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# Sequential Unfolding of Novelty and Pleasantness Appraisals of Odors: Evidence From Facial Electromyography and Autonomic Reactions

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We investigated the effects of odors on appraisal processes and consequent emotional responses. The main goal was to test whether an odor is detected as novel or familiar before it is evaluated as pleasant or unpleasant. Participants performed a recognition task in which they were presented with pairs of unpleasant or pleasant odors (sample and target odors). Within a pair, the sample and target were either identical or different to assess participants' novelty detection; unpleasant and pleasant target odors were contrasted to examine participants' appraisal of intrinsic pleasantness. We measured facial expressions using electromyography and physiological reactions using electrocardiogram and electrodermal activity in response to odors. The earliest effects on facial muscles and heart rate occurred in response to novelty detection. Later effects on facial muscles and heart rate were related to pleasantness evaluation. This study is the first to demonstrate the existence of a sequence of appraisal checks for odors eliciting emotional reaction.

*Keywords:* emotion, olfaction, appraisal theory, novelty, pleasantness

The most frequently quoted example taken from the literature to illustrate the privileged link between olfaction, memory, and emotion is referred to now as the *Proust phenomenon.* In *Swann's Way* (Proust, 1919/1922), the smell of a Madeleine biscuit dunked in tea brought the author back to his childhood, sparking off a vivid emotional experience:

> I raised to my lips a spoonful of the tea in which I had soaked a morsel of the cake. No sooner had the warm liquid, and the crumbs with it, touched my palate than a shudder ran through my whole body, and I stopped, intent upon the extraordinary changes that were taking place. An exquisite pleasure had invaded my senses, but individual, detached, with no suggestion of its origin. (p. 28)

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Although the powerful effect of odor as an elicitor of emotions and emotional memory is well established, there has been so far little concern about the underlying mechanisms. Most studies on olfaction and emotion relations embrace one of two theories: discrete emotion or dimensional. Discrete emotion theories postulate the existence of a small number of so-called basic emotions characterized by emotion-specific response patterns (Ekman, 1984; Izard, 1993; Tomkins, 1984). Dimensional theories, on the other hand, reduce emotions to positions in a two-dimensional valence by arousal space or a three-dimensional space that includes potency (e.g., Lang, Greenwald, Bradley, & Hamm, 1993; Russell, 1980; Wundt, 1909). However, neither model is able to provide explanations nor predictions for some of the central features of olfaction-induced emotion.

Indeed, discrete emotion theories focus on response patterning (e.g., Alaoui-Ismaili, Robin, Rada, Dittmar, & Vernet-Maury, 1997; Alaoui-Ismaili, Vernet-Maury, Dittmar, Delhomme, & Chanel, 1997; Collet, Vernet-Maury, Delhomme, & Dittmar, 1997; Robin, Alaoui-Ismaili, Dittmar, & Vernet-Maury, 1998, 1999; Vernet-Maury, Alaoui-Ismaili, Dittmar, Delhomme, & Chanel, 1999), but rarely explore the causal mechanisms underlying differences in emotion elicitation (often implying schema-driven response selection by emotion-specific neuromotor programs). Odor stimuli produce a rich set of highly differentiated response patterns and feeling states (as indexed by physiological and motor response signatures, as well as by "thick" verbal descriptions). In many cases, these patterns and states do not match basic emotions categories such as anger, fear, sadness, or joy (Chrea et al., 2009). Similarly, research using dimensional models has allowed the recording of physiological differences associated with verbally

reported pleasantness and arousal produced by an odor (e.g., Bensafi et al., 2002a, 2002b) and the investigation of underlying brain structures associated with each dimension (Anderson et al., 2003). However, dimensional theorists make little attempt to present an explanatory framework to predict the occurrence of such responses in a consistent manner. Moreover, projecting the odor-elicited emotions onto a bidimensional grid of pleasantness and arousal loses most, if not all, of the important qualitative differences between the effects of different types of fragrances.

We suggest that other theoretical models of emotion, the componential appraisal models (see Ellsworth & Scherer, 2003, for an overview) may be more appropriate to explain and predict the processes underlying emotion elicitation through olfactory stimulation. To date, these models had never been used to investigate olfactory-elicited emotions. In contrast to traditional discrete emotion or dimensional theories, the componential appraisal theories provide a framework that can explain both the elicitation and the reaction patterning in a dynamic perspective. Moreover, they account for the extraordinary changeability and high degree of qualitative differentiation of emotional experience as well as individual differences in emotional reactions.

In the componential appraisal models framework, the term *emotion* is reserved for short periods of time during which functionally defined organismic subsystems are coupled or synchronized to produce an adaptive reaction to an event that is considered central to the individual's well-being. Those organismic subsystems or components are (a) the cognitive system responsible for appraisal of the situation, (b) the autonomic system in charge of system regulation, (c) the motor system responsible for communication of reaction and behavioral intention, (d) the motivational system responsible for preparation and direction of action, and (e) the monitor system in charge of subjective feeling. However, how does the emotion process get started and become differentiated? The basic premise of componential appraisal theories is that the elicitation and the differentiation of emotion are determined by appraisals, the continuous, recursive evaluations of events. Those appraisals can occur on different levels of information processing, that is, sensory motor, schematic, and conceptual representational (see Sander, Grandjean, & Scherer, 2005, for a discussion on this point). Theorists differ somewhat on the appraisals they believe to be most important but as highlighted by Ellsworth and Scherer (2003): "the similarities among them are more striking than the differences" (p. 573). In this article, we mainly focus on the Component Process Model (CPM; Ellsworth & Scherer, 2003; Scherer, 1984, 2001). According to the CPM, the evaluations are organized into major types or classes of information that an organism needs to process to adaptively react to a salient event: (a) How relevant is this event for me? Does it directly affect me or my social reference group? (relevance); (b) What are the implications or consequences of this event and how do these affect my well-being and my immediate or long-term goals? (implications); (c) How well can I cope with or adjust to these consequences? (coping potential); (d) What is the significance of this event with respect to my self-concept and to social norms and values (normative significance). These major classes of appraisals are themselves organized more finely in subevaluations or subchecks. For instance, the relevance detection includes the novelty detection and the intrinsic pleasantness evaluation as subchecks, the implication evaluation including, among other subevaluations, the causal attribution and the goal conduciveness checks (see Sander et al., 2005, for further details).

Whereas it is not the case for all the appraisal theories (e.g., Smith & Lazarus, 1990), the CPM claims that this sequence of appraisal processes is fixed (Scherer, 1984, 2001; see also Sander et al., 2005, for a discussion on this point). Indeed, another basic tenet of the theory is that the result of each consecutive check will differentially and cumulatively affect the state of all other subsystems. Moments occur when the evidence concerning a particular appraisal check is sufficiently strong to elicit efferent effects on the other components. The overall patterns of emotional experience, labeled in social communication by terms such as *anger*, *fear*, or *joy*, result from sequential accumulation of the appraisal-driven local effects.

Theorists in the appraisal model tradition have started to predict the specific physiological, expressive, and motivational changes expected to occur as a consequence of specific appraisal results (e.g., Scherer, 2001; Scherer & Ellgring, 2007). Several studies (e.g., Aue, Flykt, & Scherer, 2007; Lanctôt & Hess, 2007; van Reekum et al., 2004) have used this predictive aspect of the model to provide evidence that physiological and facial responses of an emotional event could result from sequential evaluations that mediate expressive, autonomic, and somatic nervous systems to deliver immediate local adaptations. For instance, Aue and collaborators presented participants with pictures that displayed biological and cultural threat or neutral stimuli (stimulus relevance manipulation) and superimposed symbols signaling monetary gains or losses (goal conduciveness manipulation). Results showed muscle activity over the brow and cheek regions, indicating that relevance appraisal occurred significantly earlier than facial muscle activity for goal conduciveness appraisal. Previous electroencephalographic (EEG) studies using visual stimuli have shown that systematically manipulated novelty, intrinsic pleasantness, goal relevance, and goal conduciveness appraisals evoke EEG pattern modifications in brain electrical topographic maps and in different frequency bands occurring in the predicted sequence (Grandjean, & Scherer, 2008). This demonstration of sequential processing performed in the visual modality has never been done in the olfactory modality.

The CPM claims that (a) the outcome of each sequential evaluation changes the state of all other subsystems, and (b) the changes produced by the result of a preceding evaluation are modified by a consequent evaluation. Let us consider relevance detection. Organisms constantly scan their external and internal environment for the occurrence of events (or the lack of expected events) requiring deployment of attention, further information processing, and possibly adaptive reaction. In relevance detection, a first subevaluation is related to novelty detection in that any change in the ongoing flow of processed stimuli could require attention and demand further processing (novelty evaluation). In a second check, the organism evaluates, with the help of genetically fixed schemata or over learned associations, whether a stimulus event is likely to result in pleasure or pain (intrinsic pleasantness evaluation)[1]. Note that novelty and intrinsic pleasantness constitute two of those appraisal dimensions that are common to the majority of the componential appraisal theories (e.g.,

[1] We differentiate valence from intrinsic pleasantness because valence often refers to the pleasantness or unpleasantness of a stimulus itself, regardless of the current goals and concerns of a person. To distinguish valence as such from goal/concern-related valence, Scherer (1984) introduced the appraisal dimension of intrinsic pleasantness.

