The Scents of Interpersonality - On the Influence of Smells on the Evaluation and Processing of Social Stimuli

Die Düfte der Zwischenmenschlichkeit - Über den Einfluss von Gerüchen auf die Bewertung und Verarbeitung von sozialen Reizen

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Abstract

In daily life, olfactory stimuli are potential generators of affective states, but also have a strong influence on social interaction. Pleasant odors have been shown to increase perceived attractiveness and pro-social behavior, whereas unpleasant body odors are often associated with negative personality traits. Since both pleasant odors and positive affective state facilitate pro-social behavior, it is conceivable that the influence of the odors on social interaction is mediated by the induced affective state elicited by the odor itself. The present thesis aims at exploring the impact of hedonic, i.e., pleasant or unpleasant, odors on the processing and evaluation of social stimuli as assessed by verbal, physiological, and behavioral indices. First, I investigate the effects of initially neutral odors which gained threatening value through an aversive conditioning procedure on social stimuli (Study 1). Second, I study the influence of naturally hedonic odors on social interaction. Third, this thesis aims at disentangling differences in the effects of an odor attributed to either a social interaction partner or the environment where the social encounter takes place (Study 2, 3, and 4).

In the first study, a context conditioning procedure was applied, during which one out of two long-lasting neutral odors was paired with an unpredictable aversive unconditioned stimulus (US, i.e., white noise). This odor (CTX+) thereby gained threatening value, while another odor (CTX-) remained unpaired and therefore signaled safety. During a test session, facial stimuli were presented within both conditioned olfactory contexts. Results indicate that autonomic arousal was increased to faces when presented in the threatening odor context. Additionally, participants rated facial stimuli as more aversive when presented in the threatening odor as compared to the safety odor, indicating that faces acquire hedonic value from the odor they were presented in. Strikingly, angry facial expressions received additional processing resources when presented within a threatening olfactory context, as reflected on verbal reports and electrodermal activity (EDA). This latter finding suggests that threat-related stimuli, here angry faces, are preferentially processed within an olfactory context where a threat might happen.

Considering that the hedonic value of an odor may be quite subjective, I conducted a pilot study in order to identify odors with pleasant vs. unpleasant properties for most participants. Seven odors (four pleasant and three unpleasant) were rated with respect to their valence (pleasant vs. unpleasant), arousal (arousing vs. calm), and intensity. Additionally, EDA was measured. Two pleasant (Citral and Eucalyptol) and two unpleasant (“Animalis” and Isobutyraldehyde) odors were chosen from the original seven. The unpleasant odors were rated as more negative, arousing, and intense than the positive ones, but no differences were found regarding EDA.

These four odors were subsequently used in a virtual reality (VR) paradigm with two odor attribution groups. Participants of the social attribution group (*n* = 59) were always passively guided into the same room (an office) towards one out of two virtual agents who were either paired with the pleasant or the unpleasant odor. Participants of the contextual attribution group (*n* = 58) were guided into one out of two rooms which were either paired with the pleasant or the unpleasant odor and where they always met the same agent. For both groups, the agents smiled, frowned or remained with a neutral facial expression. This design allowed evaluating the influence of odor valence as a within-subjects factor and the influence of odor attribution as a between-subjects factor. Unpleasant odors facilitated the processing of social cues as reflected by increased verbal and physiological arousal as well as reduced active approach behavior. Specific influence of odor valence on emotional facial expressions was found for ratings, EDA, and facial mimicry, with the unpleasant odor causing a levelling effect on the differences between facial expressions. The social attribution group exhibited larger differences between odors than the contextual group with respect to some variables (i.e., ratings and EDA), but not to others (i.e., electrocortical potentials – ERPs – and approach behavior). In sum, unpleasant in comparison to pleasant odors diminished emotional responses during social interaction, while an additional enhancing effect of the social attribution was observed on some variables. Interestingly, the awareness that an interaction partner would smell (pleasantly or unpleasantly) boosted the emotional reactivity towards them.

In Study 3, I adapted the VR paradigm to a within-subjects design, meaning that the different attribution conditions were now manipulated block-wise. Instead of an approach task, participants had to move away from the virtual agent (withdrawal task). Results on the ratings were replicated from Study 2. Specifically, the difference between pleasant and unpleasant odors on valence, arousal, and sympathy ratings was larger in the social as compared to the contextual attribution condition. No effects of odor or attribution were found on EDA, whereas heart rate (HR) showed a stronger acceleration to pleasant odors while participants were passively guided towards the agent. Instead of an approach task, I focused on withdrawal behavior in this study. Interestingly, independently of the attribution condition, participants spent more time withdrawing from virtual agents, when an unpleasant odor was presented. In sum, I demonstrated that the attribution of the odors to the social agent itself had an enhancing effect on their influence on social interaction.

In the fourth and last study, I applied a similar within-subjects protocol as in Study 3 with an additional Ultimatum Game task as a measure of social interaction. Overall findings replicated the results of Study 3 with respect to HR and EDA. Strikingly, participants offered less money to virtual agents in the bad smelling room than in the good smelling room. In contrast to Study 3, no effects of odor attribution were found in Study 4. In sum, again I demonstrated that unpleasant odor may lessen social interaction not only when the interaction partner smells badly, but also in more complex interaction situations.

In conclusion, I demonstrated that hedonic odors in general influence social interaction. Thus, pleasant odors seem to facilitate, while unpleasant odors seem to reduce interpersonal exchanges. Therefore, the present thesis extends the body of literature on the influence of odors on the processing of social stimuli. Although I found a direct influence of odors on social preferences as well as on the physiological and behavioral responses to social stimuli, I did not disentangle impact of odor per se from the impact of the affective state. Interestingly, odor attribution might play an additional role as mediator of social interactions such as odor effects in social interactions might be boosted when the smell is attributed to an individual. However, the results in this regard were less straightforward, and therefore further investigations are needed. Future research should also take into account gender or other inter-individual differences like social anxiety.

Zusammenfassung

Im täglichen Leben dienen Gerüche als starke Auslöser von emotionalen Zuständen, doch üben sie auch einen starken Einfluss auf soziale Interaktion aus. Angenehme Gerüche sollten die Attraktivität von Gesichtern und prosoziales Verhalten verstärken, während unangenehme Körpergerüche oft mit negativen Persönlichkeitseigenschaften assoziiert werden. Dieser Zusammenhang zeigt sich auch auf physiologischen und Verhaltensmaßen. Während angenehme Gerüche prosoziales Verhalten verstärken, kann derselbe Effekt auch durch einen positiven affektiven Zustand erreicht werden. Der Einfluss von Gerüchen auf soziale Interaktion könnte daher auch durch den affektiven Zustand der Versuchspersonen vermittelt werden. Die vorliegende Arbeit hatte zum Ziel, den Einfluss von hedonischen Gerüchen auf soziale Interaktion, wie er sich auf verschiedenen verbalen, physiologischen und Verhaltensvariablen abbilden lässt, darzustellen. Auf der einen Seite wurde der Einfluss von ursprünglich neutralen Gerüchen untersucht, die in einer Kontextkonditionierung bedrohliche Bedeutung erhielten (Studie 1). Auf der anderen Seite sollte der Einfluss eines Geruchs, der direkt von einem sozialen Interaktionspartner ausgeht, von dem eines eher kontextuellen Geruchs getrennt werden, der auf den Raum attribuiert wurde, in dem die soziale Interaktion stattfand (Studien 2, 3 und 4).

In der ersten Studie wurde auf einen von zwei ursprünglich neutralen Gerüchen eine Kontextkonditionierungsprozedur angewandt. Dieser Geruch erhielt somit durch die Paarung mit einem aversiven unvorhersehbaren unkonditionierten Stimulus (US) bedrohliche Bedeutung, während der andere Geruch niemals mit einem unkonditionierten Stimulus gepaart wurde und dadurch Sicherheit signalisierte. In der Testphase wurden Gesichter entweder innerhalb des bedrohlichen Geruchs oder des Sicherheitsgeruchs präsentiert. Es konnte gezeigt werden, dass im Anschluss daran der bedrohliche Geruch die elektrokortikalen Potenziale (EKPs) auf Gesichter verstärkt, die in diesem Geruchskontext präsentiert werden. Zudem war das autonome Arousal während der Präsentation der Gesichsstimuli in diesem Kontext erhöht. Subjektive Ratings unterstützen zusätzlich die Annahme, dass die bedrohliche Bedeutung des Kontexts, in dem Gesichter präsentiert werden, auf diese übergeht. Zusätzlich zu diesem generellen Effekt konnte auf den subjektiven Ratings wie auch auf der elektrodermalen Aktivität (EDA) ein spezifischer Einfluss des olfaktorischen Kontexts auf die Verarbeitung von Gesichtern gezeigt werden. Ärgerliche Gesichter zogen dabei zusätzliche Verarbeitungsressourcen auf sich, wenn sie innerhalb eines bedrohlichen olfaktorischen Kontexts präsentiert wurden, wie sich auf der EDA und den verbalen Ratings zeigte. Zusammengefasst legen die letzteren Ergebnisse nahe, dass bedrohliche Reize (hier ärgerliche

Gesichter) bevorzugt verarbeitet werden, wenn sie in einem ebenfalls bedrohlichen Kontext präsentiert werden.

Um für die anschließenden Studien Gerüche zu identifizieren, die von den meisten Versuchspersonen als angenehm bzw. unangenehm bewertet werden, wurde vor der zweiten Studie eine Pilotstudie durchgeführt. Sieben Gerüche (vier angenehme und drei unangenehme) wurden bezüglich Valenz, Arousal und Intensität evaluiert. Zusätzlich wurde die EDA aufgezeichnet. Aus den ursprünglichen sieben Gerüchen wurden zwei angenehme (Citral und Eukalyptol) und zwei unangenehme („Animalis“ und Isobutanal) ausgewählt. Die unangenehmen Gerüche wurden als unangenehmer, aufregender und intensiver bewertet als die angenehmen, wohingegen in der EDA keine Unterschiede gefunden wurden.

