button. Once the gap appeared, the computer automatically recorded response times in milliseconds.

to ignore both flanking circles. Once the gap appeared, the computer automatically recorded response times and errors. Eighty trials (20 per condition) were randomly presented and were preceded by a set of 10 training trials. The whole session lasted approximately 7 min, and a brief pause was automatically provided by the computer in the middle of the session. No feedback was given to subjects.

#### Results

**Ambient odor estimations in the psychophysical scales.** For each odor dimension (intensity, hedonic valence, and irritation level), scores obtained in the psychophysical scale (in centimeters) were submitted to Student's *t* tests for independent samples. No difference was found between the two odors for the intensity dimension (scores were 4.5 ± 2.7 and 4.9 ± 2.7 for PEA and AIC, respectively;  $p > .6$ ), or for the hedonic valence (scores were 4.3 ± 1.9 and 4.5 ± 2.9, for PEA and AIC, respectively;  $p > .8$ ). Conversely, the scores of irritation were bigger for the AIC (6.3 ± 2.9) than for the PEA (2.3 ± 2.7), suggesting that subjects perceived the irritating properties of the AIC,  $t(30) = 4.09, p < .0003$ .

**Visual attentional capture.** RTs smaller than 100 ms or bigger than 1,000 ms were discarded as representing effects of anticipation or inattention. Discarded responses accounted for less than 3% of all responses. An analysis of variance (ANOVA) was carried out on correct RTs with the distraction condition (baseline, distractor at 50, 100, or 200 ms) as the within-subject variable and the odor session (no odor, AIC and PEA) as the between-subjects factor. The results are displayed in Figure 2. The Distraction Condition × Odor Session interaction was significant,  $F(6, 132) = 5.54, p < .0001$ . The main effect of distraction condition was also found to be significant,  $F(3, 132) = 9.09, p < .0001$ , but only a marginal effect of odor session was obtained,  $F(2, 44) = 3.00, p < .058$ . Newman-Keuls post hoc comparisons revealed that the main effect of distraction condition reflected faster RT in the baseline than when a distractor was present (all  $ps < .03$ ). The main effect of odor session mainly reflected slower RT in the PEA session than in the no-odor session ( $p < .045$ ).

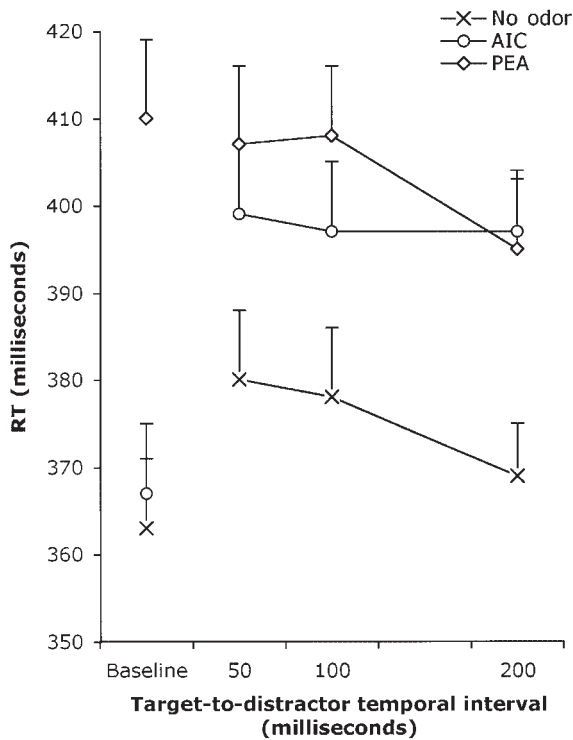


Figure 2. Mean (+SE) response times (RTs) obtained in the baseline and distractor conditions of the main experiment as a function of the odor session and the target-to-distractor temporal interval. AIC = allyl isothiocyanate; PEA = phenyl ethyl alcohol.

Planned comparisons, conducted for each odor session independently, revealed the time course of attentional capture:

**No-odor session:** Compared with the baseline (363 ms), a significant increment in RT was observed in the 50-ms target-to-distractor interval (380 ms;  $p < .02$ ) and the 100-ms interval (378 ms;  $p < .03$ ) but not in the 200-ms interval (369 ms;  $p > .26$ ).