Ellsworth & Scherer, 2003). What is more specific with the CPM is the sequence assumption (see Sander et al., 2005, for a discussion on this point).

The prediction from the model is that the detection of a novel, unexpected odor by the novelty check will produce (a) an orienting response in the support system (e.g., heart rate decrease, skin conductance increase), (b) postural changes in the motivation system (focusing the sensory reception areas toward the novel stimulus), (c) changes in goal priority assignment in the executive subsystem (attempting to deal with a potential emergency), and (d) alertness and attention changes in the monitor subsystem. When, milliseconds later, the next intrinsic pleasantness check reaches sufficient closure to determine that the novel odor is pleasant or unpleasant, the efferent effects of this result will again affect the state of all other subsystems and thus modify the changes that have already been produced by the preliminary closure of the novelty check. For example, an unpleasant evaluation might produce the following changes: (a) defense response in the support system (e.g., heart rate increase), (b) avoidance tendency in the executive subsystem, (c) motor behavior that turns the body away from the unpleasant stimulation (thus reducing intake of stimulation in the action system), and (d) negative subjective feeling in the monitor system.

The main goal of this study is to test those predictions. In particular, was Proust right when he stated that as soon as he put the petite Madeleine into his mouth, he first shuddered and then a pleasure invaded him, experiencing first the physiological outcomes of novelty detection, and then those associated with intrinsic pleasantness evaluation? More precisely, we would like to test whether, during emotion elicitation, the organism detects that an odor is novel in the ongoing stream of information (novelty detection) before it categorizes it as pleasant or unpleasant (intrinsic pleasantness evaluation). In the present study, novelty was operationalized as contextual, meaning that the participants smelled a novel odor for the first time in the experimental setting (and not necessarily for the first time in their lives). This experimental setting, from this point of view, was closed to the usual oddball paradigm used to manipulate novelty in a large number of studies in the visual or auditory modalities (e.g., Delplanque, Silvert, Hot, & Sequeira, 2005). Our main predictions were that first, modifications of the organismic subsystems would be elicited by novelty detection, and that later, other modifications would be elicited by intrinsic pleasantness evaluation.

To test this sequential assumption, we needed to measure the variations associated with both novelty detection and pleasantness on different organismic subsystems. For the motor system component that is responsible for communication of reaction and behavioral intention, several studies demonstrate the sensibility of facial electromyography (EMG) recordings to provide empirical support for the sequential nature of the appraisal process (Aue et al., 2007; Kaiser & Wehrle, 2001; Lanctôt & Hess, 2007; Smith & Scott, 1997; van Reekum et al., 2004). For instance, Lanctôt and Hess demonstrated that facial reactions to intrinsic pleasantness manipulation were observed earlier than facial reactions to goal conduciveness manipulation. Moreover, facial muscles responded differentially, as a function of both the pleasantness of the odor and the novelty of a situation. Indeed, the activity over the muscle regions responsible for frowning (corrugator supercilii) and smiling (zygomaticus major) appeared to be reliable correlates of the level of pleasantness (Cacioppo, Petty, Losch, & Kim, 1986; Lang et al., 1993: Larsen, Norris, & Cacioppo, 2003). More particularly, the corrugator activity is known to be strongest when the odorant smelled is judged unpleasant than when it is judged pleasant (Armstrong, Hutchinson, Laing, & Jinks, 2007; Bensafi et al., 2002c; Soussignan, Ehrlé, Henry, Schaal, & Bakchine, 2005). Concerning the investigation of novelty processing, the recent literature relative to mechanisms underlying facial expressions of modal emotions (e.g., Scherer & Ellgring, 2007) and using the Facial Action Coding system (Ekman & Friesen, 1978) indicates two particular action units (AU1 + 2) that would occur in situation for which appraisal of novelty is particularly salient (e.g., panic fear, anxiety). Those two action units are activated when the brows are raised, and the electromyographical activity of such a region could be obtained by recording the frontalis muscle (pars medialis and lateralis; Rosenberg, 2005).

We were also interested in the autonomic component in charge of system regulation. More particularly, heart rate variations seem to be a relevant physiological indicator of pleasantness because several studies have reported that heart rate decreased as odor became more pleasant (Alaoui-Ismaili, Robin, et al., 1997, Alaoui-Ismaili, Vernet-Maury, et al., 1997; Bensafi et al., 2002a, 2002b). Moreover, numerous studies (e.g., Graham & Clifton, 1966; Turpin, Schaefer, & Boucsein, 1999; Turpin & Siddle, 1983; Vila et al., 2007) revealed that the heart is particularly sensitive to novelty as a component of the orienting response and decelerates in response to a novel event.

To test the precedence of the effects of novelty detection over intrinsic pleasantness evaluation, we presented participants with unpleasant and pleasant odorants that were either novel or not. We used facial EMG, electrocardiography, and electrodermal methods to assess the sequential unfolding of the effects of different appraisal criteria at both the motor expression and the physiological levels. In particular, in participants' response to the odors, we expected to observe earlier variations in facial muscle activity known to be related to novelty detection (M. frontalis) than in that known to be related to intrinsic pleasantness (M. corrugator supercilii and M. zygomaticus major). Concerning electrodermal activity, we expected novel odors to elicit the strongest electrodermal responses, reflecting the orienting response on the organism (e.g., Barry & Furedy, 1993). In addition, we expected to observe the earliest modification on heart rate (heart rate decrease) in relation to novelty detection, also as a manifestation of an orienting response. The later modifications were also expected to be related to the intrinsic evaluation of the odor, showing a later increase in heart rate with unpleasantness.

## Method

### *Participants*

Eighteen (9 female) right-handed undergraduate psychology students (*M* age 27.1 ± 6.2 years) from the University of Geneva were recruited via ads posted in a university building. They were paid 50 Swiss francs for their participation. Before starting the experiment, participants completed a consent form. All declared that they had no olfactory deficits.

### *Odorant Conditioning and Selection*

Odorants were injected into the tampon of cylindric felt-tip pens (14 cm long, inner diameter 1.3 cm). The use of these highly practical devices (provided by Burghart, Germany) avoids any contamination of the environment. Thirty-two pairs of odorants were selected on the basis of a previous study conducted on 66 participants who were asked to evaluate 51 odorants in terms of subjective intensity, pleasantness, and familiarity (Delplanque et al., 2008). These 51 odorants (Firmenich, SA, Geneva, Switzerland) had been selected on the basis of previous evaluations and analyses made in the company's sensory analyses department. The odorants represent a wide spectrum of pleasant and unpleasant odors that included several families, from fruity (i.e., lime, fig, tutti fruitti), to floral (i.e., lavender, geraniol), to animal (i.e., body odor, leather). From this previous study, 16 pairs of unpleasant (U) and 16 pairs of pleasant (P) odorants were built. For 8 of the pairs in each group of 16, the two odorants in each pair were different from one another; for the other 8 pairs, the two odorants in each pair were identical[2] to one another.

### *Experimental Procedures*

On the basis of the procedure described by Hudry, Perrin, Ryvlin, Mauguiere, and Royet (2003), we presented the 32 pairs of odorants in successive trials. A trial consisted of a sample odorant (encoding condition) and a target odorant (retrieval condition). In 16 trials, the sample odorant matched the target odorant (identical odorants) and in the other 16 trials, the sample odorant mismatched the target odorant (different odorants). We presented the trials in random order for each participant. The interval between a sample odorant and a target odorant was 30 s to prevent sensory adaptation (Jehl, Royet, & Holley, 1994; Lawless, Glatter, & Hohn, 1991). An experimenter seated near the participant delivered each stimulation with the odor pen about 1 cm below both the participant's nostrils for 2 s. Before testing, participants were instructed on how to smell the odorants to minimize the intra- and interparticipant breathing pattern variability, a procedure that has been described in other studies (Jung et al., 2006). When the participants saw the signals presented on a computer screen in front of them, they were instructed to (a) breathe out deeply through the mouth; (b) wait for the request to inhale (a word presented on a screen in front of the participant); (c) breathe in evenly with the felt-tip pen containing the odorant under the two nostrils (in the training session, the felt-tip pen did not contain any odorant); (d) rest and relax for 15 s without moving; and (e) rate three subjective scales (described below) and wait for the signal to proceed to the next trial. After completing each trial (one pair of odorants), the participants wrote whether the target odor was identical to or different from the sample odor.

### *Subjective Ratings*

After each odorant presentation, participants judged intensity, pleasantness, and familiarity by rating the odors on three continuous scales. Participants drew a vertical line on paper with a black marker across a 10-cm horizontal line. They were asked to judge the subjective intensity of the odor from *not perceived* (left of the scale = 0 cm) to *medium* (middle of the scale = 5 cm) to *very strong* (right of the scale = 10 cm). Participants rated pleasantness from *very unpleasant* (left) to *neutral* (middle) to *very pleasant* (right), and familiarity from *not familiar at all* (left) to *very familiar* (right). They were also informed that they could use all of the intermediate positions.