Studie 2 wandte die ausgewählten Gerüche in einem Experiment in virtueller Realität an. Um eine soziale und eine kontextuelle Attribution der Gerüche abzubilden, erhob ich zwei Attributionsgruppen. Versuchspersonen der sozialen Attributionsgruppe (n = 59) wurden passiv immer in denselben Raum geführt, in dem sie auf einen von zwei virtuellen Agenten trafen. Jeder dieser Agenten wurden mit entweder dem angenehmen oder dem unangenehmen Geruch gepaart. Probanden der kontextuellen Attributionsgruppe (n = 58) wurden jeweils passiv in einen von zwei Räumen geführt, der entweder mit dem angenehmen oder dem unangenehmen Geruch gepaart wurde. In diesen Räumen trafen sie immer auf denselben virtuellen Agenten. So war es möglich, den Einfluss der Geruchshedonik als Innersubjektfaktor und den Einfluss der Geruchsattribution als Zwischensubjektfaktor darzustellen. Der unangenehme Geruch erzeugte eine verstärkte Verarbeitung sozialer Reize, was sich in erhöhtem physiologischen Arousal, in subjektiven Ratings und vermindertem aktiven Annäherungsverhalten zeigte. Ein spezifischer Einfluss auf emotionale Gesichtsausdrücke war außerdem auf den subjektiven Ratings, EDA und der fazialen Mimikry zu beobachten. Hierbei zeigte sich ein abflachender Effekt auf den Unterschied zwischen den Gesichtsausdrücken, wenn der unangenehme Geruch präsentiert wurde. In der sozialen Attributionsgruppe fanden sich auf manchen Variablen stärkere Effekte als in der kontextuellen Attributionsgruppe (wie den Ratings und der EDA), aber auf anderen Variablen nicht (wie den EKPs und dem Annäherungsverhalten). Zusammenfassend konnte gezeigt werden, dass unangenehme Gerüche im Vergleich zu angenehmen emotionale Reaktionen auf soziale Interaktion vermindern. Ein zusätzlicher verstärkender Effekt durch die soziale Attribution der Gerüche war auf einigen Variablen zu beobachten. Interessanterweise scheint das Wissen darüber, dass ein Interaktionspartner riechen könnte, die emotionale Reaktion auf ihn zu verstärken.

Für die dritte Studie passte ich das Paradigma für ein Innersubjektdesign an, wobei nun die beiden Attributionsbedingungen blockweise manipuliert wurden. Die Resultate der Ratings replizierten die aus Studie 2. Außerdem zeigten sich stärkere Effekte der Geruchsvalenz in der sozialen Attributionsbedingung auf allen Ratings. In der EDA wurden keine Effekte gefunden, aber in der Herzrate zeigte sich eine verstärkte Verarbeitung der angenehmen Gerüche während der passiven Annäherung an den Agenten. Statt des Annäherungsverhaltens wurde in dieser Studie das Rückzugsverhalten gemessen. Die Versuchspersonen verbrachten mehr Zeit damit, von einem Agenten zurückzuweichen, wenn ein unangenehmer Geruch präsentiert wurde. In Summe konnte ich zeigen, dass die Attribution der Gerüche auf den sozialen Agenten einen verstärkenden Effekt auf den Einfluss der Gerüche auf die soziale Interaktion hat.

In der letzten Studie wurde dasselbe Protokoll wie in Studie 3 mit einer zusätzlichen Ultimatumspielaufgabe durchgeführt. Die Ergebnisse aus Studie 3 wurden bezüglich der Herzrate und der EDA repliziert. Außerdem boten die Versuchspersonen dem Agenten im Kontext eines unangenehmen Geruchs weniger Geld an als im Kontext eines angenehmen. In Studie 4 wurde kein Effekt für die Attribution des Geruchs gefunden. Zusammenfassend wurde gezeigt dass unangenehme Gerüche einen reduzierenden Effekt auf soziale Interaktion auch in komplexeren interaktiven Situationen ausüben.

Zusammenfassend zeigte ich, dass Gerüche soziale Interaktion beeinflussen. Angenehme Gerüche scheinen soziale Interaktionen zu vereinfachen, während unangenehme Gerüche sie erschweren. Damit erweitert die vorliegende Arbeit bereits bestehende Forschung über den Einfluss von Gerüchen auf die Verarbeitung sozialer Stimuli. Obwohl ich einen direkten Einfluss von Gerüchen auf soziale Präferenzen sowie auf die physiologischen und behavioralen Reaktionen auf soziale Stimuli fand, konnte ich den Einfluss von Gerüchen per se nicht von dem Einfluss des affektiven Zustandes abgrenzen. Interessanterweise scheint die Attribution von Gerüchen einen zusätzlichen Faktor als Mediator von sozialen Interaktionen darzustellen, so dass der Effekt der Gerüche verstärkt wird, wenn er mit einem Individuum assoziiert ist. Nichtsdestotrotz waren die diesbezüglichen Effekte weniger klar und mehr Forschung auf diesem Gebiet könnte diese Unklarheit auflösen. Zukünftige Forschung sollte auch den Faktor Geschlecht nicht außer Acht lassen sowie andere inter-individuelle Unterschiede wie soziale Ängstlichkeit.

Abbreviations

ANI – Animalis

ANOVA – Analysis of Variance

BOLD – Blood oxygen level dependent contrast

CIT – Citral

CS+ – Conditioned stimulus

CS- – Unpaired stimulus

CTX+ – Aversively conditioned context

CTX-– Safety conditioned context

EDA – Electrodermal Activity

EEG - Electroencephalogram

EMG – Electromyogram

EPN – Early posterior negativity

ERP – Event-related potential

EUC – Eucalyptol (Cineol)

HR – Heart rate

HSA – High socially anxious

IBU – Isobutyraldehyde

ICA – Independent Component Analysis

ICP – Isocaproic Acid

IAM – Isoamylacetate

IPQ – I-Group Presence Questionnaire

ISI – Inter-stimulus interval

ITI – Inter-trial interval

LPP – Late Positive Potential

LSA – Low socially anxious

MEG – Magnetoencephalogram

MEN – Menthol

OFC – Orbitofrontal cortex

PANAS – Positive and Negative Affect Scale

PTSD – Post-traumatic stress disorder

SCL – Skin conductance level

SPAI – Social Phobia and Anxiety Inventory

US – Unconditioned stimulus

VNO – Vomeronasal organ

VR – Virtual reality

1 Theoretical Background

„[…] Denn die Menschen konnten die Augen zumachen vor der Größe, vor dem Schrecklichen, vor der Schönheit und die Ohren verschließen vor Melodien oder betörenden Worten. Aber sie konnten sich nicht dem Duft entziehen. Denn der Duft war ein Bruder des Atems. Mit ihm ging er in die Menschen ein, sie konnten sich seiner nicht erwehren, wenn sie leben wollten. Und mitten in sie hinein ging der Duft, direkt ans Herz, und unterschied dort kategorisch über Zuneigung und Verachtung, Ekel und Lust, Liebe und Haß. Wer die Gerüche beherrschte, der beherrschte die Herzen der Menschen.“

(Süskind (1985) „Das Parfum“ S. 198 f)

The citation above originates from a novel that approaches the subject of smells from the perspective of a man who perceives the world mainly through his nose. It nicely illustrates some intriguing facts about the role of smells for human behavior and cognition. The main character of the novel, Jean-Baptiste Grenouille, has an extraordinary ability to smell and to discriminate between different components of smells. The novel deals with his intentions and attempts to influence human beings through olfactory stimulants.

Smells are, though often underestimated, an essential part of the air we breathe and therefore hard to ignore. Even smells that are not actively recognized can influence human preferences (Li, Moallem, Paller, & Gottfried, 2007). This is partly due to the fact that, as stated by Süskind (1985), smells are processed in a very direct way, probably more direct than all other sensory input. Most of the olfactory input is not gated via the thalamus (Keller, 2011) where all other sensory input is filtered when entering the brain. Therefore, the statement that the smell enters humans with the breath and is led directly to the heart is not entirely off the mark.

The subject of substances influencing human behavior without being warded off or even noticed caused a lot of suspiciousness and wild theories in the past. In particular, the role of human pheromones[1] and how exactly they influence social interaction has been subject to a large body of research (Cowley & Brooksbank, 1991; Frey, Weyers, Pauli, & Mühlberger, 2012; Pause, 2012). Though the role of human pheromones and a lot of related questions have not been exhaustively resolved, the question on how purely olfactory substances can influence humans has received even

[1] Pheromones are messenger signals used in communication between members of the same species. In many of these species, pheromones are processed via the nose.

less attention in research. In contrast to other mammals, humans have a relatively low ability to perceive smells and to discriminate between different smells. Their importance in daily life is therefore rather low compared to the input of other senses. Still, the scarce research could offer references that pleasant odors further pro-social behavior whereas unpleasant odors attenuate it. However, hints that this influence of smells on human behavior could be mediated by the influence of hedonic[2] odors on affective state are also found (Baron & Thomley, 1994).

The present work has therefore two aims: Primarily, it explores the influence of hedonic smells on human behavior and preferences in a controlled laboratory setting. In a second step, it disentangles the influence of hedonic odors that derive directly from an interaction partner from the influence that is due to more general contextual odors. In this regard, the experiments were meant to facilitate the drawing of conclusions about the effect of odors that are attributed to human beings in contrast to odors that serve as contextual stimuli.

The first part of this thesis therefore illustrates the background to these research questions. It will first give an overview of olfactory processing, past research on the importance of odors for human beings, and several characteristics of smell research. Afterwards, different measures of social preferences, social behavior, and their processing are introduced. In a third step, the interdependency between the two factors is discussed on the basis of past research. The research question and the hypotheses conclude the first paragraph. Afterwards, four studies and a pilot study on odor hedonics are presented and discussed.

1.1 Olfaction

1.1.1 The Importance of Olfaction in Humans

In his review, Stevenson (2010) lists three major functions of the olfactory sense: ingestion, avoidance of environmental dangers by elicitation of disgust or fear respectively, and social communication. Environmental dangers can derive from various sources: contamination, air pollution, fire, etc. Within the social communication domain, Stevenson (2010) also counts the facilitation of mating behavior (Lübke, Hoenen, & Pause, 2012; Moshkin et al., 2011) by transmission of information about the individual's immune system. Still, this is not the only information transmitted via the nose. In addition, information about other individuals' emotional states can be processed via the olfactory system (deGroot, Smeets, Kaldewaij, Duijndam, & Semin, 2012). The main

[2] The term "hedonic odors" refers to the concept of pleasant or unpleasant (vs. neutral) odors with respect to their hedonic qualities, i.e., valence and arousal, and is used in this regard throughout the whole thesis.

purpose of this capacity is the ability to flexibly adapt the organism to dynamic situations (Albrecht et al., 2011).