**AIC session:** Compared with the baseline (367 ms), there was a significant increment in RT in all three target-to-distractor intervals (399, 397, and 397 ms, for the 50-, 100-, and 200-ms intervals, respectively; all  $ps < .0001$ ).

**PEA session:** Compared with the baseline (410 ms), no increment in RT was observed in the 50-ms interval (407 ms;  $p > .70$ ) or the 100-ms interval (408 ms;  $p > .80$ ). Instead, a significant decrement of RT was observed in the 200-ms interval (395 ms;  $p < .012$ ).

The baselines of all three odor sessions were compared two-by-two. Compared with the baseline of the no-odor session, RTs were significantly slower in the PEA session ( $p < .001$ ) but not in the

AIC session ( $p > .70$ ). Furthermore, there was a significant difference between the PEA and the AIC baselines ( $p < .002$ ). The isolated effects of attentional capture (calculated by subtracting the baseline to each distractor condition) in each target-to-distractor interval were compared as a function of the odor session (see Table 1).

**50-ms interval:** Compared with the no-odor session (17 ms), the effects of capture were larger in the AIC session (32 ms;  $p < .05$ ) and shallower in the PEA session (−3 ms;  $p < .033$ ).

**100-ms interval:** The differences between the odor sessions were less marked. Compared with the no-odor session (15 ms), the effects of capture were only marginally larger in the AIC session (30 ms;  $p < .07$ ) and marginally shallower in the PEA session (−2 ms;  $p < .056$ ).

**200-ms interval:** compared with the no-odor session (6 ms; no capture), the effects of capture were significantly larger in the AIC session (30 ms;  $p < .004$ ) and significantly shallower in the PEA session (−15 ms;  $p < .008$ ).

Humans generally habituate to pure odorants relatively quickly, so it is unclear whether such odorants would be likely to exert extended effects across a full experimental block. In contrast, trigeminal stimuli typically show a different pattern of responsiveness across time (Hummel, 2000). However, it is quite unlikely that subjects in the present experiment habituated differently in the AIC and the PEA sessions because of the short duration of the whole experimental session (i.e., 7 min). Nevertheless, to better investigate this issue, we carried out supplementary statistical analyses on the baseline RTs. Each session was broken down to four blocks of five trials each. The individual mean RT for each block was entered in a two-way ANOVA, with the block (Block 1, 2, 3, or 4) as the within-subject factor and the odor session (AIC or PEA) as the only between-subjects factor. The main effect of block reached significance,  $F(3, 90) = 3.27$ ,  $p < .025$ , suggesting the existence of a practice effect on RT in the visual task. This was due to faster RT in the fourth block (375 ms) when compared with the first block (400 ms,  $p < .027$ ), with the second block (400 ms,

Table 1  
Distraction Effects Observed for Each  
Target-to-Distractor Interval

Session	Target-to-distractor interval (ms)		
	50	100	200
No odor	17*	15*	6
AIC	32**	30**	30**
PEA	−3	−2	−15*

Note. Asterisks indicate significant difference compared with the baseline. AIC = allyl isothiocyanate; PEA = phenyl ethyl alcohol. \* $p < .05$ . \*\* $p < .01$ .

$p < .043$ ), and with the third block (397 ms,  $p < .023$ ). The main effect of odor session and the Block  $\times$  Odor Session interaction failed to reach significance,  $F(1, 30) = 2.14$ ,  $p > .15$ , and  $F(3, 90) = 1.14$ ,  $p > .24$ , respectively. The absence of interaction does not allow us to conclude that the AIC and the PEA have different effects on the basic RTs over time.

Finally, to establish whether, irrespective of the odor session, the amplitude of attentional capture was linked to the perceived nasal irritation caused by the olfactory stimuli, we carried out a correlation analysis on the isolated capture effects (each distractor condition baseline) and on the rates of irritation obtained in the psychophysical scale. Highly significant correlation values were obtained in all three distractor conditions,  $r^2(30) = .46$ ,  $p < .004$ ;  $r^2(30) = .42$ ,  $p < .009$ ; and  $r^2(30) = .40$ ,  $p < .012$ , for the 50-, 100-, and 200-ms target-to-distractor temporal intervals, respectively. This result suggests that the higher the score of irritation, the bigger the effects of visual distractors and that this link endures whichever temporal interval separates the appearance of the target from that of the distractor.