### *Apparatus and Physiological Recordings*

Physiological signals were assessed with the TEL 100 Remote Monitoring System of Biopac Systems (Santa Barbara, CA) with separate settings for the electrocardiogram, electrodermal activity, and respiratory activities. Signals were transferred from the experimental room to the MP100 Acquisition Unit (16 bit A/D conversion) in an adjacent room and stored on computer hard disk (sampling rate 500 Hz). Respiratory activity was assessed by placing on the participant two respiration belts that measured abdominal and thoracic expansion and contraction. Electrodermal activity was recorded (high-pass filter: 0.025 Hz) by the constant-voltage method (0.5 V). Beckman Ag–AgCl electrodes (8-mm diameter active area) filled with a skin conductance paste (Biopac) were attached to the palmar side of the middle phalanges of the second and third fingers of the participants' nondominant hand. Heart rate was assessed by fixing Biopac pregelled disposable electrodes under the participants' left and right wrists. A third electrode was placed on the left ankle. The signal was amplified by 1,000 and low-pass filtered (30 Hz). Electrocardiographic R waves were detected offline, and intervals between heartbeats were converted into heart rate, expressed in beats per minute (BPM).[3] Surface EMG was collected, digitized, and stored (bandwidth 0.1 to 417 Hz, sample rate: 2,048 Hz) with a BIOSEMI Active-Two amplifier system (BioSemi Biomedical Instrumentation, Amsterdam, the Netherlands). Six active electrodes placed over the right frontalis, corrugator, and zygomaticus regions of the face, corresponding to three distinct bipolar montages of interest (Fridlund & Cacioppo, 1986). Two additional electrodes placed above the inion (the common mode sense [CMS] active electrode and the driven right leg [DRL] passive electrode) were used as recording reference and ground electrodes (see http://www.biosemi/faq/cms&drl.htm, for more information). Conventional bipolar montages were then calculated from electrode pairs for each muscle by subtracting the activity of one electrode placed over the muscle to

[2] Unpleasant different pairs: dynascone/octamile, famboisone/octanol, isobutylquinoleine/rancid butter, diacetyl/melonal, sclarymol/ghee, isovaleric acid/skunk, aladinate/yoghourt, and body odor/isobutyric acid. Unpleasant identical odorants: carbinol, landes wood, paracresol, caproic acid, leather, sulfox, durian, and beer. Pleasant different pairs: neroli/linalol, cassis bud/green tea, methyl-salicylate/honey, magniolia grandifolia/classical body lotion fragrance, basil/cake, classical shampoo fragrance/tiare, lavender/classical detergent fragrance, and tutti fruiti/classical soap fragrance. Pleasant identical odorants: geraniol, lime, fig, amyl acetate, pineapple, lilac, bornyl acetate, and peach.

[3] Heart rate per time unit or the interbeat time interval per beat are the only measures that correctly estimate common parameters, such as the mean cardiac activity because they yield an unbiased mean of the total cardiac activity on the basis of averages of samples of this activity (see Graham, 1978a, 1978b, for a thorough examination of this point). Because the other physiological measures were expressed as a function of time, we chose to represent and analyze heart activity variations in heart rate per time.

the activity of the other electrode nearby in Brain Vision Analyzer software (Brain Products, Gilching, Germany). Signals were then filtered with a 20 to 400 Hz band-pass digital filter, rectified and low-passed filtered below 40 Hz.

### Data Analyses

*Behavioral data analysis.* We assessed recognition memory performance using parameters issuing from signal detection theory (Banks, 1970; Lockhart & Murdock, 1970). Four variables were considered as a function of the experimental condition (identical or different pairs) and the participant's behavioral response (identical or different; see Jehl et al., 1994). If the two odorants of a pair were identical and declared so by a participant, a hit was scored. If the two odorants were different but written as identical by the participant, a false alarm was recorded. From hit and false-alarm scores, we then calculated four parameters: hit rate (HR), false-alarm rate (FR), discrimination measurement (d'L), and response bias (CL). Corwin (1989) previously described these calculations as follows:

$$\mathrm{HR} = (\mathrm{hits} + 0.5)/(N1 + 1);$$

$$\mathrm{FR} = (\mathrm{false\ alarms} + 0.5)/(N2 + 1);$$

$$\mathrm{d'L} = \ln[\mathrm{HR}(1 - \mathrm{FR})/\mathrm{FR}(1 - \mathrm{HR})];$$

$$\mathrm{CL} = 0.5\{\ln[(1 - \mathrm{FR})(1 - \mathrm{HR})]/(\mathrm{HR} \times \mathrm{FR})\};$$

where $N1$ and $N2$ represent the number of match trials and no match trials, respectively.

To analyze recognition scores, we computed the mean scores obtained for hit rate, false-alarm rate, discrimination measurement, and bias response as a function of the pleasantness of the odor (unpleasant vs. pleasant).

*Respiratory parameter.* The voltage amplitude of the inhalation phase during the odorant presentation was reported and constitutes the main respiratory control.

*Electrodermal activity.* Specific skin conductance responses (SCRs) to odors were measured in microSiemens and analyzed offline. They were scored as changes in conductance starting in the 1- to 4-s interval after the beginning of the inhalation (Dawson, Schell, & Filion, 1990). SCRs were square root transformed to normalize the data (Edelberg, 1972).

*Facial muscle activity.* EMG amplitude during the 1 s before odorant presentation served as baseline. To allow us to examine the temporal profiles of facial EMG for 1 s after the inhalation of different odors, we expressed mean EMG amplitudes during subsequent 100-ms time intervals as a percentage of the mean amplitude of the baseline. Percentage scores were introduced to standardize the widely differing absolute EMG amplitudes of individual participants and thus enable comparison between individuals and groups (e.g., de Wied, van Boxtel, Zaalberg, Goudena, & Matthys, 2006).

*Heart rate.* The mean heart rate during the 10 s before odorant presentation served as baseline. To allow us to examine the temporal profiles of cardiac activity after the presentation of the odorants, we averaged the heart rate values within successive 200-ms periods, leading to 50 heart rate scores during the 10 s following stimulus presentation. Then, we expressed those 50 heart scores as a percentage of the BPM of the baseline. Percentage scores were introduced to standardize the differing absolute BPM variations of individual participants and thus to enable comparison between individuals and groups.

*Statistical analyses.* We investigated novelty detection by contrasting novel (16) and repeated (16) target odors, whereas we examined pleasantness by contrasting pleasant (16) and unpleasant (16) target odors. We computed a repeated measures analysis of variance (ANOVA; Statistica Version 7.0) for the 2 (novelty) $\times$ 2 (pleasantness) within-subjects design to analyze subjective ratings and memory performances. For variables that were assumed to capture the sequence of appraisals (heart rate and EMG), we introduced time as a multiple dependant variable into the repeated measures multivariate analysis of variance (MANOVA) and tested the significance of the differences between experimental conditions for each time window, using univariate tests (planned comparisons). Because the results reported here are related to the investigation of the sequential nature of appraisals (earlier modifications for novelty, later for pleasantness), we did not correct for alpha error, given that all contrasts were planned. Also, we did not test all possible comparisons, but only those with a direct bearing on the main hypotheses.

## Results

### Subjective Ratings

The analyses performed on intensity ratings revealed an interaction effect between novelty and pleasantness, $F(1, 17) = 21.22$, $p < .001$. Paired $t$ test analyses revealed that the unpleasant and novel odors were judged as more intense, followed by the pleasant odors (novel or repeated), and the unpleasant repeated odors (see Figure 1).

The analyses performed on the pleasantness ratings revealed a main effect of pleasantness, $F(1, 17) = 169$, $p < .001$, accounting for the fact that unpleasant a priori selection was judged less pleasant than the pleasant a priori selection. Moreover, a main effect of novelty, $F(1, 17) = 5.16$, $p < .05$; also reached significance, with the repeated odors judged as more pleasant than the novel odors. Finally, a main effect of novelty, $F(1, 17) = 9.28$, $p < .01$; and a main effect of pleasantness, $F(1, 17) = 39.94$, $p < .001$; were observed on familiarity ratings, accounting for, respectively,

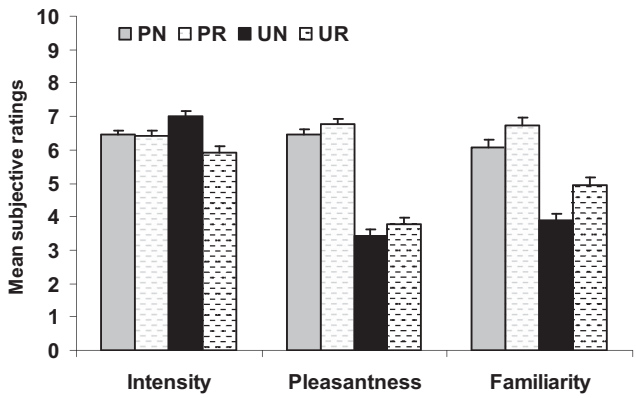


*Figure 1.* Mean subjective ratings (with *SEM* bars) of the target odors. P = pleasant; U = unpleasant; N = novel; R = repeated.

an increase in the familiarity when the odors are repeated and higher values of familiarity for the pleasant odors than for the unpleasant odors. One can wonder whether the fact that malodors are judged less familiar than pleasant odors could be a confound regarding the novelty and pleasantness appraisals. According to the prediction of the CPM, the subjective familiarity and pleasantness of the odor are related to different appraisals, the former being associated with novelty evaluation whereas the subjective pleasantness being associated with pleasantness appraisal. Thus, one would expect the familiarity of the odors to particularly influence the novelty check rather than the pleasantness check. Moreover, because novel as well as repeated odor categories contained both pleasant/familiar and unpleasant/less familiar odors, it is very unlikely that the familiarity could explain the novelty effects we observed. In sum, these results confirmed the existence of two groups of pleasant and unpleasant odors that could be contrasted to investigate the differences in physiological activation associated with pleasantness of odor.