Another important issue out of the social communication domain is the phenomenon of kinship identification via olfactory information. Porter, Balogh, Cernoch, and Franchi (1986) found that people were able to identify members of their own family just by smelling their body odors. Mothers recognize their infants‘ smell directly after birth (Kaitz, Good, Rokem, & Eidelman, 1987), and babies are able to distinguish between their mothers’ smells and others (Cernoch & Porter, 1985). In conclusion, it can be stated that processing of information via the nose is of use in bonding between members of a species and thus enhances the chances of survival of this species.

1.1.2 Olfactory Processing

Together with the sense of taste, the sense of smell constitutes the system of chemical senses. That means that the sensory organ (i.e., the olfactory epithelium or the tongue) is directly in touch with the sensory source (i.e., smell or taste molecules), in contrast to the visual sense, for example. Here, receptors of the retina react to a sensory source that can be located at a long distance. Smells can enter the nose by two ways: orthonasally, that means directly through the nose by inhaling or sniffing, or retronasally, that means through the oral cavity, for example, while eating or drinking (Albrecht & Wiesmann, 2006). Smells are then first processed ipsilaterally (Lascano, Hummel, Lacroix, Landis, & Michel, 2010). Though smell molecules can enter the nose passively, it has been argued that the act of sniffing is necessary and constitutional for an olfactory perception (Mainland & Sobel, 2006).

The olfactory epithelium is located on top of the nasal cavity and consists of a humid mucosa that comprises amongst others the smell receptors. Molecules have to bind directly to the smell receptors to evoke a smell experience in the brain. Signals from the receptors are processed via axons that are guided through the lamina cribrosa into the olfactory bulb (Albrecht & Wiesmann, 2006). From there, they proceed as the first cranial nerve, the *nervus olfactorius*, into the piriform cortex that is, by some authors, considered as primary olfactory cortex (Gottfried, 2010). The piriform cortex is not part of the neocortex (as all other primary sensory cortices are) but of the paleocortex which is phylogenetically much older (Keller, 2011). Another prominent difference to other sensory domains is that input from the olfactory system is not or only partly channeled through the thalamus (Albrecht & Wiesmann, 2006; Keller, 2011). This leads to the effect that some sensory input reaches secondary or associative cortices in a very direct way and sometimes without being consciously perceived. Supportively, influences of smells on autonomic nervous system parameters can also be observed during sleep (Badia, Wesensten, Lammers, Culpepper, & Harsh, 1990; Rasch, Büchel, Gais, & Born, 2007; Schredl et al., 2009), and olfactory attention and consciousness are linked to an indirect pathway between the thalamus and the orbitofrontal cortex (Plailly, Howard, Gitelman, & Gottfried, 2008). Later processing stages of olfactory input are the orbitofrontal cortex (OFC), the amygdala, the hippocampus, the insula, the hypothalamus, the striatum (Gottfried, 2010; Zald & Pardo, 1997), and the thalamus (Albrecht & Wiesmann, 2006). In the OFC, odors are being discriminated and identified (Albrecht & Wiesmann, 2006). There are also hints that integration of olfaction with the input of other sensory modalities (Rolls, 2004; Rolls & Baylis, 1994) and the subsequent adjustment of behavior (Seubert, Freiherr, Djordjevic, & Lundström, 2013) happen in the OFC. There is evidence that the valence component of odors is also processed here (Zatorre, Jones-Gotman, & Rouby, 2000), whereas amygdala activation is more associated with increased odor intensity (Anderson et al., 2003; Hudry, Ryvlin, Royet, & Mauguiere, 2001) or with an interaction of both intensity and valence (Winston, Gottfried, Kilner, & Dolan, 2005). The hippocampus controls memory components of olfactory input like cross-modal integration of this information (Gottfried & Dolan, 2003) and autobiographical memory (Arshamian et al., 2013). The cerebellum plays another important role in olfactory processing. It is proposed to constitute the motoric component during sniffing (Sobel et al., 1998).

Apart from the described processing of olfactory input via the *nervus olfactorius*, there are other kinds of information that are processed via the nose. Interestingly, the olfactory epithelium is not only innervated by the olfactory nerve but also by nerve endings of the fifth cranial nerve, the *nervus trigeminus* (Doty et al., 1978). It processes non-olfactory components of olfactory fragrances, like tactile stimulation that can, for example, be experienced as the cool sensation evoked by some fragrances or the itchy sensation evoked by others. Some fragrances like hydrogen sulfide (H_2S) are nearly exclusively processed olfactorily, while other substances as carbon dioxide (CO_2) are nearly exclusively processed by the trigeminal system (Albrecht & Wiesmann, 2006). Purely olfactory or trigeminal substances are anyway only rarely found in everyday environment. Additionally, a mixture of a trigeminal and an olfactory substance is found to provoke extra activation that extends activation being predicted by the sum of activations to both substances alone (Boyle, Frasnelli, Gerber, Heinke, & Hummel, 2007).

A large body of research concentrates on the effects of so-called human pheromones or human chemosignals (Cowley & Brooksbank, 1991; Frey et al., 2012; Pause, 2012). Those are messenger substances diluted in the air we breathe that are not consciously perceived and unfold their effects via hormonal pathways that differ from the classical olfactory or trigeminal ones. A very prominent field of research treats the effect of chemosignals transported via human body odors (see paragraph 1.3.1). How these chemosignals are processed from entering the nose to the effect on the autonomic nervous system is not exclusively highlighted. Rodents express a so-called vomeronasal organ (VNO) that specifically transfers non-olfactory (i.e., hormonal) social signals into the central nervous system. However, even if derivatives of the VNO are found in the human nose, no functional connections with the brain could be found by some authors (Trotier, 2011), and the subject remains under debate (for a review, see Meredith, 2001). Still, chemosignal-induced activation in hypothalamic regions is observed. This information could be transmitted by so-called receptor genes embedded in the respiratory mucosa (Witt & Wózniak, 2006). An involvement of these so-called trace-amine-associated receptors in social communication has been shown and detected in the human mucosa (Liberles & Buck, 2006). Some mammals (as well as other animal species) exhibit Grueneberg Ganglion Cells that are hypothesized to be involved in the processing of chemosensory alarm signals. These cells are found in the tip of the nose, and hints have been found that they are also prominent in humans (Brechbühl, Klaey, & Broillet, 2008). It is argued that human chemosignals are often processed subconsciously and unfold their effects without being consciously perceived (Pause, 2012). However, the exact processing pathways in humans are still under debate.

What humans experience while smelling a certain odor is, in the majority of cases, a complex mixture of different odor components binding to different receptors in the olfactory epithelium, which results in a unique smell experience by activating a characteristic pattern of receptors (Albrecht & Wiesmann, 2006). The smell of coffee, for example, consists of around 800 different odor component molecules that enter the nose (Deibler, Acree, & Lavin). One type of smell molecules can bind to different smell receptors. Contrariwise, one type of smell receptors can be activated by different molecules. Apart from different components, receptor patterns also depend on different concentrations of molecules (Albrecht & Wiesmann, 2006). Therefore, humans have long been thought to be able to distinguish between up to 10,000 smells (Buck & Axel, 1991), but more recent extrapolations suggest that more than a trillion odors are distinguishable (Bushdid, Magnasco, Vosshall, & Keller, 2014). Nonetheless, only a small number of them seems to be of importance for human beings (Dunkel et al., 2014).

Olfactory perception is influenced by nearly countless factors, an important one of them being habituation and/or adaptation. Adaptation refers to processes of the peripheral olfactory system and habituation to central nervous system processes, but both provoke a decrease in perceived intensity when exposed to a certain odor for a continued time (Thompson & Spencer, 1966). The nose is prone to adapt rapidly to surrounding smells, which is why mammals are able to detect new smells relatively rapidly even when the surrounding air is heavy with other smell molecules ("figure-ground-segmentation", Gottfried, 2010). When stimulated repeatedly, the olfactory system habituates to the smell that is in turn perceived as less intense and concurrent activations in the nervous system are less prominent (Flohr et al., 2015; Hudry et al., 2001; Poellinger et al., 2001). Thereby, the habituation curve seems to be the steeper the larger the intensity of the stimulant (Engen, 1973).

The two most prominent within-perceiver factors influencing olfactory sensitivity are age (Doty & Kamath, 2014) and gender (Brand & Millot, 2001; Larsson, Öberg, & Bäckman, 2005; Royet, Plailly, Delon-Martin, Kareken, & Segebarth, 2003; Seubert, Rea, Loughead, & Habel, 2009). Olfactory sensitivity diminishes with age and women outperform men in most kinds of smell tasks. Supportively, higher blood oxygen level dependent (BOLD) activation in the OFC is found in women compared to men (Royet et al., 2003). Olfactory sensitivity can also be influenced by attentional mechanisms (Zelano et al., 2005). Additionally, olfactory sensitivity is modified by plenty of pathological factors, somatic ones like Parkinson's (Doty, 2012; Zucco, Rovatti, & Stevenson, 2015) or Alzheimer's disease (Devanand et al., 2000; Doty, Reyes, & Gregor, 1987) and psychiatric ones like Depression (Croy et al., 2014; Negoias et al., 2010; Pause, Miranda, Göder, Aldenhoff, & Ferstl, 2001; Pollatos, Albrecht et al., 2007), Anorexia Nervosa (Lombion-Pouthier, Vandel, Nezelof, Haffen, & Millot, 2006), Schizophrenia (Hurwitz, Kopala, Clark, & Jones, 1988; Moberg et al., 1997), or Post-Traumatic Stress disorder (PTSD; Croy, Schellong, Joraschky, & Hummel, 2010).

