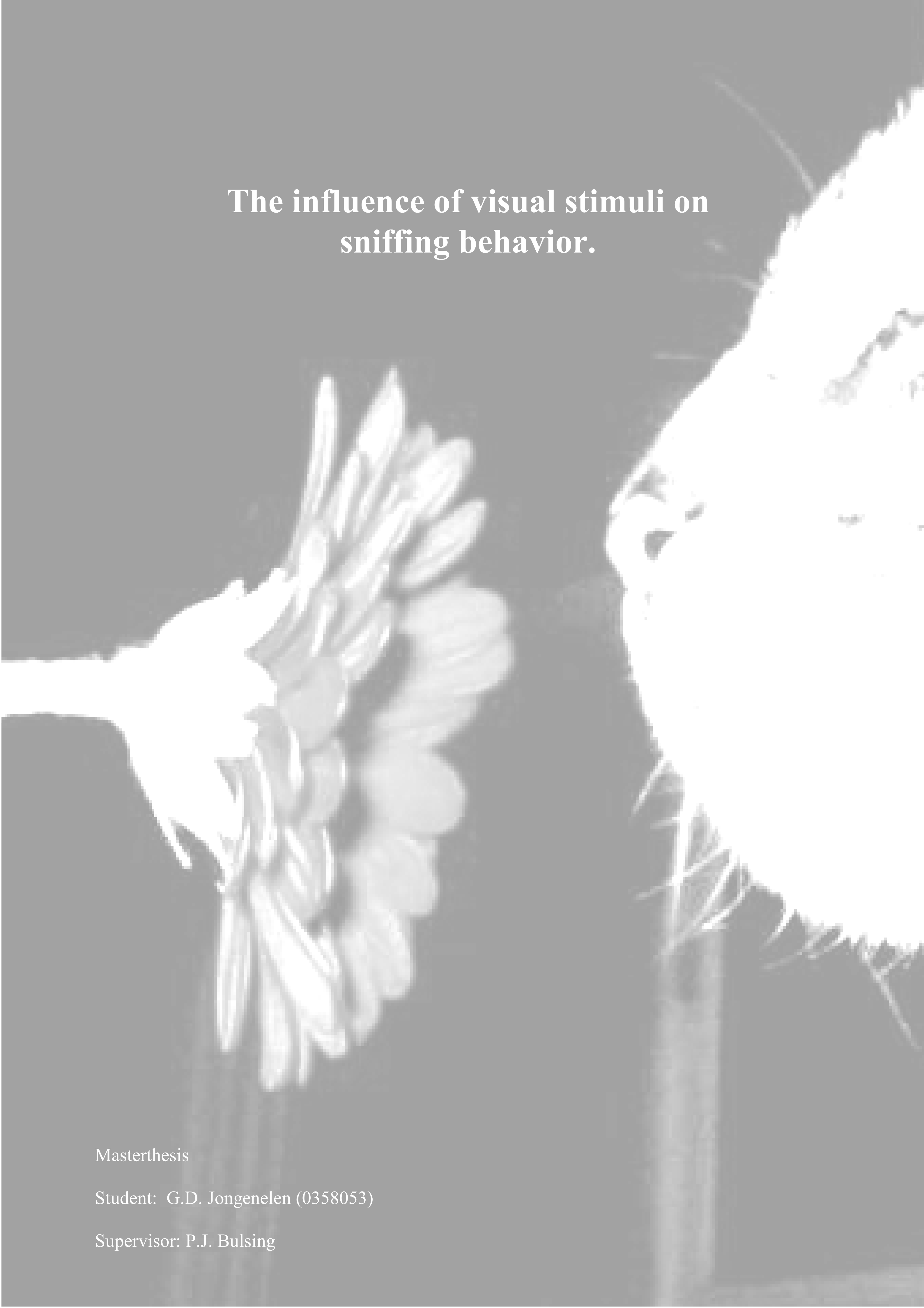

The influence of visual stimuli on sniffing behavior.

Masterthesis

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Abstract

Odor perception is influenced to an important extent by the expectations one has about the characteristics of that odor. Instead of focusing on the effect of cognitive processes on the final olfactory percept, the present experiment focused on the effect that cognitive processes – expectations- have on the early perceptual stage; the sniff. Visual stimuli, positive or negative pictures preceded the presentation of pleasant or unpleasant odors in mostly a congruent manner (positive – pleasant, negative – unpleasant) but sometimes in an incongruent manner (positive-unpleasant, negative – pleasant). Sniff vigor, total inhaled volume and sniff duration were expected to be mediated by expectation. The results showed that visual images have an influence on different sniff characteristics. The total inhaled volume of the odor increased when it was preceded by a positive picture compared to a negative picture, whatever odor was presented. Also, the sniff vigor slightly increased when the odor was preceded by a positive picture. People seem to use different 'sniff patterns' tailored to the odor they expect to perceive.

Introduction

The chance that an odor will be detected, is influenced for a great part by the expectation one has about being exposed to an odor. Furthermore, expectations may have an influence on the fysiological response in odor perception. Engen (1972) showed that the likelihood for people to report an odor was significantly greater when smelling a substance that was colored, than when it was transparent, independent of whether an odor was present or not. The presence of a visual stimulus therefore seemed to induce the expectation about smelling an odor, and as a result increased the likelihood of participants reporting the presence of an odor. Additionally, the more frequently they perceived an odor in the past, the more likely they were to report the presence of an odor later, whether or not it was actually present. In other words, the chance of reporting an odor increased based on the participants expectation to perceive the odor more frequently.