### *Memory Performances*

The two-way ANOVAs performed on mean scores for hit rate (pleasant odors = 0.83 ± 0.09; unpleasant = 0.86 ± 0.14), false-alarm rate (pleasant odors = 0.16 ± 0.15; unpleasant odors = 0.21 ± 0.18), discrimination measure (pleasant odors = 3.68 ± 1.35; unpleasant odors = 3.72 ± 1.28), and response bias (pleasant odors = −13.81 ± 9.2; unpleasant odors = −12.2 ± 9) did not reveal any significant effect of pleasantness, *F*s(1,17) = 1.34, 1.49, 0.01, and 0.3; *ns*, respectively. These results suggest that recognizing that the odors within a pair were similar or different was equally easy whatever their pleasantness might be.

### *Electrodermal Activity*

Unpleasant odors elicited stronger SCRs than did pleasant odors, $F(1, 17) = 5.6$, $p < .05$. Moreover, novel target odors elicited stronger SCRs than did repeated odors, $F(1, 17) = 4.95$, $p = .04$. Thus, the pleasantness dimension of the odors induced a clear physiological distinction, replicating the results of previous studies (e.g., Soussignan et al., 2005). Moreover, the greater amplitudes of SCRs associated with novel target odors constitute electrophysiological evidence of novelty detection.

### *Facial Muscle Activity*

Because we are specifically interested in the examination of hypotheses concerning novelty and pleasantness appraisals, the following results concern only the target odors.

*Activity over the frontalis region.* To test the timing of muscle activity for the different experimental conditions, we defined windows of 11 × 100 ms, including 100 ms of baseline, preceding the odorant presentations. We first performed a repeated measures MANOVA with the Novelty factor (two levels) on the percentage of muscular activity obtained for the 16 novel and 16 repeated target odors. The planned contrast for the first time window (0 to 100 ms) showed a significant effect of Novelty, $F(1, 17) = 10.86$, $p < .01$; with an increase in the percentage of muscular activity over this region in response to novel odors as compared to already smelled ones (Figure 2A). Then, we performed a repeated measures MANOVA with the Pleasantness factor (two levels) to compare the 16 unpleasant with the 16 pleasant target odors. The planned contrast reached significance for the fifth (400 to 500 ms) time period, $F(1, 17) = 11.21$, $p < .01$; with more percentage of muscular activity in response to unpleasant odors (Figure 2B).

*Activity over the corrugator region.* The planned contrast performed after a repeated measures MANOVA with the Novelty factor (two levels) on the percentage of muscular activity obtained for the 16 novel and 16 repeated target odors did not reach significance for any time windows. We performed a repeated measures MANOVA with the Pleasantness factor (two levels) to compare the 16 unpleasant with the 16 pleasant target odors. The planned contrast reach significance for the fifth (400 to 500 ms) time period, $F(1, 17) = 11.21$, $p < .01$; with more percentage of muscular activity in response to unpleasant odors (see Figure 3).

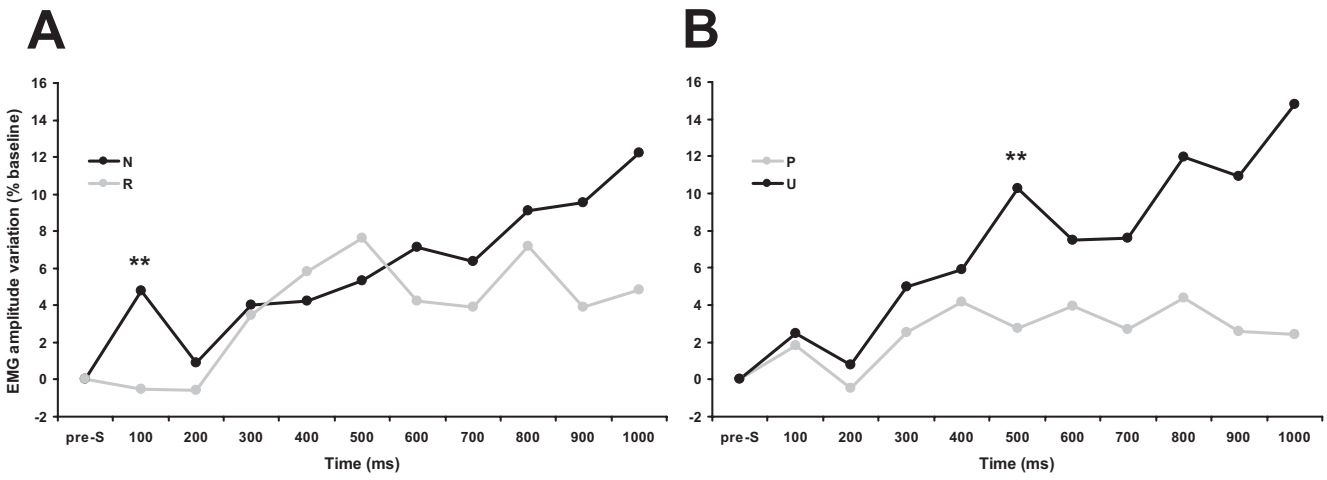


*Figure 2.* Mean electromyography (EMG) activity over the frontalis region for the different comparisons: (A) novel versus repeated target odors; (B) unpleasant versus pleasant odors. N = novel; R = repeated; U = unpleasant; P = pleasant; pre-S = prestimulus baseline. ** $p < .01$.

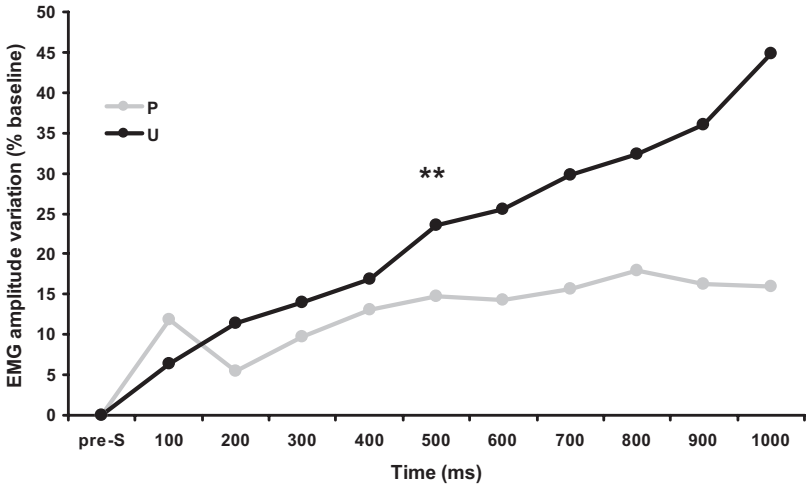


*Figure 3.* Mean electromyography (EMG) activity over the corrugator region for the different target odors. U = unpleasant; P = pleasant; pre-S = prestimulus baseline. ** $p < .01$.

Taken together, these results can be interpreted as evidence that novelty is processed earlier than pleasantness.

*Correlations between frontalis and corrugator activities.* By examining activities of both the frontalis and the corrugator muscles, one could conclude that they were both sensitive to pleasantness from 400 to 500 ms, with a more important activation in response to malodors. However, we cannot exclude the possibility that part of the activity observed on the frontalis muscle in response to unpleasant odors could be the result of diffusion of corrugator electrical activity or vice versa (i.e., a cross-talk phenomenon). Indeed, for each temporal window, we performed correlation analyses to evaluate the extent to which the activities of the two muscles were related. Within the first second, the activity of the two muscles was significantly and positively correlated in response to unpleasant and pleasant odors (minimum $r$s = 0.49, 0.48; maximum $r$s = 0.73, 0.80; $p$s $< .05$, respectively), except for the first period (0 to 100 ms; $r = .43$ and $r = .46$; *ns*, for pleasant and unpleasant odors, respectively). The activities in response to repeated odors were positively correlated between the two muscles along the entire 1-s period (minimum $r = .49$, maximum $r = 84$; $p < .05$), whereas there was no correlation during the first two periods (0 to 200 ms) in response to novel odors ($r$s $< 0.44$; *ns*; for the rest of the period, minimum $r = .51$; maximum $r = .68$; $p$s $< .05$). Thus, we cannot conclude whether the pleasantness effects observed on the frontalis and the corrugator were specific to each muscle or resulted from the diffusion of activity from one muscle to the other. In contrast, the early and stronger activity observed on the frontalis in response to novel odors was not correlated with the activity of the corrugator and thus was specific to the frontalis.

*Activity over the zygomaticus region.* The planned contrast performed after a repeated measures MANOVA did not reach significance for any time windows either for the novelty investigation or the pleasantness investigation (see Figure 4).

## Heart Rate

Figure 5 presents heart rate variations as a function of target odor for the novelty and pleasantness investigations. The biphasic response consists of cardiac acceleration peaking at about 3 s followed by a decrease in heart rate, with a minimum reached at about 6 s after the onset of inspiration.