1.1.3 Odors in the Laboratory Setting

The sense of smell is, in comparison to other sensory domains, rather slow. This is partly due to the fact that olfactory molecules depend on the act of sniffing to reach the olfactory mucosa, but even then, transmission of the olfactory information into the central nervous system takes longer than in other domains (Pause, Sojka, & Ferstl, 1997). Thus, the exact time point of the start of the sensory experience is hard to identify. This can be overcome in the laboratory setting by the use of an odor delivery device like an olfactometer (Lorig, Elmes, Zald, & Pardo, 1999b). This device normally comprises glass tubes that contain the smelling substance. Depending on the exact material of the odor source, it can be solid, fluid, or gaseous. Clean air is then guided through or over the smelling substance and gets enriched with odorous molecules. The air is guided through Teflon™ tubes into the nose, either via a breathing mask or via tubes that lead directly into the nostrils, the latter allowing a timely more precise administration of the odor. However, this approach diminishes ecological validity as participants have – under some circumstances – to practice a special breathing technique, the "velopharyngeal closure". For an overview of the olfactometer that was used in the studies, please see 2.2.2.2 and Figure 2.

Reactions to odors can be collected on the subjective level (i.e., ratings), physiological level, and behavioral level (mostly reaction times and reaction biases). Additionally, differences on the molecular level can be observed and described in olfactory substances. However, it could be observed in enantiomers[3] that not the molecular structure but the hedonic characteristic of smells accounts for reactions found towards these odors (Heuberger, 2001). Some studies elucidate that the same odorant, if evaluated differently, provokes different processing (Lundström, Seven, Olsson, Schaal, & Hummel, 2006). Since the molecular characteristics of odors are beyond the scope of this thesis, I refer to those manuscripts for the interested reader. As emotional reactions on the subjective and behavioral level do not differ from reactions to stimuli in other sensory domains (which in turn are described below), the following paragraph will concentrate on physiological reactions in the field of smell research.

The most common within the physiological measurements are those displaying reactions of the central nervous system more or less directly. Prominent among them because of its easy handling is the electroencephalogram (EEG). Chemosensory event-related potentials are strongest over the midline electrodes and have longer latencies than, for example, visually or auditorily evoked potentials (Kobal, 1981; Kobal & Hummel, 1988; Pause et al., 1997). Functional magnetic resonance imaging (fMRI) investigating brain activations associated with olfactory processing has also received a lot of interest in the past years (Albrecht & Wiesmann, 2006; Bensafi et al., 2002; Plailly et al., 2008; Zald & Pardo, 1997). The EEG offers a high temporal resolution whereas its spatial resolution is rather poor. On the contrary, fMRI measurements are characterized by a poor temporal resolution with a high spatial resolution. This drawback is hard to overcome, even though there have been attempts to record electrocortical ERPs directly from the human amygdala during surgery (Hudry et al., 2001).

Another possible method to investigate the impact of olfactory stimulation with the help of psychophysiological methods is to record visual event-related EEG-potentials during olfactory stimulation (compared to neutral control conditions), in order to disentangle the influence of smells on stimuli in other domains (Adolph & Pause, 2012; Leleu et al., 2015; Rubin, Botanov, Hajcak, & Mujica-Parodi, 2012). The advantage of this method is that visual event-related potentials are easier to evoke and to detect and, additionally, do not require a special stimulus device. Some peripheral physiological measures have found their way into smell research in the last decades. First of all, it is possible to record potentials directly from the olfactory mucosa in response to olfactory stimulation (Kobal, 1981; Lapid et al., 2011). Still, even though this method is very sophisticated, it requires a lot

[3] The term “enantiomers” refers to “mirror-image molecules” that differ only with respect to their chiral structure and whose smells are hard to distinguish (Li, Howard, Parrish, and Gottfried, 2008)

of special equipment and experience. Researchers from the field of smell did also apply measures from classical psychophysiology like the electrocardiogram (He, Boesveldt, Graaf, & de Wijk, René A, 2014), the EDA (He et al., 2014), and the breathing volume (Ferdenzi, Fournel, Thévenet, Coppin, & Bensafi, 2015). While EDA has been found to vary depending on the perceived intensity of odors, heart rate is rather a display of perceived valence (Bensafi et al., 2002a). Breathing volume seems to reflect the assumed healthiness of an odor (Auffarth, 2013), which should be highly correlated to valence.

1.1.4 Affective Properties of Odors

Generally speaking, odors that might signal harmful or noxious events to the body tend to smell bad, while odors that have a positive influence on body functioning tend to smell good (Auffarth, 2013). Still, this relationship is not a universal one as can be observed by the smell of certain types of cheese or other gourmet substances. On the other hand, odors serve as appetitive or aversive reinforcers as long as their predictive value is ensured as Gottfried, O'Doherty, and Dolan (2003b) demonstrated. Finally, odor hedonics are highly dependent on cognitive variables (Araujo, Rolls, Velazco, Margot, & Cayeux, 2005; Djordjevic et al., 2008). Djordjevic et al. (2008) were even able to show that responses of the peripheral nervous system (i.e., heart rate change and skin conductance level, SCL) varied according to verbal labels given to odors but not to plain air control stimuli. Odor hedonicity is not only modulated by the verbal labeling of the odors, but also by the personal learning history (see below). Moreover, odor hedonics are highly culturally dependent (Ayabe-Kanamura et al., 1998; Ferdenzi et al., 2011; Schiffman, Suggs, & Sattely-Miller, 1995).

It has been hypothesized that the primary feature of odor perception is the hedonic domain as it corresponds to the behavioral salience of odors (Castro & Seeley, 2014) and as most other domains are poorly developed in humans (Yeshurun & Sobel, 2010). It could be shown that the olfactory epithelium represents the hedonic domain in a structural manner (Lapid et al., 2011). Areas that respond primarily to a certain unpleasant odor also respond more to other unpleasant odors and vice versa (Lapid et al., 2011). As a second domain authors often mention the domain of odor intensity (Smeets & Dijksterhuis, 2014). Odor intensity and odor pleasantness are often negatively correlated (Engen, 1973; Henion, 1971). That means that the stronger an odor, the more unpleasant it is perceived (even if it is positive per se). Together, the two domains of valence and intensity span a virtual space where hypothetically all kinds of odors can be localized with regard to their hedonic characteristics. Anderson et al. (2003) observed that the valence component is more reflected in the OFC, whereas intensity differences cause activity differences in the amygdala. Rolls, Kringelbach, and deAraujo (2003) found similar results, though they reported the intensity domain being rather located in piriform and entorhinal cortices. Bensafi et al. (2002a) achieved a similar dissociation on the level of peripheral physiological measures. Thus, they observed that heart rate change was more associated with the subjective valence of the odors, such that the more unpleasant an olfactory experience was, the higher the heart rate increase during smelling, while high SCL during smelling was more associated with high intensity/arousal ratings. There have also been attempts to describe the emotional experience related to the perception of odors with the help of basic emotional categories (Ekman, Sorenson, & Friesen, 1969). Croy, Olgun, and Joraschky (2011) found that basic emotions evoked by olfactory perception concentrate on disgust, happiness, and fear, while sadness and anger reactions seem to be scarce. This finding seems logical when taking into account that olfaction is a proximal sense, meaning that the individual is also perceiving the source of the odor. When smelling something, the source of the odor is already about to enter the body of the perceiver. Withdrawal or disgust-related behavior must ensue quickly and is therefore prioritized (Glass, Lingg, & Heuberger, 2014).

It has been criticized, however, that the closed structure of the bidimensional emotion concept (Russell, 2003) or the basic emotion concept (Ekman et al., 1969) does not suit the emotional experience evoked by odors and attempts to match emotional reactions to odors to the basic emotions concept seem to result in a high individual variability (Vernet-Maury, Alaoui-Ismaïli, Dittmar, Delhomme, & Chanel, 1999). Chrea et al. (2009) therefore conducted a factor analysis study trying to map the emotional space of experiences made while smelling different odors onto relatively independent descriptive factors. They came up with a six-factor solution called “Geneva Emotion and Odor Scale”. A point of criticism that is stated by the authors themselves is the underrepresentation of unpleasant feelings in their emotional space. However, their impact should not be underestimated as their influence on behavior is often found to be larger than the influence of pleasant odors (Weber & Heuberger, 2008). Additionally, even though the Geneva Model seems to be sufficient for emotions evoked by odors alone and even outperforms classical approaches when it comes to elaborating odors (Delplanque et al., 2012), in the laboratory setting a) it is important to be able to compare emotions evoked by odors to emotions evoked by other stimuli and b) a six-factorial solution would be hard to imply and interpret.

Apart from subjective measures, there have been multiple attempts to characterize affective properties of odors on implicit measures like reactions of the central or peripheral nervous system or behavioral measures. Odor hedonics have been displayed with the help of the affect modulated startle (Ehrlichman, Brown, Zhu, & Warrneburg, 1995; Richardson, 2002). The affect modulated startle is interpreted as approach or withdrawal behavior respectively depending on its magnitude.

Indeed, unpleasant odors lead to startle potentiation, implicating negative implicit valence and greater fear response, while startle attenuation by pleasant odor could not be found (Ehrlichman et al., 1995; Miltner, Matjak, Braun, Diekmann, & Brody, 1994). The effect of unpleasant odors on the startle response has also been shown by Adolph and Pause (2012) in a study on emotion regulation after administration of threatening body odors. They were even able to demonstrate a superiority of odors over emotional pictures. Moreover, in pleasantly smelling rooms, pictures were observed longer than in a non-smelling room (Knasko, 1995). Participants reported having spent more time in a room when the room smelled good (compared to a neutral room), even if in absolute time, there was no difference to be found (Spangenberg, Crowley, & Henderson, 1996). A pleasant odor alters the performance in an anagram task (Baron & Thomley, 1994), even though reception of a small gift has the same effect. Moreover, cross-modal affective priming with smells has been observed (Pauli, Bourne, Diekmann, & Birbaumer, 1999). Pleasant odors have been found to increase consuming behavior, but congruency between odors and objects play an important role (Mitchell, Kahn, & Knasko, 1995). In sum, on the behavioral level, it could be demonstrated that unpleasant odors lead to withdrawal rather than approach behavior, while pleasant odors have the opposite effect.