That expectation, besides odor detection, also influences odor identification, was demonstrated by Blackwell (1995). Here, participants had to recognize fruit odors when the substance was either colored differently or the same (e.g. yellow substance to represent lemon), from the fruit substance they smelled. This appeared to be significantly more difficult when the solution was colored differently than when it had the same color as the fruit. Also, when the intensities of the odor samples had to be arranged in terms of intensity (from strongest to weakest), this proved to be more difficult when the intensity of the substance color and the odor did not match. The visual cues seemed to distract the participants from making correct decisions about the odor, in both the odor detection and the odor intensity rating experiments.

Not only us naïve individuals seem to be fooled by this 'color' effect, as even experts rely heavily on visual stimuli. The typical 'red' or 'white' wine judgments, that wine experts use to rate wines, are influenced by the color of the wine (Morrot et al. 2001). In the Morrot et al. study, white wine was colored red with a non-odorous dye. Consequently, when the experts had to rate the 'red white' wine, they did so by using 'red' attributes. This showed that color can have a priming effect on odor perception. Furthermore, the integration of visual information, in this case color, seemed to occur in an unconscious way.

In line with the previous studies, de Araujo et al. (2005) showed that words, instead of colors, can also influence odor perception. In their experiment, the odor cheddar cheese, was labeled by a visual word descriptor; either 'cheddar cheese' or 'body odor'. Participants rated the odor as significantly more unpleasant when it was labeled 'body odor'. Surprisingly, the same effect was noticeable when using a neutral odor (clean air). The effect of cognitive modulation was supported by fMRI data, which showed that activated brain regions were correlated with the participants' pleasantness ratings. This activity thus seemed to be dependent on the word labels that were provided during the odor delivery.

Distel and Hudson (2001) suggested that source information about a certain odor activates appropriate mental schemes, which lead to expectations about the odor. In their study, participants received twelve odors. In one condition, the source information (name of the odor) was known to the participants, and in the other condition it was not. The ratings of intensity, pleasantness and familiarity were enhanced when the name of the odor was provided. In a third condition, subjects were asked to report whether a given odor name matched their own perception. Ratings of intensity, pleasantness and familiarity were highest when they reported a good match. In this case, the authors speculate that people employ certain perceptual schemas which are activated in perceptual events. Perceptual schema's can be described as the way in which objects are semantically related. For example, ovens and refrigerators are typically found in kitchens, barns and chickens on a farm and desks and computers in offices. This information is acquired during a lifetime of perceptual experience (Chun & Jiang, 1999). With respect to this description, it can be assumed that perceptual stimuli activate associations throughout different modalities associated with the perceived stimuli. For example, when observing freshly baked bread, the smell and taste of it are activated simultaneously. In the Distel and Hudson experiment, the high ratings in the good match situation probably resulted from a good match between the neural activation of the perceptual schemas, and the actual perceptual input (knowing the source of the odor). Lower ratings, on the other hand, were explained as the result of an incomplete match, leading to reduced neural activity (e.g. not knowing the source of the odor). These findings led to the conclusion that cognitive processes, activated by certain information about the odor, influence odor perception.

Gottfried and Dolan (2003) underlined the principle that congruency, or good matches, can facilitate odor perception. They offered picture-odor pairs, which could be semantically congruent (picture of a bus, with diesel odor) or incongruent (picture of cheese, with fish odor). An odor appeared to be detected significantly faster when the picture and the odor were a matched pair. Furthermore, the accuracy of detection responses (odor yes/no) also differed significantly, in the favor of the congruent pairs.

Blackwell's fruit odor experiment, described earlier, showed that it is difficult to ignore visual cues, and more importantly, that these cues seemed to dominate the eventual response. Blackwell (1995) compared this effect to the Stroop effect, where names of colors are printed in ink of a different color. In the Stroop task, higher perceptual processes (reading words) interfere with lower perceptual processes (naming ink colors), resulting in slower reaction times when asked to name the ink color. The same was the case in Blackwell's study described above; the visual cues seemed to distract participants from making correct decisions about the odor. This, in turn can be integrated with Distel and Hudson's mental schemata premise, because one process activates a certain set of semantic relations, which is hard to overrule by another process, in this case odor evaluations. So, like in the Stroop task; one of the processes had a dominant effect on the eventual response, in this case the knowledge of the odor source.

The studies that have been discussed so far, all focus on the influence of cognitive processes on perception and subjective appreciation of odors. But, in order for a person to be able to smell, odorant transduction, the process of odorant binding at olfactory receptors, has to take place. Here, the first step is for odor molecules to find their way into the nasal cavity where they bind to the olfactory epithelium, a tissue that lies several centimeters in the nasal cavity. In order for the molecules to reach the epithelium, an active process called sniffing has to take place. According to Comroe (1974) sniffing can be best described as “a mechanism for bringing ambient air into contact with the olfactory receptors in the nose without carrying the air (which may contain irritant, toxic materials) deep into the lung”. Olfaction thus actually consists of two parts; sniffing and smelling. The first concerns the airflow in the nostril, regardless of the presence of odor molecules. Secondly, smelling refers to the actual odor perception, regardless of airflow in the nostril. Although olfactory perception is usually assumed to reflect the ‘smelling’ part, it is largely dependent on the ‘sniffing’ part (Mainland & Sobel, 2006). Evidence for this statement lies, among others, in a study done by Bocca et al. (1965). Here, odor molecules were injected intravenously, so that odorants could reach the epithelium through the bloodstream in the absence of sniffing. They found that no odor was perceived, when participants did not sniff. Only when they could breathe normally through the nose or when odorless nitrogen was injected to mimic a sniff, the intravenous odor was perceived. This led them to conclude that the sniff, or mechanical stimulation of the epithelium, is necessary for olfactory perception. This necessity has also been shown by Bensafi et al. (2003). In their experiment, airflow was measured when participants had to imagine different stimuli across modalities, including olfaction (odor imagination). Statistical analysis revealed that sniffing was greater during the imagery of smells, compared to other modalities. Then, the group was divided into two groups; good and bad imagers. The good, but not the bad, imagers, produced larger sniffs when imaging a pleasant smell compared to an unpleasant smell. Also, when subjects were prevented from sniffing with a nasal clip, the mental imagery of the pleasant odors of good imagers was hampered. This result suggest that sniffing functionally contributes to odor imagination. The increased length and vigor of the sniff when imagining a pleasant odor can be compared to real life situations in which the sniff is adapted to the odor that is, or is expected to, being perceived, since the characteristics of odors can influence sniffing. Intense and unpleasant odors for example, have been found to decrease the sniff vigor and length (Frank, Dulay, & Gesteland, 2003).

