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Olfactory priming leads to faster sound localization

Valérie La Buissonnière-Ariza [a,b], Johannes Frasnelli [a,*], Olivier Collignon [a,b], Franco Lepore [a,b]

[a] Centre de Recherche en Neuropsychologie et Cognition (CERNEC), Université de Montréal, Montréal, QC, Canada
[b] Centre de recherche CHU Ste-Justine, CHU Ste-Justine, Montréal, QC, Canada

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ABSTRACT

Cross-modal interactions between vision, audition and touch have been extensively studied in the last decade. However, our understanding of how the chemical senses interact with other sensory modalities remains relatively scarce. We performed a cued auditory localization paradigm in healthy young adults by measuring reaction times to monaural auditory stimuli after subjects had been cued by unilateral olfactory stimuli, mixed olfactory/trigeminal stimuli or somatosensory stimuli. As expected, all cuing conditions led to enhanced performances in auditory localization. Further, both odors led to significantly shorter reaction times when compared to the somatosensory stimuli. We did not observe any effect of side-congruency between the cues and the targets. These results suggest facilitative effects of odorous cues independent of a possible trigeminal component in the interaction between olfaction and audition.

1. Introduction

Environmental stimuli usually activate several sensory systems simultaneously. Hence, the different senses, such as audition, vision, and touch, interact with each other in our perception of the environment [26,41]. A well-known example of such interactions is the ventriloquism effect [49], a perceptual illusion in which the voice of the puppeteer is shifted to a congruent visual source, that is, the puppet, therefore seeming to emanate from it [26]. At the cortical level, higher neuronal responses to bimodal vs. unimodal stimuli provide evidence for multisensory integration [30,47]. Consequently, interactions between the senses may lead to changes in performance during the execution of perceptual tasks. Auditory cues improve the detection of a simultaneously presented visual target [29,50]. Analogous findings have been reported for vision and touch [51]. Similarly, the chemical senses, i.e., smell, taste and the trigeminal chemosensory system interact mutually. Here, most studies focused on flavor perception and thus the interactions between the chemical senses (e.g., olfactory and gustatory [14,45,52]; gustatory and trigeminal [8,10]; olfactory and trigeminal [7,27,28]).

Most odors are mixed olfactory/trigeminal stimuli, as they activate both systems [15,18]. Hence, it is difficult to isolate the effect of odors from their trigeminal component, and vice versa. Only few studies investigated cross-modal interactions between the chemical and other senses, the majority focusing on vision; even fewer compared pure odors with mixed olfactory/trigeminal odorants. Subjects who were exposed to pleasant or unpleasant background odors reacted faster to visual and auditory stimuli than control subjects who performed the test in an odor free environment, suggesting both odors induce increased arousal levels [34]. Both odors (lavender and pyridine) are considered olfactory/trigeminal stimuli [1,36] and no control condition with continuous stimulation of another sensory modality was applied, making it difficult to conclude that the observed effects are specific to olfaction. The same group investigated olfactory modulation of visual reaction times (RTs) [32,33] by exposing subjects to a mixed olfactory/trigeminal [6,16] or to a pure olfactory [15] stimulus, while performing a visual task. In partial contrast to the findings of the first study [34], subjects reacted slower when the pure olfactory stimulus was applied than in the no ambient odor baseline condition; in the mixed olfactory/trigeminal odor environment, RTs were not different from baseline. When the authors distracted the subjects with a luminance change, subjects reacted slower than in the no ambient odor baseline condition, and even more so in the mixed olfactory/trigeminal ambient odor condition. In the pure odor condition, however, subjects became significantly faster when distracted [32,33]. The authors speculated that odor exposure led to two distinct mechanisms: (1) a non-specific slowing of processing and an eventual ignorance of the distracter (pure odorant), and (2) an increase of arousal levels due to the irritant properties of the stimuli, leading to enhanced sensitivity to distracters

* Corresponding author at: c/o Maria Sanchez, Université de Montréal, Département de Psychologie, Pavillon Marie-Victorin, 90, ave. Vincent-d'Indy, Montréal, Québec, Canada H2V 2S9. Tel.: +1 514 343 6111x0705; fax: +1 514 343 5787.
E-mail address: frasnelli@yahoo.com (J. Frasnelli).