As another peripheral but also behavioral measure, breathing volume has also been shown to depend on the perceived pleasantness of odors. Pichon et al. (2015) as well as Ferdenzi et al. (2015) revealed that breathing volume increased when pleasant compared to unpleasant odors were presented. Considering the reduced inhalation as an index of avoidance, these results seem logical given the fact that unpleasant smells signal potentially harmful effects for the organism (Auffarth, 2013). The experiment by Ferdenzi et al. (2015) even demonstrated that the less intense an unpleasant odor was, the deeper the breaths that were taken. Consistently, Pichon et al. (2015) as well as He et al. (2014), Li et al. (2007), and Bensafi et al. (2002b) found a stronger heart rate increase during administration of unpleasant compared to pleasant odor. Nonetheless, the latter study demonstrated the importance of the awareness of odor pleasantness by participants. In a control task, no influence of odor pleasantness on heart rate was found but reported arousal during stimulation with odors was positively correlated to skin conductance measurements. Later studies by Glass et al. (2014) as well as He et al. (2014) demonstrated that high SCL also corresponds to low valence ratings. However, it should be taken into account that the latter study used vomit and burnt smell as unpleasant odors which both signal threat and should also correspond to high arousal. Results from the field of electromyografic (EMG) research demonstrated that, though practiced less frequently, odor pleasantness can also be displayed on this variable (Jäncke & Kaufmann, 1994). Delplanque et al. (2009) received higher activity of the *musculus corrugator supercilii* (the muscle active during frowning and therefore indicating negative affect) when presented with unpleasant than with pleasant odor. Additionally, long-term administration of a pleasant odor reduced self-reported stress and increased activity of the *musculus zygomaticus major*, an objective measure of positive affect as active when smiling (Joussain, Rouby, & Bensafi, 2014). However, subjective measures of affective state were not influenced. Results from this field of research are somewhat inconsistent and do not always display what is reflected on subjective measurements (Jäncke & Kaufmann, 1994).

While the hedonic power of odors received a lot of interest in the last decades, the reverse relationship (i.e., the influence of affective state on olfaction) has been highlighted less extensively. Still, some evidence on the influence of affective state on olfactory sensitivity has been found. Chen and Dalton (2005) were able to show that emotional vs. neutral affective state altered the perceived intensity of odors in women. Pollatos, Kopietz et al. (2007) demonstrated that when participants experienced an unpleasant affective state, olfactory sensitivity (as measured by olfactory testing) and subjective intensity ratings of odors were altered. This was paralleled by the finding that after induction of a sad affective state, chemosensory ERPs were slower and their amplitudes were lower (Flohr, Erwin, Croy, & Hummel, accepted). Moreover, anxiety induction lead to an increase in olfactory processing as reflected by altered BOLD-responses in the anterior cingulate cortex and the OFC (Krusemark, Novak, Gitelman, & Li, 2013).

1.1.4.1 The influence of affective learning

Herz (2009) stated in a review about the differential effects of odors: "[…] odors exert their effects through emotional learning, conscious perception, and belief/expectation. […] responses to odors are learned through association with emotional experiences, and […] consequently take on the properties of the associated emotions and exert the concordant emotional, cognitive, behavioral, and physiological effects themselves." (p.276).

Odor preferences seem to develop during the first years in life. Most of them are not innate, and four year old children tolerate more smells than adults, even though the children are able to better discriminate among them (Engen, 1973). Additionally, human fetuses learn preferences to those odors their mothers have been exposed to during pregnancy (Schaal, Marlier, & Soussignan, 2000). Learning therefore seems to be involved in odor preferences as they are observed in children and adults. A study by Poncelet et al. (2010) illustrates that odors smelled in earlier life stages are processed more slowly and evoke more experience-related associations than control odors. It has been proposed that learning and consequently memory consolidation lead to plastic changes (Hebb, 1949), which has been found in primary olfactory areas like the piriform cortex as well (Li, 2014). In turn, olfactory perception automatically involves memory processes (Wilson & Stevenson, 2003). In sum, emotional judgments about odors highly depend on personal learning history (Ayabe-Kanamura et al., 1998; Poncelet et al., 2010; Rouby, Pouliot, & Bensafi, 2009; Schaal et al., 2000).

Still, even in later stages of life, odor preferences can be influenced by learning processes and can even outperform prior odor preferences (Herz, Beland, & Hellerstein, 2004). Epple and Herz (1999) as well as Herz, Schankler, and Beland (2004) found that olfactory learning was able to transfer frustrated affective state from one situation into another. Specifically, participants spent less time in doing a task when they were exposed to the same olfactory context in which they had been frustrated before. Related effects have been demonstrated with subjects expressing dental fear and the application of eugenol odor that is evocative of dental offices (Robin, 1999) and with subjects suffering from post-traumatic stress disorder (PTSD) often reporting olfactory cues as elicitors of flash backs (Vermetten & Bremner, 2003). Pairing of neutral odors with unconditioned stimuli (US) has been shown to lead to augmented processing of these olfactory stimuli in conditioning paradigms (Åhs, Miller, Gordon, & Lundström, 2013; Krusemark et al., 2013; Li, Howard, Parrish, & Gottfried, 2008). Conditioning of the human eye-blink reflex to an olfactory stimulus has also been reported (Moore & Murphy, 1999). The use of either another olfactory (Stevenson, 2001) or a trigeminal substance as unconditioned stimuli (Bensafi, Frasnelli, Reden, & Hummel, 2007) led to enhanced P2 components of chemosensory event-related potentials after stimulation with the conditioned odor. Marinkovic, Schell, and Dawson (1989) demonstrated conditioned skin conductance responses after the pairing of an odor with an unpleasant electric shock (aversive US), but only if participants were aware of the contingency between the US and the conditioned stimulus (CS+).

Moreover, appetitive conditioning was found in a study that paired previously neutral odors with a sweet liquid (appetitive US) or with water (control US) that was administered to the participants' tongues. Subsequently, the odor associated with the appetitive liquid was rated as more pleasant than the control-associated odor evaluation of the same odor in a test session (Barkat, Poncelet, Landis, Rouby, & Bensafi, 2008). Accordingly, when a (neutral) massage oil was associated with a pleasant odor, the massage itself was perceived as more pleasant than receiving a massage performed with an unpaired oil (Bayens, Wrzesniewski, Houwer, & Eelen, 1996). In addition to Epple and Herz (1999), Chu (2008) was successful in demonstrating that pleasant experiences could also be transferred into another situation. Children were exposed to a certain odor while successfully solving a task. This positive effect affected a novel situation where participants were more successful in problem solving when exposed to the same odor again.

The influence of learning on odor hedonics has not only been investigated applying conditioning paradigms, but also instructed learning. Sakai, Imada, Saito, Kobayakawa, and Deguchi (2005) showed an influencing effect of cognitions about the supposed unhealthiness of odors. They led to a more negative evaluation of the odor. In a similar study by Laudien, Wencker, Ferstl, and Pause (2008), prolonged latencies of chemosensory event-related potentials were observed when odors were supposed to be unhealthy (as had been instructed before). Additionally, labeling the same odorant as body odor vs. cheddar cheese resulted in a more negative evaluation and higher BOLD-activation in the anterior cingulate cortex and the OFC in the body odor condition (Araujo et al., 2005).

1.1.5 Challenges in Smell Research

A first challenge when delving into the research field of smell is how to imitate everyday odors in the laboratory. Odors in the laboratory setting always seem rather artificial, as odors in daily life consist of thousands of different molecules and are additionally dependent on conditions of the air like humidity, temperature, and wind, as well as conditions of the perceiver. So, caution is warranted with regard to the generalizability of smell experiences evoked in the laboratory. This could be at least partly the reason for the somewhat small or even contradictory results that are often encountered in smell research, especially on the physiological level (Jäncke & Kaufmann, 1994; Møller & Dijksterhuis, 2003).

Furthermore, different effects can be found for different odors of the same hedonic tone. For example, the smell of lavender is perceived as calming and broadens the attentional focus, whereas peppermint has an arousing effect and leads to more focused attention (Colzato, Sellaro, Rossi Paccani, & Hommel, 2014). Colzato et al. (2014) as well as Sellaro, Hommel, deKwaadsteniet, vandeGroep, and Colzato (2014) found differential effects on participants' task performance. While they found a positive effect of peppermint and a negative effect of lavender on attention, Degel and Köster (1999) found a positive effect of lavender and a negative one of jasmine on working memory performance. For a review on differential effects of odorants entailing similar valence, see Herz (2009). Notably, in her review of 18 studies, Herz (2009) concludes that the most influencing factor on mood and behavior is the perceived hedonic quality of the odor. In the same regard, Burnett, Solterbeck, and Strapp (2004) found a differential effect of odors only when considering perceived quality of the odors as a covariate. Lately, it has been argued that odor effects on mood can be attributed to their hedonic tone rather than to specific qualities of the molecular structure of the odorant (Hoenen, Müller, Pause, & Lübke, 2016). Moreover, in some experiments, effects of difference in odor hedonics are only evident if participants chose the pleasant vs. unpleasant odors applied in the laboratory experiment and not if they were presented with previously chosen odors (Villemure, Slotnick, & Bushnell, 2003). These results suggest inter-individual differences in odor preferences.

According to the two-dimensional model of odor hedonics, intensity often varies across odors of different valence. That means that commonly, pleasant odors are perceived as less intense than unpleasant ones. It has been shown to be difficult to balance intensity across different stimulants. Moreover, intensity varies with stimulation time (Mainland, Lundström, Reisert, & Lowe, 2014), and this time-dependent variation might be different for different stimulants. However, as unpleasant odors become more unpleasant with increasing intensity, while pleasant odors become more pleasant with decreasing intensity, the phenomenon of unpleasant odors being rated as more intense is not uncommon (Pichon et al., 2015).

As stated above, there are countless factors influencing olfactory sensitivity and preferences for odors, among them the menstrual cycle in women (Renfro & Hoffmann, 2013). For an extensive review see Pause, Sojka, Krauel, Fehm-Wolfsdorf, and Ferstl (1996). Also, women after the menopause differ in sensitivity to odor-induced mood changes (Schiffman, Sattely-Miller, Suggs, & Graham, 1995). Caution with regard to influencing factors is therefore especially warranted when engaging in smell research.