To highlight the importance of the sniff in perceiving odor, it has been compared to eye movements, which are the basis for visual perception. When the eye is completely motionless, no image will be relayed to the brain. The same applies to olfactory perception; when there is no air flow in the nasal cavity, there will be no olfactory percept (Mainland & Sobel, 2006).

In conclusion, external, non-olfactory factors can induce certain expectation about odors, which in turn influence odor perception. However, odor perception is impossible without prior sniffing. Because in previous studies, the influence of cognitive processes has only been studied for the smelling phase, this study sets out to investigate the influence of expectation, on the motorical component of olfactory perception; the sniff. In other words, do expectations have an influence on characteristics of the sniff? Or is sample behavior solely influenced by the characteristics of the odor, like intensity and hedonics (Frank, Dulay, & Gesteland, 2003)?

In the present experiment, pictures were shown on a computer screen while at the same time, participants were asked to smell an odor. Three odors (a pleasant, unpleasant and clean air) and three pictures (a positive, negative and a neutral one) were used. The odor-picture pairs either occurred in a congruent (a pleasant odor preceded by a positive picture, an unpleasant odor preceded by a negative picture and a neutral odor preceded by a neutral picture) or incongruent (e.g. a pleasant odor preceded by a negative picture) fashion. By mostly offering the congruent pairs, an expectation about the odor was created. So, by offering multiple congruent pleasant pairs, participants would immediately expect a pleasant odor when seeing the positive picture. The sniff characteristics of interest were sniff vigor, sniff duration and the total volume that was being inhaled per sniff.

According to the idea of the activation of mental schema's, as suggested earlier by Distel and Hudson (2001), it was expected that the sniff characteristics of congruent pairs would differ from those of incongruent pairs. In the present experiment, perceptual schemas were thought to be activated by visual stimuli (pictures). It was hypothesized that when the picture ~~is~~ was a bad match with the odor, this would lead to different sniff responses than when there was a good match. More concretely, it was expected that when a pleasant odor ~~is~~ was perceived in combination with a negative picture, the sniff vigor, duration and total inhaled air would be smaller than when the same odor ~~is~~ was preceded by a positive picture, because an unpleasant odor was expected. The perception of an unpleasant odor in combination with a positive picture was expected to result in greater sniff vigor, increased duration and total inhaled volume compared to when the unpleasant odor was perceived together with a congruent picture, because a pleasant odor was expected.

Besides these physiological characteristics, the subjective experience was measured after every trial. Participants had to rate the pleasantness and intensity of the perceived odor. As with the sniff characteristics, differences between congruent and incongruent pairs were expected here as well. Higher ratings in pleasantness and intensity were expected when a pleasant odor was perceived with a congruent, positive picture in comparison to a negative picture. On the other hand, when subjects perceived an unpleasant odor with a negative picture, lower pleasantness ratings were expected compared to the condition in which an unpleasant odor was perceived in combination with a positive picture. As is the case with the sniff data, these hypotheses are based on perceptual schemas. It is expected that certain schemas are activated by the positive and negative pictures, which in turn result in the enhancement or reduction of the subjective experience, respectively.

Methods

Participants

Twenty-eight participants (6 male, 22 female) were recruited from Utrecht University. Their ages ranged from 19 to 35 years, with a mean of 23 years. All participants had a normal sense of smell (tested by rating the intensity of the odors that were used in the experiment on a 7-point scale. When achieving an average score, subjects were allowed to participate). Subjects received financial or study compensation.

Stimuli

To determine which two odors and two pictures had be used during the experiment, an independent testpanel (n= 15) was asked to fill out a questionnaire about four pleasant and four unpleasant odors. Based on the outcome, it was determined which odor-picture combinating fitted best. Participants had to rate the following characteristics of an odor on a five point scale (with extreme categories 'very much' versus 'not at all'); familiarity, intensity, pleasantness and naturalness. Also, four possibly matching pictures, chosen from a picture database according to the description of the odors, were shown alongside each odor. Participants had to choose the picture that best matched the odor. After rating the odors on all characteristics, the most pleasant and most unpleasant odor, and simultaneously the most pleasant and unpleasant picture, was chosen by the participant. The odor and picture that were chosen most often were included in the experiment. So, one pleasant odor, with an associated picture and one unpleasant odor with an associated picture, were used for the experiment. The odor that was rated as most pleasant was lavender (chosen by seven participants) and the odor that was rated as most unpleasant was dimethylsulfide (ten participants). For the associated visual stimuli (see figure 1) this was a lavender field (four participants) and a dirty sink (four participants), respectively.

 

Figure 1: Left; The picture used to predict the presentation of the unpleasant odor. Right; The picture for the prediction of the pleasant odor.