### Discussion

The aim of the present study was to investigate the effects of the presence of two different ambient odors, the PEA and the AIC, on the time course of attentional capture. In a no-odor condition a reliable slowing in RT was found when sudden increments in luminance occurred during processing of a target. This interference dropped off progressively and ceased when subjects were given 200 ms to focus on the target. In agreement with previous findings (Theeuwes, 1995; Yantis & Jonides, 1990), these results suggest that resistance to interference during early stages of visual processing is difficult to achieve. Nevertheless, when the appearance of the target precedes the appearance of the distractor for about 100 to 200 ms, the latter no longer has effects on the processing of the former. This lack of interference is thought to occur because individuals are given enough time to focus their attention on the target. The attentional system can thus show the properties of a filtering mechanism, blocking out all information outside the attended area (Theeuwes, 1995).

The pattern of results obtained in the AIC session was quite different from the one obtained in the no-odor session. Whatever the target-to-distractor interval, attentional capture was present, and it did not diminish or cease over time. Compared with the no-odor session, the trigeminal AIC increased the amplitude of attentional capture without influencing the basic RT. Furthermore, despite the opportunity given to subjects to focus their attention on the target, irrelevant luminance increments still captured attention, and the amplitude of this effect was reliably larger than that observed in the no-odor session. In a previous work (Michael et al., 2003), we reported that the AIC gave rise to larger effects of attentional capture. The present results replicate those findings and add new evidence suggesting that the AIC also produces long-lasting effects. Several points are highlighted by the present results: (a) As no difference was found in the baseline condition between the no-odor and the AIC sessions, it may be suggested that the focusing of attention is rather unaffected by the AIC (similar results and interpretations were reported previously; Michael et al., 2003); (b) the larger capture effects suggest, once more, that the AIC increases the attentional responsiveness in the presence of a visual distractor; and (c) finally, focusing cannot

control the responsiveness of the attentional system to visual distractors because capture is still quite ample even when subjects are given 200 ms to focus on the target.

The results obtained in the PEA session are quite complex and, along with our previous findings (Michael et al., 2003), offer some interesting insights on the way the PEA influences visual attention and perception. First of all, compared with the no-odor session, slower RTs were observed in the baseline of the PEA session (approximately 50 ms). Second, the classical effects of attentional capture by irrelevant items (i.e., slower RT) were not observed. As a point of fact, distractors occurring 50 or 100 ms after the presence of the target did not capture attention at all. Finally, when presented 200 ms after the target, distractors accelerated chronometric performance. We believe that the key for understanding the whole pattern of performance is the baseline condition. As in our previous study on cross-modal interactions between olfaction and visual attention (Michael et al., 2003), the PEA caused a reliable slowing of RT in this condition. There are three possible explanations that we consider below. First, the PEA might have caused difficulties in narrowing the focus of visual attention on the area containing the target. A second account is that the PEA might have led the arousal level to drop off; in such a case, the facilitation observed in the 200-ms target-to-distractor interval would reveal improvements in phasic alerting because of the occurrence of luminance increments. Finally, the between-subjects nature of the study design may be responsible for the observed differences.