1.2 The Processing of Social Stimuli and Their Evaluation

In the history of psychological research, social stimuli have always received special attention (Darwin, 1872; Öhman & Dimberg, 1978) given their relevance in communication and social interaction. This may be due to the fact that human beings are social organisms and that there is hardly any person not having to communicate all day long in one way or the other. Social stimuli in general (and human faces in particular) constitute an important source of information in communication and interaction (Darwin, 1872). In other words, they have been found to catch special attention (Phan & Wagner, 2004), evoke specific BOLD-responses (e.g., in the fusiform face area, Kanwisher and Yovel, 2006), and are thus preferentially processed. With regard to facial stimuli, the facial expression constitutes the main source of information and therefore received a lot of attention in the past (Darwin, 1872; Phan & Wagner, 2004). Facial expressions are sources of information, for example in the interpretation of ambiguous situations (van Doorn, van Kleef, & van der Pligt, Joop, 2015). Therefore, the following paragraph aims at giving an overview on subjective and objective reactions to social stimuli and on possible influencing factors. This attempt will be based on a statement by Lang

(1995a) according to which the processing of motivationally significant stimuli can be approached on three levels: verbal reports, psychophysiology measures, and behavioral responses.

1.2.1 Measures of Evaluation and Processing of Social Stimuli

1.2.1.1 Verbal Reports

The most straightforward method to assess social preferences is to simply ask participants how they feel towards a person or a group of persons. Both categorical approaches like basic emotions (Ekman et al., 1969) and the bimodal approach (i.e., displaying two axes of an emotional experience, them being valence and arousal) related to the circumplex model by Russell (2003) are being used in research on social preferences. Similar to the responses to odors, the latter two domains are displayed on different psychophysiological measurements (see below).

The classical way to ask for valence and arousal evoked by social stimuli has been to ask how people feel when exposed to a social stimulus (Bradley, Codispoti, Cuthbert, & Lang, 2001). This approach reflects the assumption that when exposed to an emotional stimulus, the affective state of a perceiving person would be affected in the respective manner. In other words, exposure to an aversive stimulus most certainly results in a more negative affective state, while an arousing stimulus would cause aroused feelings in the perceiver and so forth. This has been interpreted as preparation for actions and has been referred to as *motivational priming* (Lang, 1995b). Emotional facial expressions (like anger, fear, sadness, disgust, happiness or surprise) have been found to evoke higher arousal ratings than neutral ones (Langner et al., 2010). Moreover, negative facial expressions have been rated as less pleasant than neutral ones, which in turn are rated as less pleasant than positive facial expressions. This relationship has been extensively tested with the help of data bases of numerous identities performing different facial expressions and being rated by a large body of naïve raters (Goeleven, Raedt, Leyman, & Verschuere, 2008; Langner et al., 2010).

However, it can be criticized that the emotional power of, for example, emotional facial expressions is rather weak. Their influencing effect on participants' affective states would thus be rather small. A more straightforward method would be to ask participants more directly about their evaluation of a picture or situation in order to receive stronger and more distinct results (e.g., ask for perceived sympathy towards a person).

1.2.1.2 Psychophysiological Responses

As already mentioned above, ERPs are physiological indices which offer a high temporal resolution but a low spatial resolution. Importantly, they have been shown to reflect small differences of content with regard to visual, auditory, or even tactile stimuli and are reliable indices of attentional processes with respect to emotional stimuli (Olofsson, Nordin, Sequeira, & Polich, 2008). ERPs to facial stimuli have been extensively studied, hereby manipulating different features of faces, such as structural characteristics, gaze direction, and emotional expression (Wieser & Brosch, 2012). All these facial features constitute communication tools for social interplays. Emotional content has been shown to be especially important for human beings (Darwin, 1872), thereby leading to attention shifts towards emotional faces (Fenske & Eastwood, 2003) and faster reactions to them (Fox et al., 2000) in comparison to neutral faces. In particular, angry facial expressions as inherently threatening cues seem to catch special attention. In fact, Schupp et al. (2004) found enhanced early posterior negativity (EPN) and late positive potential (LPP) amplitudes to angry compared to happy and neutral facial expressions. This was replicated by Wei, Ruz, Zhao, and Zheng (2015). However, Bublatzky, Gerdes, White, Riemer, and Alpers (2014) found generally enhanced LPP, EPN, and N170 to emotional compared to neutral facial expressions without specific effects on some facial expressions.

Activation of facial muscles, i.e., muscle tension as measured by means of the EMG, can be useful to explore reactions to social stimuli in two ways. On the one hand, it constitutes an objective measure of affective state. Microexpressions of the facial muscles occur concurrently to changes in perceived valence (Baur, Conzelmann, Wieser, & Pauli, 2015; Cacioppo, Bush, & Tassinary, 1992; Ekman & Rosenberg, 1997; Wu, Winkler, Andreatta, Hajcak, & Pauli, 2012). There are various muscles which can be measured for EMG studies and the *musculus corrugator supercilii* (the “frowning” muscle, an indicator of negative affect, Lang, Greenwald, Bradley, & Hamm, 1993) as well as the *musculus zygomaticus major* (the “smiling” muscle, an indicator of positive affect, Lang et al., 1993) are the two most extensively studied ones. The corrugator muscle has been found to reflect hedonic content of pictures in a specific way, i.e., an increase in activation for unpleasant and a decrease in activation for pleasant pictures, both compared with neutral ones, whereas the zygomaticus muscle displays an increase in activation for pleasant stimuli (Cacioppo et al., 1992).

On the other hand, EMG activity has been used to study facial mimicry as a parameter of social interactions. This has been interpreted as a peripheral measure of the activity of the mirror neuron system (Rizzolatti & Fabbri-Destro, 2008). Facial expressions observed in others have been found to be imitated by observers, as can be measured by EMG activation (Dimberg & Thunberg, 1998; Stel, vanBaaren, & Vonk, 2008). Notably, the effect sizes of this imitation effect depend on various factors like sympathy, group membership (Bourgeois & Hess, 2008), personality traits like empathy (Chartrand & Bargh, 1999; Stel et al., 2008), and future interaction with the partner (Chartrand

& Bargh, 1999). Interestingly, imitating others has been found to smoothen social interactions and increase perceived sympathy (Chartrand & Bargh, 1999).

A model that comes into play when exploring psychophysiological responses to social encounters is the *defense cascade model* by Fanselow (1994). It subdivides the encounter into three different phases, depending on the proximity between the two acting parties with respect to both temporal and spatial proximity. Fanselow argues that different motivational systems are activated in the different stages of social encounter. Specifically, the model predicts orienting responses during a so-called “pre-encounter-phase”. Subsequently, in a “post-encounter-phase”, the organism stops its current action and exhibits an anxiety-related response that is associated with a deceleration in heart rate (bradycardia), while an acceleration of heart rate is predicted during the phase of actual threat (“circa-strike-phase”), i.e., when being directly exposed to an assumed opponent (Löw, Lang, Smith, & Bradley, 2008). Heart rate increase is therefore interpreted as a preparation for action (i.e., fight or flight, Fanselow, 1994). Heart rate change displays a differential effect for the emotional content of pictures, i.e., a larger initial drop for unpleasant than for pleasant pictures that in turn lead to a larger drop than neutral ones (Bradley et al., 2001). This was interpreted with respect to motivational priming (i.e., preparative freezing behavior), and it was also found for threatening compared to rewarding stimuli (Löw et al., 2008). However, there are contradicting results with regard to heart rate changes in response to affective stimuli in the phase of overt action. Thus, Löw et al. (2008) found an enhanced heart rate increase after 6 sec of presentation for rewarding compared to threatening and neutral pictures, while the model would predict the opposite effect. Also, Lang et al. (1993) showed that heart rate acceleration correlated positively with picture valence, so the more pleasant a picture was perceived, the steeper was the acceleration in the heart rate.

In contrast to heart rate change, activation of the sweat glands and thereby the electrodermal activity should increase throughout all phases of social encounter as predicted by the *defense cascade model* (Fanselow, 1994). This could be confirmed in various studies (Lang et al., 1993; Löw et al., 2008) and supports the notion of EDA serving as a measure of autonomic arousal (Bradley et al., 2001). There is a distinction to be made between tonic modulation of electrodermal activity as measured with the SCL and phasic modulation as a measure with skin conductance responses (SCR; Boucsein, 2012). Even though paradigms and analyses differ between those two variables, both seem to reflect autonomic arousal.

1.2.1.3 Behavioral Responses

A very direct behavioral measure of social interaction can be gained by collecting data about the duration of an interaction or the interpersonal distance between social agents. The interpersonal space is defined as the "buffer space" (Bailenson, Blascovich, Beall, & Loomis, 2001) that people maintain around them while interacting with others (Hall, 1959). It is a variable of interpersonality that is flexibly adjustable and frequently comes into play in everyday life. People seem to be very sensitive to interpersonal space, and there are various factors influencing it. For example, an influence of the sex of participants has been demonstrated (Bailenson et al., 2001), such that women kept larger distances to men who engaged eye-contact, whereas men did not show any difference. Moreover, it could be shown that people keep smaller distances to persons that have their eyes closed (Argyle & Dean, 1965) and show more avoidance behavior to virtual agents that perform a direct vs. averted gaze (Bailenson, Blascovich, Beall, & Loomis, 2003; Wieser, Pauli, Grosseibl, Molzow, & Mühlberger, 2010). In the latter study, this influence is moderated by the sex of virtual agents (i.e., the effect is larger for male agents) and social anxiety of participants. Emotional (vs. neutral) facial expressions led to an over-estimation of the interpersonal space, an effect that was more pronounced in women (Kim & Son, 2015). Influences on interpersonal space (i.e., sex and gaze direction) were even found in online computer role games, where both interaction partners were completely digitalized and did not interact directly (Yee, Bailenson, Urbanek, Chang, & Merget, 2007). Moreover, Castelli, Zogmaister, Smith, and Arcuri (2004) nicely demonstrated that when confronted with a member of a positively evaluated social group, approach behavior (i.e., grasping forward) was facilitated in contrast to members of a negative group. Blood testosterone concentration leads to smaller distances to potentially threatening opponents in men, while to neutral or potentially friendly opponents, no differences were found (Wagels, 2016). Concerning the duration of an interaction, Wei et al. (2015) demonstrated that it took participants longer to decide about an offered amount of money when looking into an angry in contrast to a happy facial expression. Adams and Kleck (2003b) demonstrated that the effect of gaze direction highly depended on the emotional expression shown by the face. Expressions associated with approach (i.e., happiness and anger) gained from direct gaze, such that they were detected more rapidly and more correctly, whereas expressions associated with avoidance (i.e., sadness and fear) gained from averted gaze. The duration of the interaction and the distance between social agents therefore seem to sensitively reflect interpersonal preferences in an ecologically valid way.