To exclude an effect of intensity on sniffing behavior, another independent testpanel (n=11) was used to determine which two concentrations (of both the pleasant and unpleasant odor) were iso-intense. An intensity selected unpleasant odor, was presented to the participants. Participants were given four solutions of the pleasant odor that differed in intensity[1]. From these, they had to choose the solution that was most equal to the unpleasant one in terms of intensity. The concentration that was most often considered as equally intense to the other concentration was included in the experiment. The included intensity for the pleasant odor was 65 µl lavender with 35 µl DPG (chosen by eight participants). Also, a neutral (clean air with a grey screen as visual stimulus) condition was incorporated, which functioned as a control, to determine the sniff characteristics without any visual or olfactory input.

Five drops of each odor solution were offered on a Sorbarot (Lakon, UK), which is a cylinder (approximately 2,5 cm in height and 3 cm in diameter) with material inside that has good absorption abilities (cellulose acetate). The sorbarots were renewed on each test day.

Sniff procedure

Participants were asked to watch a computer screen, on which the pictures appeared for 4000 ms. When the picture appeared on the screen, they heard a tone which lasted for 500 ms. At the end of this tone, they had to start smelling the odor. At a second tone, which was heard

[1] *The four solutions are **1**. 5 µl lavender and 95 µl DPG, **2**. 35 µl lavender with 65 µl DPG., **3**. 65 µl lavender with 35 µlDPG., **4**. 95 µl lavender and 5 µlDPG.*

500 ms. before the picture was removed from the screen and the odor was taken away, participants had to stop smelling. After each trial, there was an inter stimulus interval of 30 seconds, before the next picture appeared on the screen (see Figure 2). This cycle was repeated untill the end of the experiment, which consisted of fourty-four odor-picture pairs.

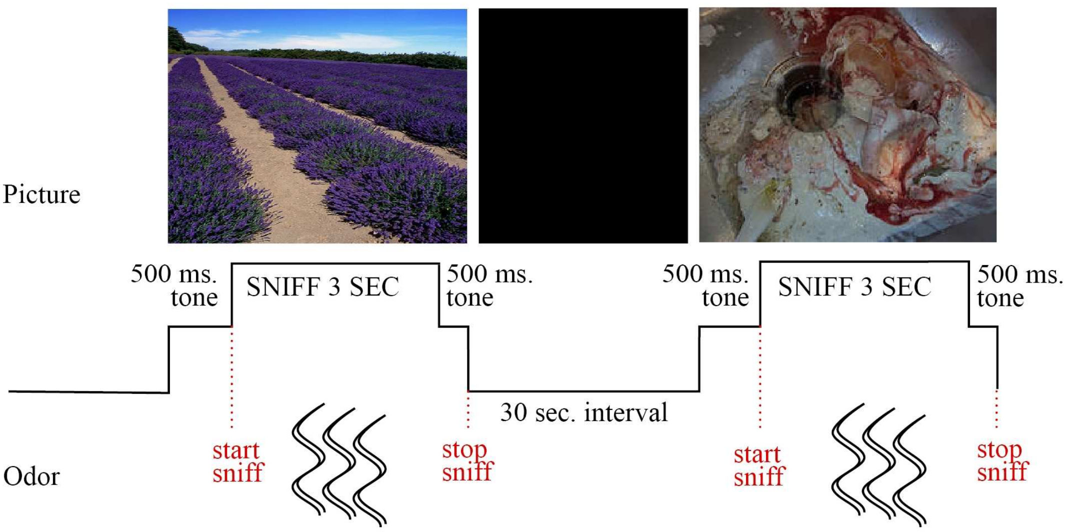

Figure 2: Experimental design: each trial lasted for 4000 ms. The first tone, the indication for participants to start smelling, occurred at the same time as the visual stimulus and lasted for 500 ms. The second tone, the indication to stop smelling, occurred 500 ms. before the picture dissappeared from the computer screen.

During the entire experiment, participants wore a nasal pressure monitoring cannula (normally used to deliver oxygen to patients in hospitals or nursing homes), which was connected to a pressure transducer (PT; Sleep Sense). The PT registered sniffing behavior by measuring air pressure in the nose (every 10 ms; in a range of 0 - 40 mmH_2O). The PT amplified the signal, which was in turn digitized using a 16 bit analog-digital converter (National Instruments). Only periods (“blocks”) in which a stimulus was presented, were analyzed. The start and end of each block was automatically marked in the data: As soon as a subject placed his or her head in a fixed position (on a chin rest) to sniff (the only manner to come close to the Sorbarot), a micro switch was activated when the participant’s forehead pressed it (see also figure 3). The switch was released as soon as subjects drew back their head.

The sniffing data was analyzed using a computer program (Sniff Pressure Analyzer, version 2), which was developed by the lab technician. The program was capable of automatically scanning the data in search for sniff pulses. The period between the moment at which the air pressure level fell below a certain baseline, until the moment where it reached the baseline again was interpreted as a sniff. In order to minimize the noise in the data, only pulses which took at least 400 ms (Laing, 1983) and at most 7500 ms were recognized as sniffs by the program. Pulses starting after 3500 ms were not accepted as sniffs because both the visual and the olfactory stimuli were no longer available to the participant. If a sniff started before onset of a block, but ended within a block, it was included in the analyses.

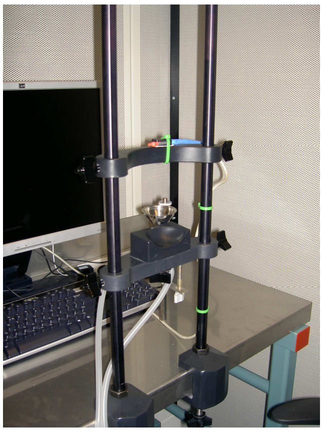

Figure 3: The construction with the chin rest and the micro switch. The sorbarot with the odor was placed in front of the chin rest.