Whereas the two last accounts are considered in a control experiment, the first one may be discarded on the basis of scientific literature. A growing corpus of evidence suggests that visual attention is something like a window or a zoom lens of varying size and resolution, acting to encompass behaviorally relevant information (Eriksen & St. James, 1986). When its size covers a large region of the visual field, it encompasses several objects, but it possesses low resolution that renders extraction of details difficult. Conversely, when its size covers a small region of the visual field, it encompasses only one item or a small cluster of items, but it possesses high resolution. Thus, resolution is inversely proportional to the size of attentional focus. Indeed, some studies (Benso, Turatto, Mascetti, & Umiltà, 1998; Maringelli & Umiltà, 1998) showed that the efficiency and speed of processing were higher inside a small focus than inside a larger one, as the zoom lens metaphor predicts. If the PEA caused an alteration in the capacity to narrow the focus of attention, then RT in the baseline should be considerably slower compared with the no-odor session. This is what we observed. However, such a difficulty is frequently associated with greater interference caused by distractors. Indeed, when the focus of attention is large, several other items are processed along with the target, resulting in increased interference (Eriksen & St. James, 1986; Facoetti & Molteni, 2000). Larger capture effects should, hence, be expected if the PEA caused the focus to cover distractors. No evidence of such effects was found (see also Michael et al., 2003). Thus, an alteration in narrowing the scope of the attentional focus cannot account for the results obtained in the PEA session.

### Control Experiment

The between-subjects nature of the study design renders the interpretation of the results of the PEA session difficult. Despite

our random assignment of subjects to an odor session, there is still a possibility that the differences obtained mainly in the baseline condition between the PEA and the no-odor sessions reflect group differences. Yet, similar results were obtained in a previously published study (Michael et al., 2003) in which the same odorants were used, suggesting that the PEA results are genuine. To discard any doubt, we investigated this issue in a control experiment using an A–B design. Two independent groups of subjects participated twice in a visual task. During Phase A, no odorants were used; during Phase B, the first group completed the visual task without odor in the room (no-odor group), whereas PEA was sprayed in the room for the second group (PEA group). This design allowed us to establish the equivalence of both groups in Phase A in terms of chronometric performance and to investigate eventual RT differences induced by the PEA in Phase B.

Alternatively, the possible effects of PEA on the arousal level were previously mentioned (Michael et al., 2003). It has been largely admitted that some olfactory stimuli can modulate arousal (Ilmberger et al., 2001; Moss, Cook, Wesnes, & Duckett, 2003). If the PEA led arousal level to drop off, a generally increased RT would be found and would be accompanied by a considerable decrement of capture effects because of reduced processing of peripheral events. Our results can, indeed, reflect such effects. To collect some data on this issue, we asked subjects to rate their arousal level at the end of Phase B. A diminution of the arousal level would be evidenced by lower scores for the PEA group than for the no-odor group.

### Materials and Method

**Subjects.** Nineteen young female subjects ( $22.3 \pm 4$  years old) with normal or corrected-to-normal vision participated in the control experiment. They were free of head colds or nasal allergies at the time of the test. After the session was completed, subjects were fully informed on the precise purpose of the study, that is, the visual attention/ambient odors interaction. The study was conducted in accordance with the declaration of Helsinki/Hong Kong.

**Design.** Two independent groups of subjects were created. Each group participated twice in the visual task, following a Phase A–Phase B design. Both groups were tested first with no odorant present; then the first group was tested again without odorant (no-odor group;  $n = 10$ ), and the second was tested in the presence of PEA (PEA group;  $n = 9$ ). At the end of Phase B, visual analog psychophysical scales (a continuous line of 10 cm) were administered to all subjects, and they were asked to rate, by means of a mark, the general arousal level as well as the perceived intensity of the odorant ambiance and the level of nasal irritation.

**Visual task.** The task was the same as the baseline condition of the main experiment. It was conducted in a dimly lit room. Subjects were installed in front of a computer monitor, at a distance of 30 cm from the screen. Each trial started with the presentation, for 300 ms, of a small white circle (i.e., target;  $25\text{cd/m}^2$ ) on the center of the black screen. This target was flanked on the right and the left by two big gray circles ( $5\text{cd/m}^2$ ) located at an angular distance of  $5.7^\circ$ . Then, a gap appeared on either the upper or lower side of the target. The next trial started 1,000 ms after the response. Subjects were asked to focus their attention on the central item (i.e., target) and to indicate the gap position (up or down) as quickly as possible by pressing one of two predetermined, vertically arranged response buttons. Once the gap appeared, the computer automatically recorded RT and errors. Twenty trials were presented and were preceded by a set of 10 training trials. Each phase lasted approximately 1 min, and a brief pause was automatically provided by the computer. No feedback was given to subjects.