Another less direct behavioral variable of social preferences is collecting data about the amount of money people would offer other persons or trust other persons with. Stel et al. (2008) were able to demonstrate that people whom participants imitated more (and thus supposedly liked better) were finally donated a larger amount of money for a charity project. VanBaaren, Holland, Kawakami, and van Knippenberg (2004) found the same effect for people that were imitated by the experimenter (as measured by the readiness to help him to collect something he dropped). Moreover, Underwood, Froming, and Moore (1977) were able to demonstrate that happy affective states increased the amount of donated money to charity in contrast to neutral affective states, whereas sad affective state decreased it. A special paradigm developed to understand the rationale between economic choices is the Ultimatum Game (Güth, Schmittberger, & Schwarze, 1982). The given task is to divide an amount of money between two players. One player makes an offer which the other player can accept or decline. If the offer is rejected, neither of the two players gains any money, whereas if accepted, each player receives the indicated amount of money. While following game theory, it would be logical to accept any given offer, it has been shown that both proposer and receiver behavior can be influenced by various factors such as perceived fairness (Camerer, 2003), gender (Solnick & Schweitzer, 1999), mood (Harlé & Sanfey, 2007; Moretti & Di Pellegrino, 2010; Pillutla & Murnighan, 1996), perceived attractiveness (Solnick & Schweitzer, 1999; Zaatari, Palestis, & Trivers, 2009), or altruism (Rodrigues, Ulrich, & Hewig, 2015). There seems to be a general effect of unpleasant emotional states. Sadness (Harlé & Sanfey, 2007), disgust (Moretti & Di Pellegrino, 2010), as well as anger (Pillutla & Murnighan, 1996) lead to more rejections of unfair offers than neutral affective state. Moreover, rejection of unfair offers seems to be associated with high subjective and autonomic arousal (van'tWout, Kahn, Sanfey, & Aleman, 2006). To extend findings of the approach task, offers in the Ultimatum Game were lower if men were administered testosterone beforehand (Zak et al., 2009).

1.2.2 Influencing Factors on the Processing of Social Stimuli

1.2.2.1 Learning Processes

It can be assumed that only the very basic features of social interaction are innate as, for example, the baby's attraction to its mother (McFarlane, 1975). Throughout ontogenesis, a human being learns to navigate the social world with all its rules and habits. Social preferences are formed this way, and social behavior is adopted by means of model learning, classical conditioning, and operant conditioning (and to be exhaustive, even though less important for young infants, instructed learning also plays its part, Phelps et al., 2001). A prominent explanation of the formation of social preferences is offered by the *reinforcement-affect model of attraction* (Byrnes & Clore, 1970). It refers to the ability of other people to reward or punish human beings directly. These agents then become associated with rewarding or penalizing experiences through classical or operant conditioning processes. Thereby, the interacting person serves as CS and the consequence of the interaction as US. In simple words, people tend to like others with whom they associate pleasant experiences and dislike those with whom they have made unpleasant experiences before (Byrnes & Clore, 1970). Interestingly, threatening (i.e., angry) facial expressions are more easily conditionable, and human beings thus exhibit some sort of preparedness towards threatening effects of angry facial expressions as reflected by enhanced SCRs (Öhman & Dimberg, 1978). This is most probably due to angry faces having been paired with unpleasant experiences before. Interpersonal preferences (and consequently social behavior) seem to rely on aversive or appetitive experiences that have been made with the same (or another) person before. A plethora of studies supports the fact that learning plays its part in the formation and maintenance of social preferences (Büchel, Morris, Dolan, & Friston, 1998; Dawson, Rissling, Schell, & Wilcox, 2007; Luo, Wang, Dzhelyova, Huang, & Mo, 2016). Büchel et al. (1998) found enhanced BOLD responses in areas related to emotional processing (i.e., in the anterior cingulate cortex and the insula) towards faces that had been paired with an aversive US before. It could be shown that aversive expectations had a greater impact than appetitive ones (Lissek et al., 2008), meaning that faces that had been paired with pleasant verbal labels did not differ from unpaired faces whereas faces paired with unpleasant verbal labels were associated with potentiated startle responses. This finding is paralleled by results of the N170 and EPN component in the study by Luo et al. (2016). Thus, learning factors play an important role, either by external stimuli paired with an interacting person (like something happening during or after the social interaction) or by features within the interacting persons (like facial expression, verbal comments etc.).

Interestingly, the awareness of the contingency between facial stimuli and a reinforcing unconditioned stimulus has also been proven to be an important factor (Dawson et al., 2007). Namely, participants who were able to recall contingency between the US and the facial CS+, showed a more consistent pattern of conditioning effects than participants that were not able to do so. However, an inconsistent body of results has been found concerning the influence of awareness on conditioning processes (Hamm & Vaitl, 1996). Therefore, in studies on learning processes in social situations, the factor of contingency awareness should be taken into account.

1.2.2.2 Contextual Factors

In daily life, social actors are never encountered in isolation; they always appear in a certain context (Wieser & Brosch, 2012). Contexts are long-term background stimuli. Thus, they are characterized by long duration and can be constituted of environmental stimuli or within-perceiver factors (Wieser & Brosch, 2012). The emotional content of the context influences the processing of social agents that one interacts with and that are perceived within this context. Moreover, the hedonic value of environmental factors relates directly to interpersonal relations happening within this environment (Byrne, Allgeier, Winslow, & Buckman, 1975). A dissociation can be observed between a general influence of the context, such that facial cues that are perceived within an unpleasant context are processed preferentially independent of the expression that is shown (Dunning, DelDonno, & Hajcak, 2013; Righart & de Gelder, 2005; Rubin et al., 2012), and a specific influence of the context on facial expressions, such that in a threatening context, fearful facial expressions gain additional value compared to neutral facial expressions (Grillon & Charney, 2011; Righart & de Gelder, 2005). Not only negative but also positive influences of contexts on the processing of social cues can be observed. May and Hamilton (1980) were able to show that pleasant music alters women's judgments regarding the attractiveness of men when rated in contrast to unpleasant music.

However, not all stimuli are equally prone to be influenced by a surrounding context. In their review about contextual influences on face processing, Wieser and Brosch (2012) conclude that the context's emotional content gets more important the more ambiguous the emotional significance of the face is. Following this argumentation, neutral facial expressions should be more easily influenced by contextual stimuli than faces displaying a clear emotion (Somerville, Kim, Johnstone, Alexander, & Whalen, 2004; Yoon & Zinbarg, 2007, 2008).

Not only external contextual stimuli, but also internal contextual states influence variables of social interaction. Affective states of perceiving persons play an important role in social interaction. For example, a differential effect of affective state in social interaction paradigms could be found, such that Underwood et al. (1977) found a linear increase in generous behavior from sad affective state to neutral to happy as measured by the amount of donated money. Bublatzky et al. (2014) were able to show that the expectancy to further interact with persons shown on pictures leads to higher LPP amplitudes for happy facial expressions than when not expecting to interact with them. Moreover, Wieser, Pauli, Reicherts, and Mühlberger (2010) found enhanced EPN amplitudes for angry facial expressions when participants were preparing to give a public speech. This suggests that not only the fact that a person is going to play his or her part in a future interaction but also the kind of interaction plays a role in face perception.

1.2.2.3 Social Anxiety

There are various within-subjects factors influencing social behavior and the processing of social cues. The present thesis focuses on the most prominent influencing factor among them that is trait social anxiety. It is a personality trait characterized by a fear to be exposed to or evaluated by other persons (American Psychiatric Association, 2000). Next to a general influence of trait anxiety as a personality factor, social anxiety is especially prone to influence face perception and social interaction (Mogg & Bradley, 2002). High socially anxious participants are found to display a stronger attention bias towards threatening facial cues, such as angry faces, than control participants. This is reflected on the behavioral (Garner, Mogg, & Bradley, 2006; Mogg & Bradley, 2002) as well as on the physiological level (Wieser, McTeague, & Keil, 2012), the latter being characterized by enhanced steady-state visually evoked potentials for angry facial expressions in high vs. low socially anxious individuals. Moreover, effects of social anxiety were found on approach and avoidance behavior in a VR paradigm (Garau, Slater, Pertaub, & Razzaque, 2005; Wieser, Pauli, Grosseibl et al., 2010). Namely, low socially anxious participants were not influenced by the gaze direction of the avatars, whereas high socially anxious women showed more withdrawal behavior when the avatar was looking directly at them (Wieser, Pauli, Grosseibl et al., 2010). Learning factors also seem to come into play in high socially anxious individuals, especially regarding social aversive conditioning (Lissek et al., 2008). Moreover, the influence of threatening contexts on face processing (i.e., facial cues that are presented within a threatening olfactory context are preferentially processed) has been found to be more pronounced in high socially anxious as compared to low socially anxious individuals (Adolph & Pause, 2012). The pronounced processing of social stimuli in high vs. low socially anxious participants has additionally been shown to lead to a less pronounced differentiation between emotional facial expressions as reflected on reduced LPP amplitudes (Mühlberger et al., 2009). The authors interpreted this reduction of LPP amplitude as a general increase of arousal towards social stimuli in social anxiety, which impairs the processing of facial expressions.

1.3 Interdependency of Olfaction and Social Interactions

Low (2005) wrote a sociological essay illustrating the role of olfaction in social life in a vivid way (p.399): “And whether we like it or not, we remain odoriferous beings despite all our cleaning routines; and these odours play important roles in virtually every sphere of social interaction […]”. He describes odors as intriguing factors of the constitution of the social identity, as they correspond to personal characteristics like sex, race, and ethnicities. It could even be shown that olfactory abilities are correlated to emotional empathy (Spinella, 2009).