Procedure

Instruction

All participants received the same instruction before the start of the experiment. The exact goal of the experiment remained unclear to the participants.

> Welcome. During this experiment, you will watch a computer screen, on which pictures will be shown. At the same time, you will have to smell an odor, that will be placed in front of your nose. When the picture appears on the screen, you will hear a

tone, which indicates that you can start smelling the odor. When you hear a second tone, you have to stop smelling and the odor will be removed. The experiment will start after six trials for which you can decide for yourself –by pressing a button on the keyboard- when the next picture will appear on the screen. In this way, you can get accustomed to the time you have to smell each odor during a trial. During the main experiment, after each trial, you will be asked two questions about how you have experienced the odor.

To kow exactly when you smelled the odor, this lever will be used. When you start smelling, you have to press this lever with your forehead and release it when you stop smelling. We will practise this in a minute.

The nasal cannula that you will have to wear, is used as a control, to allow the researchers to check which odor you have received during each trial.

Training and Test phase

To accustom participants to the experiment, and to induce expectations about the odor –induced by the picture- they received a short trainingsession before the main experiment started. First, participants learned to press the lever in the correct way and at the right time, without any olfactory or visual stimuli. Secondly, six congruent pairs were presented, the pleasant odor preceded by the pleasant picture and the unpleasant odor preceded by the unpleasant picture. In the main experiment, the congruent and incongruent pairs were offered to the paricipants in a semi-random order. This order was reverted for half of the participants, to avoid an order effect. In total, they received fourty-four odor-picture pairs, which consisted of thirty congruent pairs (fifteen pleasant and fifteen unpleasant), two neutral congruent pairs, and fourteen incongruent pairs that were offered twice in all possible combinations (see Table

1). After each trial participants had to rate the intensity and pleasantness of the odor on a VAS scale (0-100).

Picture	Odor	Number of occurrence during experiment
positive	pleasant	15
negative	unpleasant	15
neutral	neutral	2
positive	unpleasant	2
positive	neutral	2
negative	pleasant	2
negative	neutral	2
neutral	pleasant	2
neutral	unpleasant	2

Table 1: Number of odor-picture combinations during the test phase.

Analyses

Sniff behavior

Repeated measures ANOVA's were conducted for the analysis of the sniff data, with within-subject factors Odor (3 levels) and Picture (3 levels). Amplitude (sniff vigor), Area under the curve (total inhaled volume) and Width (duration of the sniff) were used as the dependent variables in this analysis.

Subjective ratings

Also, for the analysis of the subjective ratings repeated measures ANOVA's were conducted, with within-subject factors Odor (3 levels) and Picture (3 levels). Here, the VAS scores for intensity and pleasantness were used as dependent variables.

A main effect of Odor would demonstrate sniffing or rating differences depending on the odor (pleasant, unpleasant, neutral). A main effect of Picture would show sniffing or rating differences depending on visual information preceding the odor (positive, negative, neutral information). An interaction between Odor and Picture would demonstrate different influences of visual information depending on the odor that is perceived.

Results

Fifteen congruent pairs were presented in the experiment (See Methods, Table 1), and all possible combinations of incongruents pairs were presented twice. To be able to compare the congruent and incongruent odor-picture pairs, only the data of the first two congruent pairs were used in the analyses. Generally, participants displayed a single sniff (pulse) when sampling an odor. However, some participants sampled some odors by taking two or more sniffs. In these cases, to display the true volume and duration of the sniff, data of both pulses (per block) were added together and included in the analyses. Addition was applied for the dependent variables 'Area under the curve' (total volume inhaled air) and 'Width' (sniff duration). For 'Amplitude' (sniff vigor), only data of the first sniff (per block) was included in the analyses.

Subjective ratings

Intensity

Figure 4 shows that the pleasant and unpleasant odor were both rated as more intense than the neutral odor. This is reflected by a main effect of 'odor', which was found on perceived odor intensity, $F(2, 54) = 122.32$, $p < 0.01$. Post hoc tests with Bonferroni corrections showed that both the pleasant and the unpleasant odor were perceived as significantly more intense than the neutral odor ($M_{\text{neutral}} = 14.70$, $SD = 2.37$ and $M_{\text{pleasant}} = 64.82$, $SD = 2.71$, $M_{\text{unpleasant}} = 63.01$, $SD = 3.14$, both Post hoc test: $p < 0.01$). Although these results do not display what was expected (differences between congruent and incongruent pairs; an interaction effect), the pleasant and unpleasant odors do not differ significantly, which implies that subjects experienced both odors as equally intense. No main effect of the factor 'picture' was found, $F(2,54) = 0.40$, $p = 0.67$, nor an interaction effect between 'odor' and 'picture', $F(4,108) = 2.51$, $p = 0.08$. Intensity ratings were thus not influenced by visual information preceding the odor.