### Results and Discussion

**Ambient odor estimations in the psychophysical scales.** For each scale (intensity, irritation level, and general arousal level), scores obtained in the psychophysical scale (in centimeters) were submitted to Student's *t* tests for independent samples. A difference was found between the PEA and the no-odor groups for the intensity dimension ( $5.02 \pm 0.9$  and  $2.46 \pm 2$ , respectively;  $p < .002$ ), suggesting that the presence of PEA in the room was correctly detected. No difference was evidenced for the irritation level ( $2.26 \pm 1.76$  and  $1.85 \pm 2.82$ , for PEA and no-odor, respectively;  $p > .36$ ). Finally, the general arousal level was significantly greater for the no-odor group ( $6.8 \pm 2$ ) than the PEA group ( $4.06 \pm 2.3$ ;  $p < .007$ ). This last result supports the previously evoked hypothesis concerning the modulation of arousal by the PEA.

**Visual task.** RT smaller than 100 ms and bigger than 1,000 ms were discarded as representing effects of anticipation or inattention. Discarded responses accounted for 1% of all responses. We carried out an ANOVA on correct RT with the phase (A and B) as the within-subject variable and the odor group (no-odor and PEA) as the between-subjects factor. The results are displayed in Figure 3A. The Phase  $\times$  Odor Group interaction was significant,  $F(1, 17) = 6.60$ ,  $p < .02$ , but the main effect of neither phase nor odor group reached significance,  $F(1, 17) = 0.25$ ,  $p > .62$ , and  $F(1, 17) = 1.06$ ,  $p > .31$ , respectively. Planned comparisons revealed no difference between the two groups in Phase A, in which no odorant was used (364 and 359 ms, respectively;  $p > .42$ ). This result establishes the basic chronometric equivalence of subjects constituting the two groups. A significant difference was found between the two groups in Phase B, with the no-odor group obtaining faster RT (336 ms) than did the PEA group (378 ms;  $p < .012$ ). The difference in RT obtained in Phase B between the two groups (43 ms) is very close to the one observed in the baseline condition of the main experiment (approximately 50 ms), adding some supplementary evidence against a statistical bias due to the between-subjects design used in the main experiment. A practice effect was also evidenced between Phase A and Phase B for the no-odor group ( $p < .02$ ) but not for the PEA group ( $p > .27$ ). If considered in isolation, this result does not allow one to determine whether the PEA affects practice effects, general speed of information processing, or both. Nevertheless, in light of the results obtained in the main experiment, it is clear that the PEA affects the basic speed of information processing. We conducted a comparison of the distributions of RT obtained in phase B to better understand the differences between the no-odor and the PEA groups. As for the no-odor group, the PEA RT seem to follow the Gaussian distribution (Kolmogorov–Smirnov  $d = 0.07$ ,  $p > .20$ ). Furthermore, the slowing in RT observed in Phase B cannot be attributed to a general shift of the distribution to the right (toward slower RT; Figure 3B). Rather, the distribution is slightly flattened and has only its right tail prolonged. Indeed, planned comparisons revealed that there were fewer trials with RT ranging from 301 to 350 ms in the PEA group (26.7% of trials) than in the no-odor group (35% of trials;  $p < .068$ ) and more with RT ranging from 501 to 550 ms in the PEA group (6.7% of trials) than in the no-odor group (0% of trials;  $p < .022$ ). This was also confirmed by means of a significant partial RT Class (301–350 ms vs. 501–550