To investigate whether those two phases are sensitive to different odors, we analyzed the maximum positive variations for each participant in the 2- to 4-s window to examine cardiac acceleration and the maximum negative variation in the 5- to 8-s window to examine heart rate decrease. We performed a repeated measures MANOVA with the Novelty factor (two levels) on the percentage of muscular activity obtained for the 16 novel and 16 repeated target odors. The planned contrast for the acceleration phase showed a significant effect of Novelty, $F(1, 17) = 6.59$, $p < .05$; with an increase in the heart rate in response to repeated odors as compared to novel ones (Figure 6A). This effect was not observed for the deceleration phase $F(1, 17) = 0.9$, *ns*. Then, we performed a similar repeated measures MANOVA with the Pleasantness factor (two levels) to compare the 16 unpleasant and the 16 pleasant target odors. The planned contrast reached significance for the deceleration phase, $F(1, 17) = 6.73$, $p < .05$; with a weaker heart rate decrease in response to unpleasant odors (Figure 6B). This effect was not observed for the acceleration phase $F(1, 17) = 0.5$, *ns*. Thus, as for the muscular activity, the results of the cardiac activity can be interpreted as evidence that novelty is processed earlier than pleasantness.

## Respiratory Controls

The objective of this control analysis was to check whether the physiological differences observed between the different target odors was not related to the inhalation of the odors themselves (see Brownley, Hurwitz, & Schneiderman, 2000, for a review). The mean variations of the respiratory amplitude during the inhalation phase are represented in Figures 7A and Figure 7B for the abdominal and the thoracic belts, respectively.

To investigate whether the inhalation phase was sensitive to the different odors, we analyzed maximum positive variations and their latencies for each participant in a 1- to 4-s window. A significant Pleasantness × Novelty interaction, $F(1, 17) = 7.74$,

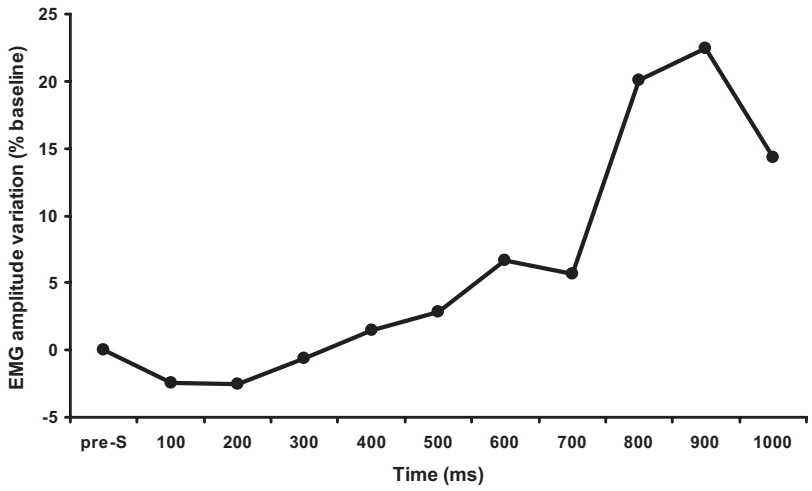


*Figure 4.* Mean electromyography (EMG) activity over the zygomaticus region for all of the target odors together.

$p < .05$, revealed that the abdominal respiratory amplitude was bigger for repeated pleasant odors than for all the other conditions. There was no difference in the maximum latencies, all $F(1, 17) < 4.3$, *ns*. The same procedure was applied to the thoracic belt measures and the analyses did not reveal any significant amplitude or latency difference between conditions, all $F(1, 17) < 0.28$ and $< 2.63$, *ns,* respectively.

Thus, despite the more pronounced abdominal respiratory amplitude in response to pleasant repeated odors, the procedure used in this study seems suitable for reducing the variability of respiratory activity. Moreover, it is improbable that the physiological effects reported in this study could be due to different respiratory patterns as a function of the odor.

Because phasic changes in respiration influence cardiac activity (see Brownley et al., 2000, for a review), one can wonder whether the early novelty effect observed on heart rate activity could be the result of the more pronounced abdominal inhalation phase observed for pleasant repeated odors. The existence of such a bias is highly improbable because the effect of novelty on the first phase of the cardiac response remains significant when adding the corresponding respiratory amplitudes as continuous predictor in the planned comparisons $F(1, 15) = 6.47$, $p < .05$. Moreover, the individual correlations between heart rate variations and respiratory amplitudes in response to each category of odors (unpleasant novel, unpleasant repeated, pleasant novel, and pleasant repeated odors) were nonsignificant ($-0.58 < r < .63$, *ns;* except for one participant, $r = .72$, $p < .05$).

## Discussion

For the first time in the olfactory modality, our data provide evidence for the hypothesis that the appraisal processes of novelty and intrinsic pleasantness are organized in a sequential

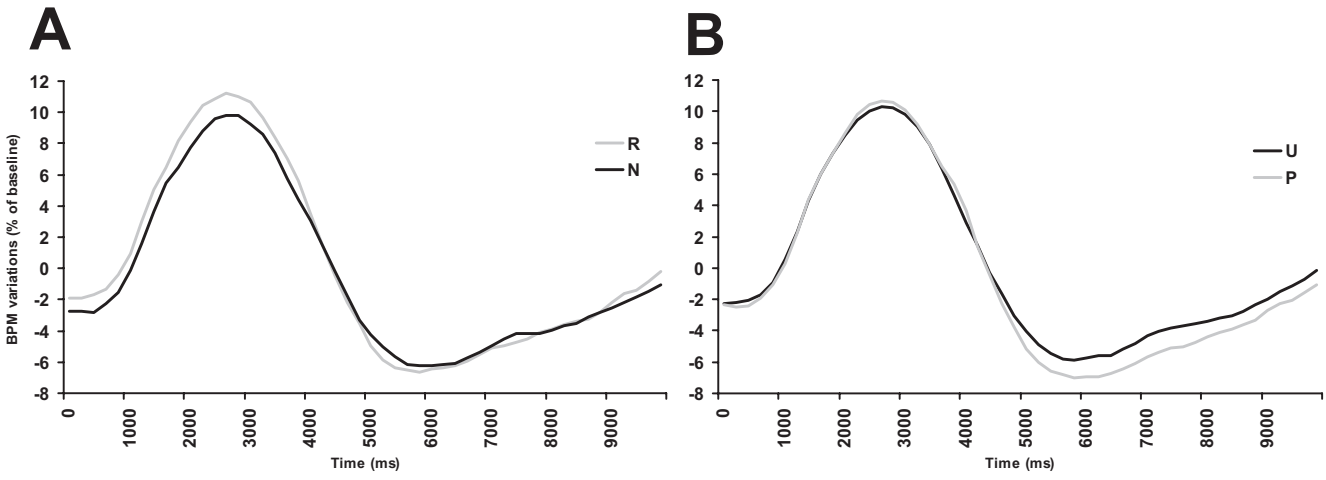


*Figure 5.* Mean heart rate variations for the different target odors: (A) novel versus repeated target odors; (B) unpleasant versus pleasant odors. BPM = beats per minute; R = repeated; N = novel; U = unpleasant; P = pleasant.

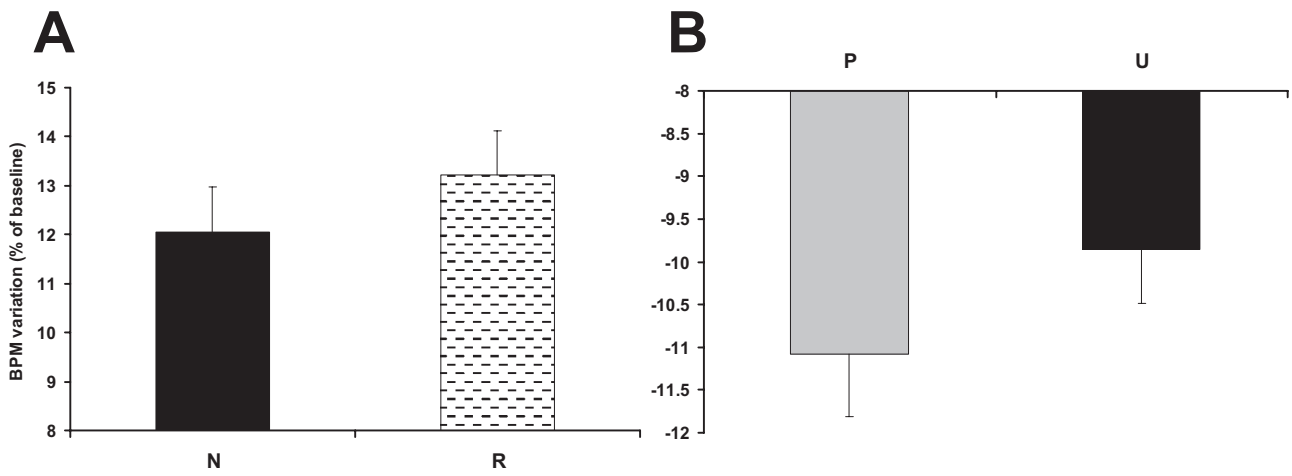


*Figure 6.* (A) Mean cardiac increase in the 2- to 4-s window as a function of novelty. (B) Mean cardiac decrease in the 5- to 8-s window as a function of pleasantness. BPM = beats per minute; N = novel; R = repeated; P = pleasant; U = unpleasant.

fashion. In particular, different appraisals have efferent effects on physiological responses at different points in time, as postulated by Scherer's (2001) CPM. An effect of stimulus novelty started with activity over the frontalis region, followed by an effect of pleasantness on activity over the corrugator and the frontalis regions. Furthermore, we found evidence for primacy of novelty processing over intrinsic pleasantness processing in heart rate activity, with novel odor processing being observed for heart rate increase just after stimulus onset, and intrinsic pleasantness processing being observed during the subsequent heart rate decrease. Thus, effects of the novelty relevance check preceded effects of the intrinsic pleasantness check. Therefore, these results support the notion that, the first appraisal processes and their efferent peripheral effects occur in sequential order (see also Grandjean & Scherer, 2008).