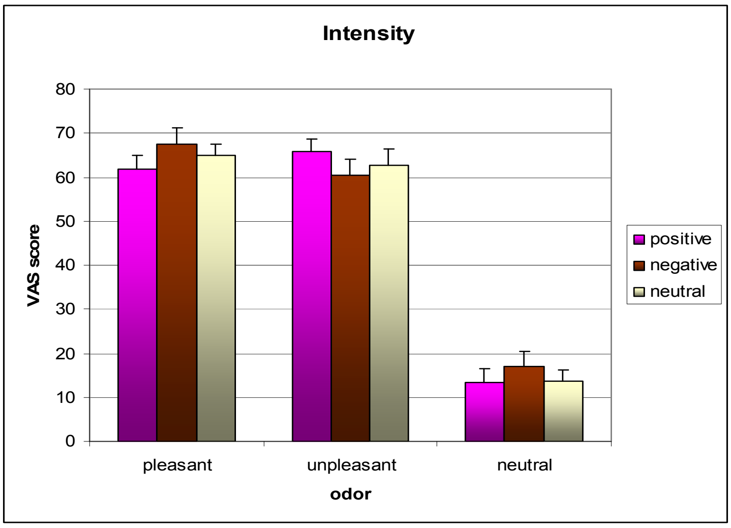

Figure 4 *VAS ratings of perceived intensity as a function of 'odor' and 'picture'.*

Pleasantness

On the variable perceived pleasantness, a main effect of the factor 'Odor' was found, $F(2,54) = 79.13$, $p < 0.01$. All odors differed significantly from one another ($p < 0.01$), according to the post hoc test ($M_{pleasant} = 68.68$, $SD = 2.88$ and $M_{unpleasant} = 19.31$, $SD = 2.77$ and $M_{neutral} = 47.98$, $SD = 2.59$). The pleasant odor was rated as most pleasant and the unpleasant odor as least pleasant (see also Figure 5). No main effect was found of 'Picture' $F(2,54) = 2.30$, $p = 0.11$. There was also no interaction effect between 'odor' and 'picture' $F(4,108)=1.32$, $p = 0.27$. Pleasantness ratings were thus not influenced by visual information preceding the odor.

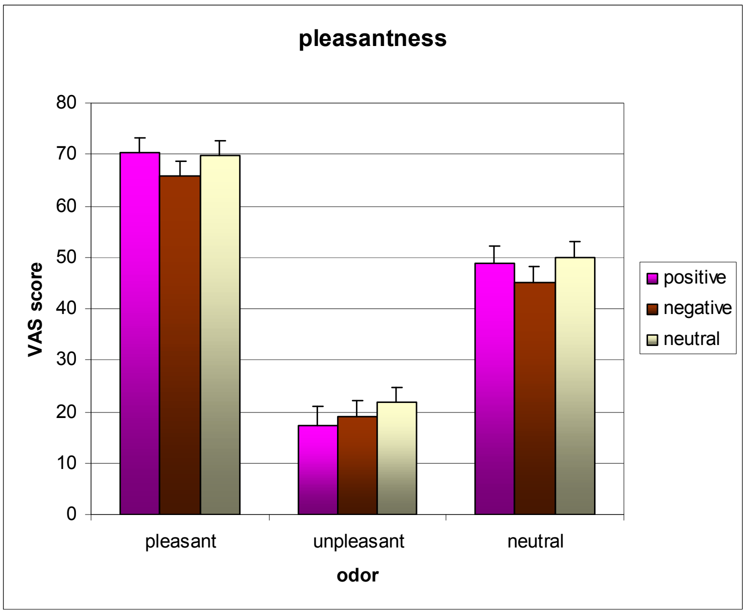

Figure 5 *VAS ratings of perceived Pleasantness as a function of 'odor' and 'picture'.*

Sniff behavior

Amplitude(sniff vigor)

For the dependent variable Amplitude (sniff vigor), a main effect of 'Odor' was found, $F(2,54) = 7.33$, $p < 0.05$. As can be seen in Figure 6, the pleasant and neutral odor were inhaled more vigorously than the unpleasant odor. Post hoc testing revealed significant differences between the pleasant and unpleasant odor ($M_{pleasant} = -12.30$, $SD = 10.36$ and $M_{unpleasant} = -11.03$, $SD = 9.74$, $p < 0.01$), and the neutral and unpleasant odor ($M_{neutral} = -11.93$, $SD = 9.36$, $p = 0.05$). Although there was no main effect of 'Picture', $F(2,54) = 2.53$, $p = 0.12$, post hoc tests were executed in order to test our specific hypothesis. This revealed a significant difference between the positive and negative picture ($M_{pleasant} = -12.30$, $SD = 10.36$ and $M_{unpleasant} = -11.03$. $SD = 9.74$, $p = < 0.05$), showing that sniff vigor increased if the odor was preceded by a positive picture, as opposed to a negative picture. There was no interaction effect between 'odor' and 'picture', $F(4,108) = 1.89$, $p = 0.12$.

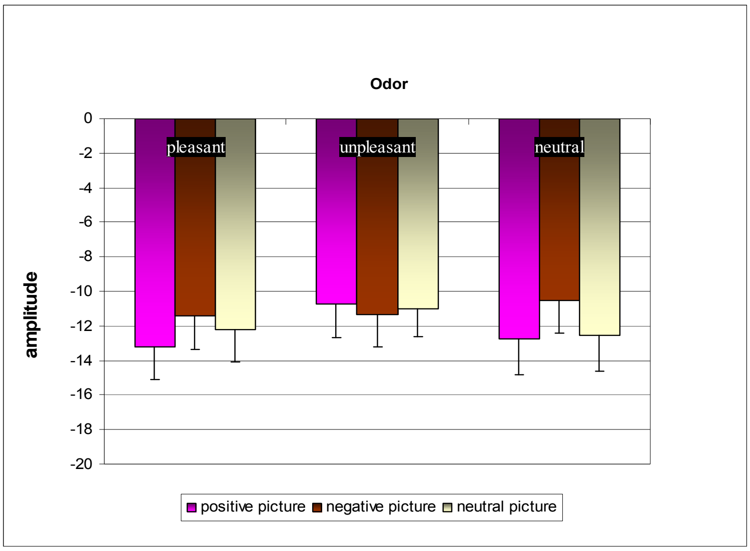

Figure 6 *Sniff vigor expressed in mmH2O as a function of ' odor' and ' picture' .*