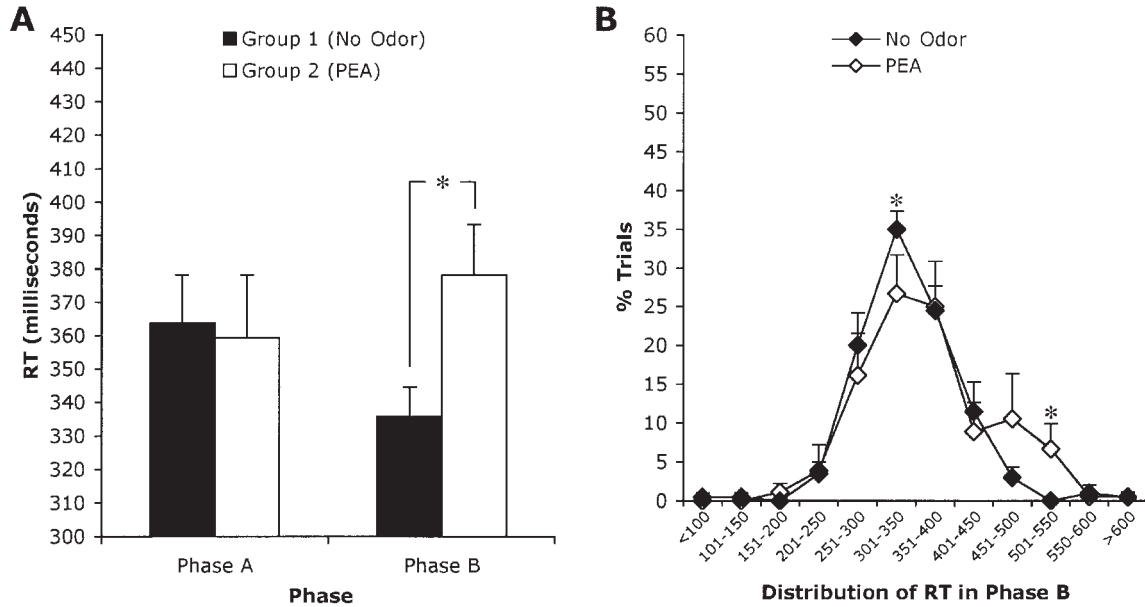


Figure 3. Results of the control experiment. A: Mean (+SE) response times (RTs) obtained in Phases A and B. B: Distribution of RT of the no-odor and phenyl ethyl alcohol (PEA) groups observed in Phase B. The PEA distribution seems to be flattened and extended to the right. Asterisks indicate that there is significant difference between the no-odor and PEA groups.

ms) × Odor Group (no odor vs. PEA) interaction,  $F(1, 17) = 4.22, p < .05$ .

Finally, a correlation analysis suggested that the slowing observed in Phase B for the PEA group was linked to the general arousal levels, not to the odor intensity or irritation levels. Indeed, a negative correlation was found between RT and the scores of arousal obtained in the psychophysical scale,  $r^2(17) = -.56, p < .02$ , but not between the RT and the scores of the perceived intensity or irritation scales,  $r^2(17) = .18, p > .10$ , and  $r^2(17) = -.01, p > .10$ , respectively. The sign of the significant correlation suggests that the lower the score of arousal, the slower the RT. The hypothesis of arousal modulation by the PEA was mentioned in the discussion of the main experiment. The present result constitutes an argument in favor of this hypothesis.

### General Discussion

Sudden task-irrelevant visual events seem to be processed automatically and unintentionally (Yantis & Jonides, 1984) despite intention to ignore them (Theeuwes, 1991). As a consequence, they interfere with the attentive processing of targets, and interference is reflected by slower RT. However, sudden events have little or no effect at all when enough time is given to subjects for focusing attention on the target (Theeuwes, 1995; Yantis & Jonides, 1990). In the main experiment, the results of the no-odor session were in accordance with previous findings. Sudden increments in luminance slowed RT, and this distraction effect dropped off progressively and disappeared with increasing target-to-distractor temporal interval.

The results obtained in the AIC session suggest that this mixed olfactory/trigeminal stimulus influenced attentional activity in a way that irrelevant increments in luminance triggered larger and

robust, long-lasting reactions. Indeed, distraction effects were bigger than in the no-odor condition and did not undergo any modification over time. It is as if these events were inspected more lengthily and in detail, suggesting that this trigeminal, irritating odor modulated the intensity and duration of the visual attentional analysis. In other words, the AIC could have influenced visual analysis in a way that distractors were considered as being of great importance and received, consequently, maximal attention. The irritating properties of trigeminal stimuli are considered as low-intensity painful agents. Several studies suggested that pain affect is coded in the amygdala and other limbic structures (Bornhovd et al., 2002; Rainville, 2002). Converging evidence was also given from anatomical studies, which showed that the amygdala receives nociceptive information through the trigeminal system (Barnett, Evans, Sun, Perlman, & Cassel, 1995). Thus, it can be hypothesized that the trigeminal modulation of the amygdala could have made observers perceive the sudden distracting increments in luminance as noxious or offensive stimuli. As dangerous items may compromise survival, a detailed and long inspection is required.