### *Novelty Detection Outcome on the Frontalis Muscle*

Concerning the facial expression component that is responsible for communication of reaction and behavioral intention, an effect of novelty started as early as 100 ms after odor presentation for activity over the frontalis region. Although the effect of novelty appraisal has already been reported for several facial action units (AU1 + 2; Scherer & Ellgring, 2007), this study constitutes the first electromyographical evidence of frontalis reactivity to novelty evaluation. The rapidity of this response may be explained by the conjunction of experimental factors and functional properties of facial muscles activities. Indeed, we positioned the onset of response at the beginning of the inspiration phase as recorded with respiratory belts. However, it is possible that the expansion of the thoracic cage, and

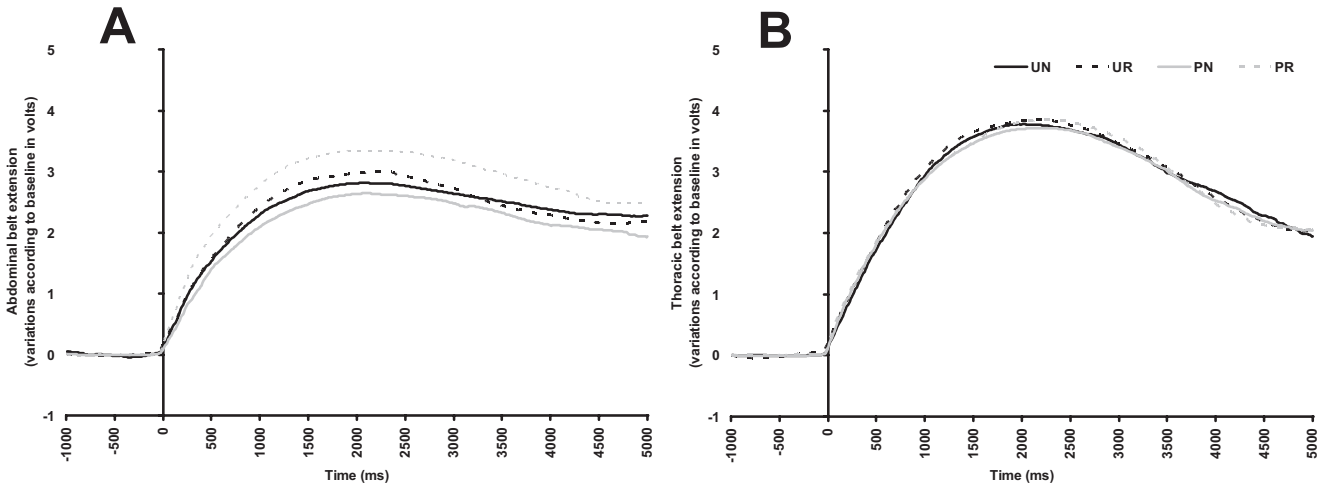


*Figure 7.* Mean abdominal (A) and thoracic (B) belt extension as a function of time for the different conditions. U = unpleasant; N = novel; R = repeated; P = pleasant.

consequently the entrance of the air charged with odor through the nostrils, began several dozens of milliseconds before the belts were sufficiently tightened to produce a readable increase in voltage amplitude in the signal. In other words, the perception and the evaluations of the odor may have begun slightly before the experimentally fixed onset of the response. This latency is, however, independent from the status of the odor delaying the timing of electrophysiological measures, and their sequential order remains unaffected. Thus, this methodological limitation cannot constitute a bias in the interpretation of our results.

The precocity of the response we observed is nevertheless a characteristic of the facial electromyographic responses. Indeed, in a recent review on rapid facial reactions to emotionally relevant stimuli, Thunberg (2007) reported that changes in facial muscle activity can occur within as little as 125 to 200 ms (Hatfield, Cacioppo, & Rapson, as cited in Thunberg, 2007). According to Thunberg, this early effect reflects a genetically preprogrammed and automatic capacity to evoke basic facial expressions. Our interpretation differs: we regard the rapidity of the contraction as being elicited by the appraisal process. Furthermore, previous EEG studies have shown an early novelty effect occurring before 100 ms after the onset of visual stimuli (Grandjean & Scherer, 2008). In our experiment, the early reactivity observed on the frontalis muscle reflects the very precocity of novelty appraisal, a process that could be considered to be genetically preprogrammed and automatic itself (see Grandjean, Sander, & Scherer, 2008; Grandjean & Scherer, 2008; Sander et al., 2005, for a review).

### *Pleasantness Evaluation Outcome on Facial Muscles*

The effect of pleasantness on activity over the corrugator regions reached significance after 500 ms. This result constitutes a replication of the recent results obtained in the visual modality during a video game paradigm (Lanctôt & Hess, 2007). Moreover, in the latter study, the effect of pleasantness appraisal on facial activity occurred in the same latency window as in our study (i.e., between 400 and 500 ms after the onset of stimulus). More generally, we observed a dissociation of unpleasant emotions (anger or fear) and pleasant emotions (happy) on corrugator activity 500 ms after perception of static (Dimberg & Petterson, 2000; Dimberg & Thunberg, 1998) or dynamic faces (Dimberg, Thunberg, & Elmehed, 2000), even when the contractions were unconscious (Achaibou, Pourtois, Schwartz, & Vuilleumier, 2008; Weyers, Muhlberger, Hefele, & Pauli, 2006). This last point constitutes evidence in favor of time consistency in appraisal processes across sensory modalities. Taken together with the observed activities of the frontalis and the corrugator, our results demonstrate that the effect of novelty clearly preceded those of pleasantness, supporting the notion that the appraisal process and its efferent expressive effects occur in sequential order.

We did not find any influence of intrinsic pleasantness on zygomaticus muscle activity, as one might have expected because our instructions required participants to breathe out deeply through the mouth, to block the respiration, and then to breathe in evenly with the nose, a procedure that is likely to constrain any emotion-induced contraction of the muscles in the cheek region.

### *Sequential Dynamic of Emotional Facial Expression*

From a functional point of view, our results argue in favor of a cumulative, dynamic construction of facial expressions of emotion. This mechanism seems highly adaptive from an evolutionary perspective. As is generally recognized, the expressive component of an emotional episode plays an important social role by communicating the emotion to others in the group (see Frank, 2004, for a review). This interpretation is mainly based on studies that use static facial displays, which place little emphasis on the dynamic nature of facial expression and on the increase in communication accuracy afforded by the dynamic unfolding of expression as driven by appraisal results. In particular, the CPM model postulates that individual elements of facial expression (i.e., the innervation of particular facial muscles) are determined by sequential appraisal results and occur in a dynamic, cumulative manner (e.g., Scherer & Ellgring, 2007). Because emotions also include the preparation of behaviors with potentially important consequences to others, it is particularly adaptive for the transmitter of the facial expression to communicate, in a dynamic manner, the outcome of the different appraisals as they unfold. This broadcast allows conspecifics to make correct inferences about the transmitter's evaluation of the situation and resulting mental state, allowing the observer to adopt the most appropriate attitude and behavior preparation (see also Sander, Grandjean, Kaiser, Wehrle, & Scherer, 2007).

At the individual level, facial expressions could act as functional adaptations for interactions with the physical environment (Susskind et al., 2008). Thus, the early contraction of the frontalis muscle, corresponding to raising the eyebrows and associated with opening the eyes, is related to the detection of a novel or unexpected stimulus and is associated with an orienting response, including increased alertness and attention (Darwin, 1872/1998).[4] Since this early explanation, the precise interpretation of the raise of the eyebrows remains largely unknown, some authors evoking an increase in vigilance and acuity (e.g., Scherer & Ellgring, 2007). In this framework, a very recent study showed that raising the eyebrows resulted in an increase of the size of the subjective visual field, potentially favoring the sensorial exposure (Susskind et al., 2008). After this novelty detection, we demonstrated a differential activity of the corrugator as a function of pleasantness. The activity of this

[4] As mentioned by Darwin (1872/1998) in the "elevation of the eyebrow" section of his famous book, the expression of emotions in man and animals:

> As surprise is excited by something unexpected or unknown, we naturally desire, when startled, to perceive the cause as quickly as possible; and we consequently open our eyes fully, so that the field of vision may be increased, and the eyeballs moved easily in any direction. But this hardly accounts for the eyebrows being so greatly raised as is the case, and for the wild staring of the open eyes. The explanation lies, I believe, in the impossibility of opening the eyes with great rapidity by merely raising the upper lids. To effect this the eyebrows must be lifted energetically. Any one who will try to open his eyes as quickly as possible before a mirror will find that he acts thus; and the energetic lifting up of the eyebrows opens the eyes so widely that they stare, the white being exposed all round the iris. (p. 280)

muscle is associated with action unit 4, often activated during an unpleasant emotional state (Scherer & Ellgring, 2007). When the stimulus is aversive or threatening, a defensive response repertoire linked to avoidance is activated. This activation could result in an opposing action tendency to close off the senses, that is, to reduce exposure of the eyes by lowering the eyebrows. In that sense, this action constitutes an attempt to reject the stimulus or to protect the individual from it (e.g., Susskind et al., 2008).