Area under the curve (Total volume inhaled air)

For the dependent variable Area under the curve (total volume inhaled air), a main effect of 'Odor' was found, $F(2, 54) = 10.499$, $p < 0.01$. After conducting post hoc tests, the pleasant and the unpleasant odor differed significantly from another, as well as the unpleasant and neutral odor. More air was inhaled while sampling the pleasant or the neutral odor compared to sampling the unpleasant odor ($M_{pleasant}$ = 30,21, $SD = 4.83$ and $M_{unpleasant} = 26.33$, $SD = 4.90$, $p < 0.05$ and $M_{neutral} = 32.24$, $SD = 4.73$, $p < 0.01$). Also, a non-significant trend was observed for ' Picture' $F(2, 54) = 3.02$, $p = 0.06$. Post hoc testing revealed a significant difference between the positive and the negative visual stimulus ($M_{positive} = 31.57$, $SD = 5.01$ and $M_{negative} = 28.25$, $SD = 4.48$, $p < 0.05$). Investigating the means revealed that more volume of an odor is inhaled, when it is presented in combination with a positive picture rather than with a negative picture (see also Figure 7). There was no interaction effect between 'odor' and 'picture', $F(4,108) = 1.26$, $p = 0.29$.

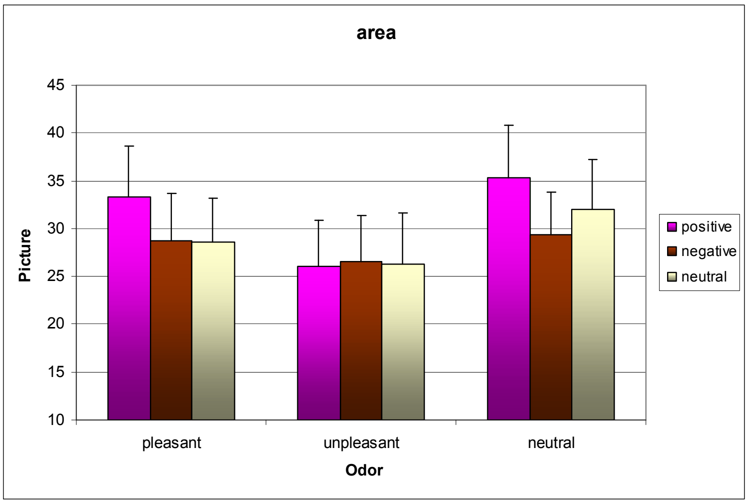

Figure 7 *Area under the curve expressed in mmH2O x sec. as a function of ' odor' and ' picture' .*

Width (sniff duration)

For the dependent variable Width (sniff duration), a main effect of 'Odor' was found $F(2,54) = 5.82$, $p < 0.01$. Post hoc tests revealed a difference between the pleasant and neutral odor (see also Figure 8), whereby the neutral odor was sniffed longer than the unpleasant odor ($M_{neutral} = 5.31$, $SD = 0.30$ and $M_{unpleasant} = 4.54$, $SD = 0.30$, $p < 0.01$). Furthermore, a non-significant trend was observed between the pleasant and unpleasant odor ($M_{pleasant} = 4.99$, $SD = 0.23$, $p = 0.06$). For the factor 'Picture', no main effect was found, $F(2,54) = 0.61$, $p = 0.55$. There was no interaction effect between 'odor' and 'picture', $F(4,108) = 0.76$, $p = 0.55$. Visual information did not influence sniff duration.

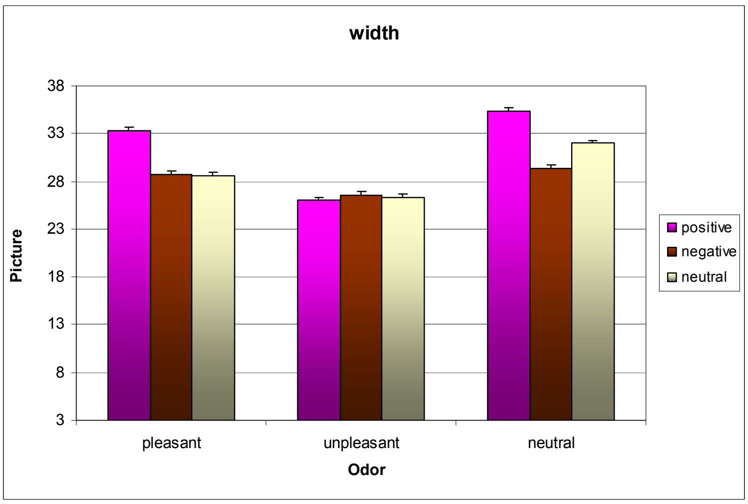

Figure 8 *Sniff duration expressed in seconds as a function of ' odor' and ' picture' .*

Discussion

The present study examined the influence of cognitive processes – expectations- on the motor component of olfactory perception; the sniff. During the experiment, an expection about the odors was created by presenting pictures (positive or negative), before the odor (pleasant, unpleasant or clean air) was administered. The visual and olfactory stimuli could be either congruent (e.g. positive picture and pleasant odor) or incongruent (e.g. positive picture and unpleasant odor). The dependent sniff variables of interest –measured by registering air pressure in the nose- were sniff vigor, total inhaled air per sniff and sniff duration.
It was hypothesised that visual information would influence characteristics of the sniff, because a specific odor would be expected based on the visual information. More concretely, it was hypothesized that when a pleasant odor was perceived in combination with a negative picture, the sniff vigor, total time and total inhaled volume would be smaller than when the same odor was preceded by a positive picture, because an unpleasant odor was expected. The perception of an unpleasant odor in combination with a positive picture was believed to result in greater sniff vigor, increased duration and total inhaled volume compared to when the unpleasant odor was perceived together with a congruent picture, because a pleasant odor was expected.