A modulation of the general arousal level can fully account for the results obtained with the PEA as ambient odor. The most striking result was the reliable slowing in RT observed in the baseline condition of the main experiment between the PEA and the no-odor sessions. The hypothesis of a group difference was discarded in the control experiment, and supplementary psychophysical data clearly suggested that the presence of PEA in the experimental room led arousal to diminish. Furthermore, a significant negative correlation was observed between the arousal scores and RT in Phase B, suggesting that the effects of PEA on RT may be due to a modulation of arousal. A drop-off in the arousal level

could cause ceiling effects in RT to show up. For instance, if ceiling effects were reached already in the baseline condition, attentional interference would not be obtained in the presence of distractors. Indeed, distractors had little distracting effect in the PEA session of the main experiment, except those presented well after the appearance of the target, which accelerated performance. A possible explanation for this is that the occurrence of the luminance increments would improve phasic alertness. Posner and Petersen (1990) suggested that there is a close relationship between the alert state and the speed of information processing in that it produces rapid responding. They stated that the whole attention system is under the regulatory activity of arousal and alertness and that, when this activity is disturbed, the performance of the whole organism is reduced. It is interesting to note that this regulatory system depends on the integrity of the right hemisphere and that the noradrenalin system plays a crucial role in the alert state (Posner & Petersen, 1990; Robinson, 1985). This is a quite interesting issue because it suggests that the PEA may exert a modulation on arousal at a biochemical level.

The observed differences between the AIC and the PEA sessions cannot be attributed to a different habituation effect. As a matter of fact, several studies have shown that human subjects habituate to pure odorants quickly. In contrast, trigeminal stimuli classically show a different pattern of responsiveness across time (Hummel, 2000). Such effects could have been observed in our study if the whole experimental session had endured much longer than 7 min. Appropriate statistical analyses showed that there are no different effects on RT of the AIC and the PEA over time, at least during our short experimental session. Rather, the pattern of performance depends on some of the properties of each odorant. Although the amplitude and duration of attentional capture by visual distractors seem to be linked at least to the trigeminal, irritating properties of these odorants (see Main Experiment; see also Michael et al., 2003), the basic speed of information processing seems to be primarily linked to an influence of the odorants on the arousal level, at least as far as PEA is concerned (see Control Experiment). This suggests that odors may exert multiple influences on visual attention and, by extension, that cross-modal integration may be accomplished at different levels of information processing.

Our study provided evidence that ambient odors influence both the amplitude and time course of visual attentional capture but may also influence the basic speed of information processing. These results suggest the existence of a cross-modal integration of visual, olfactory, and trigeminal information, resulting in the modulation of behavior. What do we know about the links between these sensory systems? Cross-modal integration starts already at a sensory level. Mick, Cooper, and Magnin (1993) have identified discrete retinal projections branching off from the optic tract and coursing toward the olfactory tubercle. The amygdala is rather concerned with the perceptual integration (Zald, 2003). A higher order area, the prefrontal cortex, has also been described as being a locus of cross-modal integration (Gottfried & Dolan, 2003; Zald & Padro, 1997). These findings suggest the existence of an early level of cross-modal processing, concerned most probably with the perceptual integration of spatiotemporally contiguous multimodal signals and a second, post-perceptual level responsible for the generation of plans and goal-directed actions contributing to the elaboration of a situation-adapted behavior. Ambient odors may

exert strong modulation at both levels of processing. Finally, a modulation of the arousal level by some ambient odors was already suspected or reported (Ilmberger et al., 2001; Millot et al., 2002). The results of the present study argue in favor of this hypothesis. We believe that our results are quite encouraging, and future research should allow for better understanding of the cross-modal relations between visual attention, olfaction, and the trigeminal system.

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Received May 21, 2004

Revision received January 5, 2005

Accepted January 24, 2005 ■