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(mixed olfactory/trigeminal odorant). Pure odorant cues were also found to induce priming effects during the presentation of emotionally valenced visual stimuli, illustrated by faster RTs to disgusted faces after the presentation of odorous cues vs. ambient air [43,44]. In summary, odors have effects on RTs to heteromodal stimuli, suggesting cross-modal interactions between olfaction and other senses.

In addition to temporal contiguity, spatial proximity is a critical feature of multisensory integration: in order to integrate two stimuli from two different sensory modalities and enhance performance, both stimuli need to co-occur in time, but also in space [26,39]. This is particularly salient in spatial localization tasks, where spatially congruent cues from a different modality enhance the detection of a stimulus, whereas incongruent cues may have no influence or impair performance [20,26].

In the present study, we planned to elucidate the impact of olfactory or trigeminal cuing on auditory processing. We performed a cued auditory localization paradigm by measuring RTs to monaural auditory stimuli after cuing subjects with unilateral chemosensory stimuli. Humans cannot lateralize odors unless the odors also activate the trigeminal system [17,19,25]; thus odor lateralization allows to dissociate between olfactory and trigeminal stimulation. Air puffs and a baseline condition served as controls.

We expected all cues to induce shorter RTs than in the baseline condition. We also hypothesized (1) the facilitative processing induced by cuing to be enhanced by both kinds of olfactory stimuli when compared to simple somatosensory stimulation [29]. Next we hypothesized (2) spatial congruency between cue and target to lead to faster RTs than incongruent stimulation [46], but only for stimuli which we can localize in a monorhinal stimulation design namely the mixed olfactory/trigeminal (b) and somatosensory (c) conditions. Pure olfactory stimuli, which cannot be localized [19,25], should not have any effect of side-congruent stimulation.

2. Materials and methods

The protocol was approved by the Ethics Board of the University of Montreal and subjects gave informed written consent prior to testing.

2.1. Subjects

Thirty-one subjects (14 women) aged between 18 and 35 years (mean age = 23; standard deviation [SD] = 3) participated in the study. Two subjects were removed from analysis because their mean RTs were more than two SD from global mean. No participant suffered of any medical condition at the time of the testing and did not report any olfactory or auditory problem.

2.2. Stimuli

2.2.1. Olfactory stimuli

We used pure eucalyptol (eucalyptus odor; Galenova, St.-Hyacinth, QC) and pure phenyl ethyl alcohol (PEA; rose odor; SAFC, St. Louis, MO) as chemosensory stimuli, and air puffs as somatosensory stimuli. Eucalyptol is considered a mixed olfactory/trigeminal stimulus [15,16], whereas PEA is considered a relatively pure odor [15]. Air puffs activate only somatosensory trigeminal fibers.

We used the same adapted stimulation computer controlled device (IBB, University of Münster, Germany), which delivers air pulses of well-defined duration, as in an earlier study [19], to deliver the nasal stimuli. We connected the outlet channels to odor chambers (50 mL glass bottles, filled with 4 mL of odorant) via polyurethane tubing with 8 mm outer diameter and an inner diameter of 4.8 mm (Fre-Thane 85A, Freelin-Wade, McMinnville, OR). The odor chambers were connected to the subjects' nose with the same polyurethane tubing of approximately 50 cm length inserted into the subjects' nostrils, and maintained there with an elastic band around subjects' head. Odor channels were completely separated to avoid cross contamination of odors. During odor presentation, air (2 L/min) was switched into the respective channel. All nasal stimuli lasted 750 ms.