### *Sequential Outcomes of Novelty and Pleasantness Appraisals on Heart Rate*

Concerning the autonomic system component in charge of system regulation, we found evidence for temporal priority of stimulus novelty processing over pleasantness processing on cardiac activity, with novelty processing being observed about 2 to 4 s after stimulus onset, and pleasantness being observed only 5 s after odor presentation. Thus, effects of novelty clearly preceded those of pleasantness. Taken together, these results support the notion that the appraisal process and its efferent peripheral effects occur in sequential order.

The biphasic response we observed for heart rate (an increase followed by a decrease) was not specific to odor but was related to the respiratory pattern induced by our experimental setup. Indeed, we asked the participants to breathe out deeply through the mouth, to wait for the request to inhale (1 to 3 s), and to breathe in evenly, with the felt-tip pen containing the odorant under the two nostrils. During the experiment, we observed that participants had a tendency to amplify their inspiration amplitude although they were not requested to do so. It is well known that changes in respiration have a gating influence on cardiac activity via vagal efferents: During the inspiratory and expiratory phases, the heart rate increases and decreases, respectively (Brownley et al., 2000). Consequently, the biphasic response was clearly evoked by the instructions and not by the perception of the odor.

In contrast, the modulations of the two phases were clearly associated with the status of the smelled odors, the first phase being sensitive to novelty and the second phase to pleasantness. More precisely, the earliest influence we observed was a weaker cardiac acceleration (i.e., a relative deceleration) in response to novel odors as compared with odors that had already been presented. The later influence corresponded to a weaker deceleration (a relative acceleration) in response to unpleasant odors as compared with pleasant odors. Taken together, these two modulations fit the classical differentiation between orienting and defense reflexes that corresponded to a shift from cardiac deceleration to acceleration reasonably well (Graham & Clifton, 1966; Turpin & Siddle, 1983; Turpin et al., 1999; Vila et al., 2007). Thus, the fine-grained analysis and high-temporal resolution that we used allowed us to show that the detection of unexpected odors by the novelty check produces an orienting response noticeable in the support system by a heart rate decrease. Later, the intrinsic pleasantness check reaches sufficient closure to determine that the novel odor is unpleasant or pleasant. An unpleasant evaluation might produce a defense response in the support system (i.e., heart rate increase). Functionally speaking, the result of novelty detection is associated with focusing the organism's attention on the novel stimulus and potentially alerting the social environment to the event, whereas the unpleasantness evaluation that follows leads to defense reactions to avoid processing of unpleasant stimulation or to reject or expel noxious matter (Graham & Clifton, 1966; Turpin & Siddle, 1983; Turpin et al., 1999; Vila et al., 2007).

For the first time with respect to the olfactory modality, our results clearly support the notion that some appraisal processes are organized in a sequential fashion and that different appraisals have efferent effects on physiological responses at different points in time. More particularly, our data provide evidence that novelty detection precedes intrinsic pleasantness evaluation, supporting the prediction of the CPM (Scherer, 1984, 2001). In line with a growing number of investigators (Aue et al., 2007; Grandjean & Scherer; Kaiser & Wehrle, 2001; Lanctôt & Hess, 2007; Smith & Scott, 1997; van Reekum et al., 2004), we would like to underscore the utility of using the general approach subtended by the appraisal theories in general and the CPM in particular (i.e., manipulating appraisal outcomes experimentally and measuring their efferent effects over time). Future studies will aim at manipulating other specific individual appraisals in a given situation. As in the current study, the accumulation of efferent effects corresponding to these appraisals should determine the final physiological response pattern that is observed.

## References


Achaibou, A., Pourtois, G., Schwartz, S., & Vuilleumier, P. (2008). Simultaneous recording of EEG and facial muscle reactions during spontaneous emotional mimicry. *Neuropsychologia, 46,* 1104–1113.

Alaoui-Ismaili, O., Robin, O., Rada, H., Dittmar, A., & Vernet-Maury, E. (1997). Basic emotions evoked by odorants: Comparison between autonomic responses and self-evaluation. *Physiology and Behavior, 62,* 713–720.

Alaoui-Ismaili, O., Vernet-Maury, E., Dittmar, A., Delhomme, G., & Chanel, J. (1997). Odor hedonics: Connection with emotional response estimated by autonomic parameters. *Chemical Senses, 22,* 237–248.

Anderson, A. K., Christoff, K., Stappen, I., Panitz, D., Ghahremani, D. G., Glover, G., et al. (2003). Dissociated neural representations of intensity and valence in human olfaction. *Nature Neuroscience, 6,* 196–202.

Armstrong, J. E., Hutchinson, I., Laing, D. G., & Jinks, A. L. (2007). Facial electromyography: Responses of children to odor and taste stimuli. *Chemical Senses, 32,* 611–621.

Aue, T., Flykt, A., & Scherer, K. R. (2007). First evidence for differential and sequential efferent effects of goal relevance and goal conduciveness appraisal. *Biological Psychology, 74,* 347–357.

Banks, W. P. (1970). Signal detection theory and human memory. *Psychological Bulletin, 74,* 81–99.

Barry, R. J., & Furedy, J. J. (1993). Stimulus intensity and novelty interact in elicitation of the phasic electrodermal orienting response. *International Journal of Psychophysiology, 14,* 249–254.

Bensafi, M., Rouby, C., Farget, V., Bertrand, B., Vigouroux, M., & Holley, A. (2002a). Autonomic nervous system responses to odors: The role of pleasantness and arousal. *Chemical Senses, 27,* 703–709.

Bensafi, M., Rouby, C., Farget, V., Bertrand, B., Vigouroux, M., & Holley, A. (2002b). Influence of affective and cognitive judgments on autonomic parameters during inhalation of pleasant and unpleasant odors in humans. *Neuroscience Letters, 319,* 162–166.

Bensafi, M., Rouby, C., Farget, V., Bertrand, B., Vigouroux, M., & Holley, A. (2002c). Corrélats neurophysiologiques des états affectifs déclenchés par les odeurs chez l'homme [Psychophysiological correlates of affects in human olfaction]. *Neurophysiologie Clinique/Clinical Neurophysiology, 32,* 326–332.

Brownley, K. A., Hurwitz, B. E., & Schneiderman, N. (2000). Cardiovas-

cular psychophysiology: Function, methodology, and use in pathophysiological investigation. In J. T. Cacioppo, L. G. Tassinary, & G. G. Berntson (Eds.), *Handbook of psychophysiology* (pp. 224–264). New York: Cambridge University Press.

Cacioppo, J. T., Petty, R. E., Losch, M. E., & Kim, H. S. (1986). Electromyographic activity over facial muscle regions can differentiate the valence and intensity of affective reactions. *Journal of Personality and Social Psychology, 50,* 260–268.

Chrea, C., Grandjean, D., Delplanque, S., Cayeux, I., Le Calvé, B., Aymard, L., et al., (2009). Mapping the semantic space for the subjective experience of emotional responses to odors. *Chemical Senses, 34,* 49–62.

Collet, C., Vernet-Maury, E., Delhomme, G., & Dittmar, A. (1997). Autonomic nervous system response patterns specificity to basic emotions. *Journal of the Autonomic Nervous System, 62,* 45–57.

Corwin, J. (1989). Olfactory identification in hemodialysis: Acute and chronic effects on discrimination and response bias. *Neuropsychologia, 27,* 513–522.

Darwin, C. (1998). *The expression of the emotions in man and animals* (3rd ed.). New York: Oxford University Press. (Original work published 1872)

Dawson, M. E., Schell, A. M., & Filion, D. L. (1990). The electrodermal response system. In J. T. Cacioppo & L. G. Tassinary (Eds.), *Principles of psychophysiology: Physical, social and inferential elements* (pp. 295–324). Cambridge, England: Cambridge University Press.

Delplanque, S., Grandjean, D., Chrea, C., Aymard, L., Cayeux, I., Le Calvé, B., et al. (2008). Emotional processing of odors: Evidence for a non-linear relation between pleasantness and familiarity evaluations. *Chemical Senses, 33,* 469–479.

Delplanque, S., Silvert, L., Hot, P., & Sequeira, H. (2005). Event-related P3a and P3b in response to unpredictable emotional stimuli. *Biological Psychology, 68,* 107–120.

de Wied, M., van Boxtel, A., Zaalberg, R., Goudena, P. P., & Matthys, W. (2006). Facial EMG responses to dynamic emotional facial expressions in boys with disruptive behavior disorders. *Journal of Psychiatric Research, 40,* 112–121.

Dimberg, U., & Petterson, M. (2000). Facial reactions to happy and angry facial expressions: Evidence for right hemisphere dominance. *Psychophysiology, 37,* 693–696.