The results of this study demonstrate a difference in the characteristics of the sniff when smelling pleasant, unpleasant or neutral odors. These findings are congruent with previous studies (Liang 1983; Warren et al. 1994; Johnson et al. 2003, Mainland and Sobel 2006). More volume is being inhaled when sampling a pleasant odor or clean air, compared to an unpleasant odor. Furthermore, these odors are inhaled more vigorously and for a longer period of time. Striking is the more vigorous sniff when sampling clean air, compared to the pleasant odor. This finding is compatible with Gottfried and Dolan's (2003) finding; because there is no odor, participants sample the odor more vigorously to be certain of its absence. The present results also reveal an effect of the visual stimuli on the total volume of the odor that is inhaled. When being presented with a positive or negative picture, participants inhaled more volume than when being presented with a neutral picture. So, no matter which odor was presented to the participant, when a positive picture preceded the odor, more volume was inhaled when sampling the odor. On the other hand, when a negative picture preceded the odor, less volume was being inhaled. Additionally, a non significant trend was found of the factor 'picture' on sniff vigor (sniff amplitude), Post hoc tests revealed a significant difference, again between the positive and negative picture. Pictures thus seems to influence the way an odor is being sampled. Distel and Hudson (2003) suggested that source information about a certain odor activates appropriate mental schemes, which lead to expectations about the odor. The visual stimuli that were presented during the present experiment, were used to induce expectations about the odor that the participant would perceive. The difference in total inhaled volume, that was seen between the positive and negative picture, shows that the visual stimuli indeed seemed to induce an expectation, which Distel and Hudsons speculated, could be a display of the activation of certain associative mental sets.

In line with their view, Rolls et al. (2003) suggest the existence of a hedonic 'smelling map' in the brain in which pleasant odors activate different brain areas than unpleasant odors do. Pleasant, but not unpleasant odors were found to activate a medial region of rostral orbitofrontal cortex. Different, and more lateral regions of the orbitofrontal cortex are correlated with the subjective pleasantness ratings of the odors. That the brain prepares itself for perceiving odors, is demonstrated by another study by Rolls et. al (2008). Top-down influence, through different instructions, influence the brain areas that become active before perceiving an odor. When participants are instructed to pay attention to the intensity of an odor, different brain areas become activated than when they had to pay attention to its affective value.

Bocca (1965) concluded that mechanical stimulation of the epithelium concomitant with odorant delivery was necessary for perception to take place. In other words, the sniff is necessary for olfactory perception. However, it remains unclear as to how the sniff arises and how the characteristics of the sniff are determined when sampling an odor. Are they determined before the the odor is being sampled, guided by external information, or is the sniff adjusted while sampling? Integrating all the above studies could lead to the suggestion that certain mental sets, that are activated by external stimuli, are related to different brain areas. It seems plausible that the visual stimuli, which are used in the present experiment, activate brain areas that are related to the pleasantness of the odor that is expected. Taken together, it may be speculated, that these brain areas activate certain sniff patterns -e.g. customized volume and vigor- that are used specifically for the odor that is expected. This idea is underlined by a study done by Bensafi (2005). In his imaging study, it was shown that participants took a larger sniff during the imagery of a pleasant smell compared to the imagery of an unpleasant smell. The sniff pattern view could be applicable here as well, in the way that imaging an odor activates a tailored sniff pattern and thereby contributes to the vividness of the imagery.

Also, our results fit nicely in the comparison Blackwell (1995) makes with the Stroopeffect. In her experiment, visual cues seemed to distract participants from making correct decisions about the odor. In the present experiment, the visual stimuli seemed to distract participants from using the correct ‘sniffing pattern’, at least for the volume that is being inhaled. If, as stated above, mental schemes are activated because of expectations about the odor which lead to sniffing patterns that are related to the odor, it is quite plausible that these patterns are hard to overrule.

Although the picture-odor pairs were trained, as to induce expectations about the odor a participant would perceive, this was only done for the pleasant and unpleasant odors. The neutral visual and olfactory stimulus –clean air and a grey screen respectively- were not presented to the participant before the experiment started, nor were they informed about the presence of these stimuli. The fact that this may have influenced the results can not entirely be excluded. In future research, training of neutral stimuli should be a topic of consideration.

In summary, the present study demonstrates the effect that visual information (pictures) has an effect on the way people sample odors, especially for the total volume of air that is being inhaled when sniffing an odor. This work speculates that specific sniffing patterns could underpin the differences in sniff characteristics that have been found. This may shed a different light on the way odors are being sampled in human olfaction, which in turn could help to understand individual differences in reactions to chemicals. For example, expectations may alter the perception of odors; when expecting an odor to be dangerous, one may use a different sniff pattern which in turn is speculated to influence hedonic characteristics of the odor. As Dalton (1997) already described in her study, cognitive expectations about a chemical can affect how individuals respond to it. In line with this and the present study, it could be of interest to investigate the link between sniffing patterns and health symptoms from odor exposure. This research could also be of relevance for the understanding food related disorders. Raudenbusch et al. (1998) report that differences in sniffing behavior may contribute to differences in odor ratings made by neophobics and neophilics (people who approach new foods). Questions that follow from the abovementioned examples are for instance: How is the odor perceived when the sniff is manipulated? Does sniff training (e.g. learning to use an appropriate sniff pattern for certain odors) influence hedonic characteristics of an odor, and in turn reduces health symptoms?

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