2.2.2. Auditory stimuli

Unilateral white noise was presented to the right or to the left ear through headphones for 150 ms (5 ms rise/fall time) per trial at a comfortable hearing volume.

2.3. Procedure

Subjects were blindfolded and tested in one session of approximately 1.5 h. An alerting high-pitched sound (150 ms) was delivered via headphones to announce the next trial arising from 2000 to 4600 ms after the alerting sound. Subjects were asked to breathe in when hearing the alerting sound and hold the breath until after their response. Subjects had to localize left or right unilateral auditory stimuli (target stimulus), by pressing one of two buttons as fast as possible in order to indicate if they had perceived the auditory stimulus in the left or the right ear. We delivered cuing stimuli consisting of (1) air puffs (somatosensory stimulation), (2) PEA stimuli (olfactory stimulation), (3) eucalyptol stimuli (olfactory/trigeminal stimulation) 600 ms before the target stimulus; a control condition without cuing was also applied. When chemosensory stimuli (2 and 3) were presented to one nostril, an odorless air puff of same pressure and duration was simultaneously delivered to the other nostril to isolate the effects of chemosensory and somatosensory cues.

Subjects received a nasal-auditory stimulation each 15 s. Testing was done in 10 blocks of 28 stimuli (2 of each combination per block).

Stimulus delivery and responses recording were controlled by the "Presentation" software (Neurobs) running on a HP PC (AMD Phenom X3 processor) with Windows XP.

2.4. Statistical analysis

Subjects' performance was evaluated in terms of hit rates (proportion of correct responses) and RTs (only for correct responses in the range 100–1500 ms post stimuli (99.61% of correct trials)). To evaluate the effect of a cuing stimulus, we performed paired *t*-tests (cued stimulation vs. uncued stimulation). Next, we performed a repeated measures ANOVA with side of the auditory stimulus (left, right), modality of the cuing stimulus (somatosensory, olfactory–trigeminal, olfactory), and side congruency of the cuing stimulus (congruent, incongruent) as within subject factors and RT as the dependent variable. We performed post hoc paired *t*-tests with Bonferroni correction.

3. Results

On average, subjects were able to indicate the side of the auditory stimulation with very high accuracy (>93%of the trials in all conditions). They responded after 500 (SD: 97) ms and 489 (115) ms, for the left and the right auditory stimulus, respectively. Independent of its nature, preceding co-stimulation reduced RTs significantly (all $ps < 0.001$) to the auditory stimulus by over 100 ms.

We observed a significant effect of cuing stimulus ($F[2,27] = 6.26$; $p = 0.006$), in that both chemosensory stimuli led to shorter RTs than somatosensory air puffs. Post hoc comparisons showed that when alerted by the somatosensory air puffs, subjects reacted after 394 (standard error of the mean [SEM]: 88) ms, whereas they were significantly faster when alerted by either a mixed olfactory–trigeminal stimulus (382 (92) ms; $p = 0.027$) or a pure olfactory stimulus (381 (82); $p = 0.026$) (Fig. 1). There was no significant difference between the two chemosensory alerting stimuli ($p = 1.0$). No other factor or interaction reached significance, most importantly side congruency of the alerting stimulus ($F[1,28]$ 1.06; $p = 0.31$) (Fig. 2).

3.1. Control experiment

We performed a second 25-min experiment in 31 subjects (14 women) to ensure effects would be specific to chemosensory properties of the costimulation and not to the amount of stimulation available (two vs. one air puff in the somatosensory condition), by comparing RTs following the presentation of 1 vs. 2 odor-free air puffs. Settings and parameters were the same as in the main experiment. No significant difference in mean RTs between unilateral (465 ms (146)) and bilateral (481 ms (149)) costimulations ($F[1,30] = 1.10$; $p = 0.302$) was found.

4. Discussion

We show that odorous cues, independent of a possible chemosensory-trigeminal component, lead to shorter RTs to auditory targets. This corroborates an earlier report, where ambient