Dimberg, U., & Thunberg, M. (1998). Rapid facial reactions to emotional facial expressions. *Scandinavian Journal of Psychology, 39,* 39–45.

Dimberg, U., Thunberg, M., & Elmehed, K. (2000). Unconscious facial reactions to emotional facial expressions. *Psychological Science, 11,* 86–89.

Edelberg, R. (1972). Electrical activity of the skin: Its measurements and uses in psychophysiology. In N. S. Greenfield & R. A. Sternbach (Eds.), *Handbook of psychophysiology* (pp. 367–418). New York: Holt.

Ekman, P. (1984). Expression and the nature of emotion. In K. R. Scherer & P. Ekman (Eds.), *Approaches to emotion* (pp. 319–344). Hillsdale, NJ: Erlbaum.

Ekman, P., & Friesen, W. V. (1978). The Facial Action Coding System: A technique for the measurement of facial movement. Palo Alta, CA: Consulting Psychologists Press.

Ellsworth, P. C., & Scherer, K. R. (2003). Appraisal processes in emotion. In R. Davidson, K. R. Scherer, & H. H. Goldsmith (Eds.), *Handbook of affective sciences* (pp. 572–595). New York: Oxford University Press.

Frank, M. G. (2004). Facial expressions. In N. Eisenberg (Ed.), *International encyclopedia of the social and behavioral sciences* (pp. 5230–5234). Oxford, England: Elsevier.

Fridlund, A. J., & Cacioppo, J. T. (1986). Guidelines for human electromyographic research. *Psychophysiology, 23,* 567–589.

Graham, F. K. (1978a). Constraints on measuring heart rate and period sequentially through real and cardiac time. *Psychophysiology, 15,* 492–495.

Graham, F. K. (1978b). Normality of distributions and homogeneity of variance of heart rate and heart period samples. *Psychophysiology, 15,* 487–491.

Graham, F. K., & Clifton, P. K. (1966). Heart-rate change as a component of the orienting response. *Psychological Bulletin, 65,* 305–320.

Grandjean, D., Sander, D., & Scherer, K. R. (2008). Conscious emotional experience emerges as a function of multilevel, appraisal-driven response synchronization. *Consciousness and Cognition, 17,* 484–495.

Grandjean, D., & Scherer, K. R. (2008). Unpacking the cognitive architecture of emotion processes. *Emotion, 8,* 341–351.

Hudry, J., Perrin, F., Ryvlin, P., Mauguiere, F., & Royet, J. P. (2003). Olfactory short-term memory and related amygdala recordings in patients with temporal lobe epilepsy. *Brain: A Journal of Neurology, 126,* 1851–1863.

Izard, C. E. (1993). Four systems for emotion activation: Cognitive and noncognitive processes. *Psychological Review, 100,* 68–90.

Jehl, C., Royet, J. P., & Holley, A. (1994). Very short-term recognition memory for odors. *Perception and Psychophysic, 56,* 658–668.

Jung, J., Hudry, J., Ryvlin, P., Royet, J. P., Bertrand, O., & Lachaux, J. P. (2006). Functional significance of olfactory-induced oscillations in the human amygdala. *Cerebral Cortex, 16,* 1–8.

Kaiser, S., & Wehrle. T. (2001). Facial expressions as indicators of appraisal processes. In K. R. Scherer, A. Schorr, & T. Johnstone (Eds.), *Appraisal processes in emotion: Theory, methods, research* (pp. 285–300). New York: Oxford University Press.

Lanctôt, N., & Hess, U. (2007). The timing of appraisals. *Emotion, 7,* 207–212.

Lang, P. J., Greenwald, M. K., Bradley, M. M., & Hamm, A. O. (1993). Looking at pictures: Affective, facial, visceral, and behavioral reactions. *Psychophysiology, 30,* 261–273.

Larsen, J. T., Norris, C. J., & Cacioppo, J. T. (2003). Effects of positive and negative affect on electromyographic activity over zygomaticus major and corrugator supercilii. *Psychophysiology, 40,* 776–785.

Lawless, H. T., Glatter, S., & Hohn, C. (1991). Context-dependent changes in the perception of odor quality. *Chemical Senses, 16,* 349–360.

Lockhart, R. S., & Murdock, B. B. (1970). Memory and the theory of signal detection. *Psychological Bulletin, 74,* 100–109.

Proust, M. (1922). *Remembrance of things past: Swann's way* (C. K. Scott-Moncrieff, Trans.). New York: Holt. (Original work published 1919) Retrieved October 23, 2007, from http://www.gutenberg.org/dirs/etext04/8swnn10.txt

Robin, O., Alaoui-Ismaili, O., Dittmar, A., & Vernet-Maury, E. (1998). Emotional responses evoked by dental odors: An evaluation from autonomic parameters. *Journal of Dental Research, 77,* 1638–1646.

Robin, O., Alaoui-Ismaili, O., Dittmar, A., & Vernet-Maury, E. (1999). Basic emotions evoked by eugenol odor differ according to the dental experience: A neurovegetative analysis. *Chemical Senses, 24,* 327–335.

Rosenberg, E. L. (2005). The study of spontaneous facial expressions in psychology. In P. Ekman & E. L. Rosenberg (Eds.), *What the face reveals* (2nd ed., pp. 3–20). New York: Oxford University Press.

Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology, 39,* 1161–1178.

Sander, D., Grandjean, D., Kaiser, S., Wehrle, T., & Scherer, K. R. (2007). Interaction effects of perceived gaze direction and dynamic facial expression: Evidence for appraisal theories of emotion. *European Journal of Cognitive Psychology, 19,* 470–480.

Sander, D., Grandjean, D., & Scherer, K. R. (2005). A systems approach to appraisal mechanisms in emotion. *Neural Networks, 18,* 317–352.

Scherer, K. R. (1984). On the nature and function of emotion: A component process approach. In K. R. Scherer & P. Ekman (Eds.), *Approaches to emotion* (pp. 293–317). Hillsdale, NJ: Erlbaum.

Scherer, K. R. (2001). Appraisal considered as a process of multi-level sequential checking. In: K. R. Scherer, A. Schorr, & T. Johnstone (Eds.),

*Appraisal processes in emotion: Theory, methods, research* (pp. 92–120). New York: Oxford University Press.

Scherer, K. S., & Ellgring, H. (2007). Are facial expressions of emotion produced by categorical affect programs or dynamically driven by appraisal? *Emotion, 7,* 113–130.

Smith, C. A., & Lazarus, R. S. (1990). Emotion and adaptation. In L. A. Pervin (Ed.), *Handbook of personality: Theory and research* (pp. 609–637). New York: Guilford.

Smith, C. A., & Scott, H. S. (1997). A componential approach to the meaning of facial expressions. In J. A. Russell & J.-M. Fernández-Dols (Eds.), *The psychology of facial expression* (pp. 229–254). New York: Cambridge University Press.

Soussignan, R., Ehrlé, N., Henry, A., Schaal, B., & Bakchine, S. (2005). Dissociation of emotional processes in response to visual and olfactory stimuli following frontotemporal damage. *Neurocase, 11,* 114–128.

Susskind, J. M., Lee, D. H., Cusi, A., Feiman, R., Grabski, W., & Anderson, A. K. (2008). Expressing fear enhances sensory acquisition. *Nature Neuroscience, 11,* 843–850.

Thunberg, M. (2007). Rapid facial reactions to emotionally relevant stimuli. *Digital Comprehensive Summaries of Uppsala Dissertations from the Faculty of Social Sciences, Uppsala University.* Retrieved October, 23, 2007, from http://publications.uu.se/abstract.xsql?dbid=8219

Tomkins, S. S. (1984). Affect theory. In K. R. Scherer & P. Ekman (Eds.), *Approaches to emotion* (pp. 163–196). Hillsdale, NJ: Erlbaum.

Turpin, G., Schaefer, F., & Boucsein, W. (1999). Effects of stimulus intensity, rise time, and duration on autonomic and behavioral responding: Implication for the differentiation of orienting, startle, and defense responses. *Psychophysiology, 36,* 453–463.

Turpin, G., & Siddle, D. A. (1983). Effects of stimulus intensity on cardiovascular activity. *Psychophysiology, 20,* 611–624.

van Reekum, C., Banse, R., Johnstone, T., Etter, A., Wehrle, T., & Scherer, K. R. (2004). Psychophysiological responses to appraisal responses in a computer game. *Cognition and Emotion, 18,* 663–688.

Vernet-Maury, E., Alaoui-Ismaili, O., Dittmar, A., Delhomme, G., & Chanel, J. (1999). Basic emotions induced by odorants: A new approach based on autonomic pattern results. *Journal of the Autonomic Nervous System, 75,* 176–183.

Vila, J., Guerra, P., Munoz, M. A., Vico, C., Viedma-Del Jesus, M. I., Delgado, L. C. et al. (2007). Cardiac defense: From attention to action. *International Journal of Psychophysiology, 66,* 169–182.

Weyers, P., Muhlberger, A., Hefele, C., & Pauli, P. (2006). Electromyographic responses to static and dynamic avatar emotional facial expressions. *Psychophysiology, 43,* 450–453.

Wundt, W. (1909). *Grundriss der psychologie. Achte auflage* [Outlines of psychology]. Leipzig, Germany: Engelmann.

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