1.3.1 The Influence of Body Odors

Body odor has been revealed to be one of the most reliable factors influencing interpersonal attraction (Herz & Inzlicht, 2002). In fact, unpleasant body odors have been associated with negative personality traits (McBurney, Levine, & Cavanaugh, 1976), and people may judge certain personality traits from the body odor of other people (Sorokowska, Sorokowski, & Havlíček, 2016). In contrast to olfactory abilities, this tendency has even been shown to be equally important in men and women (Franzoi & Herzog, 1987). In their review about olfactory communication, Stockhorst and Pietrowsky (2004) state that influencing hormones are found in body secretions such as sweat, urine, and vaginal discharge, while due to obvious reasons, the most prominent body of research concentrates on social communication via human sweat. Body odors transmit different kinds of information about human beings, such as affective states. For example, information about the menstrual cycle of women can be transmitted via underarm sweat and leads to adaptation of the cycle (Stern & McClintock, 1998). Even human tears contain chemosignals, such that men report less sexual arousal, the galvanic skin response increases, and the testosterone level decreases when exposed to female faces while smelling female tears in contrast to saline water (Gelstein et al., 2011).

A prominent method to evaluate chemosensory communication between humans is to collect anxiety sweat from a sample of donors that find themselves under conditions of stress (e.g., directly before an exam or while performing a high rope course). These samples are compared with samples of sport sweat when applied to participants. The effectiveness of this method has been demonstrated in a plethora of studies (Adolph, Meister, & Pause, 2013; Albrecht et al., 2011; Zernecke et al., 2011) on both subjective and objective variables (Mujica-Parodi et al., 2009; Pause, Adolph, Prehn-Kristensen, & Ferstl, 2009). Still, not only threat but also aggression (Mutic, Parma, Brünner, & Freiherr, 2016) and competition (Adolph, Schlösser, Hawighorst, & Pause, 2010) seems to be transmitted via human body odors leading to enhanced skin conductance responses in receivers. Nonetheless, the question arises whether the effect of anxiety and competition signals is not really a specific one but rather an unspecific effect of experienced arousal in donators. Other authors, however, achieved a double dissociation in a double-blind study between sweat samples after induction of disgust vs. anxiety (deGroot et al., 2012), indicating that the induction of affective state is a specific effect and not only mediated via affective state.

The impact of chemosensory information on face processing has mainly been investigated using chemosensory anxiety signals as context stimuli (Rubin et al. 2012; Adolph et al. 2013). Neutral as well as emotional faces elicited higher P1, N170 (Adolph & Pause, 2012), and LPP amplitudes (Rubin et al., 2012) in the presence of a threatening body odor compared to a neutral body odor (Adolph et al., 2013; Rubin et al., 2012) with an especially strong influence on neutral or ambiguous facial expressions (Rubin et al., 2012). Chemosensory threat stimuli lead to higher arousal ratings of faces (Adolph et al., 2013). Presentation of chemosensory threat signals influence emotion perception in a hedonic-specific way (Zhou & Chen, 2009). Thus, ambiguous facial expressions are evaluated as less happy in the context of anxiety sweat (Zernecke et al., 2011), and the discrimination between threatening and non-threatening faces is sharpened (Mujica-Parodi et al., 2009). It has even been proposed that smelling chemosensory threat signals automatically activates empathy-related resources in the brain, as it activates similar neural circuits as empathy-associated tasks (Prehn-Kristensen et al., 2009). A more straight-forward method is to extract pheromonal substances from human body odors. It could be shown that male pheromones facilitate social interactions in female receivers (Cowley & Brooksbank, 1991) and that approach to and withdrawal from faces is facilitated under conditions of masked androstadienone administration with a special boost for angry facial expressions (Frey et al., 2012).

To summarize, a large body of literature exists supporting the influence of human pheromones, whether they might be in their pure state or transmitted via sweat samples, on face processing and social behavior. The underlying mechanisms of these effects are, however, hard to distinguish from possible confounding factors, and the processing of human pheromones has not been extensively explored. How and whether the nose and olfactory processing comes into play when talking about pheromonal signaling is another open question. The next paragraph therefore summarizes the literature treating the subject of purely olfactory fragrances on the processing of social cues.

1.3.2 The Influence of Purely Olfactory Fragrances

The discrimination between smells which are directly attributable to persons and smells which exude from the surrounding air is, of course, an artificial one, and the decision line to discriminate between both is thin. However, as this differentiation is of special importance for most of my studies, for the following paragraph, literature is divided into these two categories.

1.3.2.1 Personally Attributable Smells

A large body of evidence for the influence of olfactory stimuli on emotional processing of social situations comes from classical olfactory conditioning of social stimuli, i.e., olfactory cues constitute the USs, and social stimuli serve as CSs. It has even been argued that during conditioning processes, an odor becomes part of the social Gestalt of a certain person (Kirk-Smith & Booth, 1987). Gottfried, O'Doherty, and Dolan (2002a) conducted a study where they paired a pleasant, an unpleasant, and a neutral odor with three neutral faces (appCS+, neuCS+, and avCS+) respectively, while a fourth face remained unpaired (CS-). After conditioning, BOLD response was analyzed for the faces alone. They were able to show that central nervous processing displayed olfactory learning processes, with differential activation in the OFC, the amygdala and the piriform cortex to appetitive vs. aversive CS+. Additionally, they found activation differences in the nucleus accumbens, highlighting the involvement of the reward system in this kind of learning. Faces paired with pleasant vs. unpleasant odors also gain significance as measured by subjective ratings (Gottfried et al., 2003b). Besides, the latter study showed that olfactory extinction learning enhances activation in the OFC and the amygdala, indicating that extinction learning might also be transmitted via this neural system. On the same account, Hermann, Ziegler, Birbaumer, and Flor (2000) performed appetitive and aversive conditioning of neutral male faces by the help of odors. They found stronger effects for the aversive conditioning than for the appetitive one. Precisely, they were able to show that pairing of faces with an unpleasant odor led to lower valence and higher arousal ratings, a trend towards higher activation of the corrugator muscle, higher SCRs, and higher amplitudes of the late positive complex (LPC) of the EEG as compared to a facial CS-. However, there were no differential effects on the heart rate, startle response, zygomaticus muscle, and other ERP-components. For appetitive conditioning, the authors found higher arousal ratings and marginally higher amplitudes for the N1 and the LPC than for a CS-. On all other variables, no differential effect of appetitive conditioning could be shown. This study demonstrates that effects of olfactory conditioning are rather small and not always consistent throughout different variables. The authors replicated a similar study with only aversive conditioning and its influence on social phobic participants (Hermann, Ziegler, Birbaumer, & Flor, 2002). This time, they found a somewhat more consistent result pattern on subjective ratings, corrugator activation, startle response, and skin conductance response. No enhanced conditionability was found for socially phobic participants. Nonetheless, socially phobic participants exhibited an expectancy bias for both the CS+ and the CS- and a delayed extinction of the conditioned SCR, pointing towards an impaired learning of the safety signal. Olfactory conditioning of faces has also been shown to evoke differential responses on early and late components of the magnetoencephalogram (MEG) in a study by Steinberg et al. (2012). Still, even though it seems obvious to use pictures of faces for olfactory conditioning, the above mentioned results do not answer the question whether the observed effects are really social in nature or whether similar effects would also have been found with pictures of objects instead of faces. However, they support the importance of olfactory stimuli in the process of social preference learning.

Todrank, Byrnes, Wrzesniewski, and Rozin (1995) conducted a series of studies where participants rated photos of different persons who were previously paired with pleasant or unpleasant odors. Primarily, they were able to show that unpleasant odors decrease pleasantness ratings, while pleasant ones increase them. However, as they demonstrated in a second study, this relationship was only found if odors were semantically attributable to humans and not if they were semantically unconnected. These results point towards the importance of attribution of smells to the social agent in order to influence social interaction. Nonetheless, the same results could possibly also have been obtained by the use of objects and semantically related olfactory stimuli.

Having stated that, one comes across some studies that did not explicitly apply classical conditioning paradigms in order to explore the influence of odors on social variables, but simply presented odors and social stimuli simultaneously. This approach holds an obvious drawback that is the so-called "halo-dumping": When presenting two stimuli at the same time, one cannot be sure whether a hypothetical effect would be due to one or the other stimulus or to the interaction of both. Still, this approach nicely displays what humans encounter in daily life when meeting persons for the first time. Pleasant olfactory stimuli alter perceived attractiveness of neutral faces (Cook et al., 2015; Dematte, Osterbauer, & Spence, 2007). The study by Dematté and colleagues did not find any effect for "body odor" vs. "non-body odor", i.e., easily attributable vs. not so easily attributable smells. Kirk-Smith and Booth (1990) found an influence of smells on social preferences next to an influence of the attributional features of the olfactory sensation. Whether and how the effect unfolded depended on how easily attributable the smell was. Congruently to studies of olfactory conditioning, it could be shown that priming with pleasant or unpleasant odors leads to higher amplitudes in different late components of the EEG after presentation of neutral faces (Cook et al., 2015) compared to unpaired faces. One study that tried to overcome the problem of halo-dumping has been conducted by Li et al. (2007). It was shown that subliminally presented odors influenced social preferences in the way that faces presented together with a pleasant odor were rated as more pleasant than those presented together with an unpleasant odor. Interestingly, the differences disappeared if participants successfully detected the odor. However, for heart rate changes after picture presentation, no influence of awareness was found. Bensafi et al. (2002) also found no effect of supraliminally presented smells on the evaluation of faces, but a differential modulation of a pleasant odor (vs. no-odor control) on late components of the EEG. An interesting approach is found in a study by Baron (1981a). In fact, he was able to demonstrate that wearing perfume increases ratings of likability and attractiveness, but only in informal relationships and not in formal ones, in particular when females were judging men. Additionally, wearing perfume increased the likelihood to succeed in job interviews (Baron, 1983).

1.3.2.2 Surrounding Smells

A recent study by Leleu et al. (2015) applied affective olfactory contexts (i.e., pleasant vs. unpleasant vs. no-odor) on face processing. Recording EEG components (i.e., the P1), they were able to demonstrate that olfactory (vs. no-odor) contexts facilitated the processing of faces independently of their emotional expressions. Additionally, they found a differential effect of the unpleasant odor on the processing of the P2-component for happy and disgusted expressions, but not for the processing of angry, fearful, sad, and neutral facial expressions. Forscher and Li (2012) demonstrated a differential effect on subliminal fearful vs. neutral facial expressions within an aversive olfactory context, while in a neutral olfactory context, no differences were found. This preferential processing was reflected on both reaction times and ERP components (i.e., larger P1 and N170 amplitudes). In other words, aversive olfactory contexts seem to boost the perception of fearful facial expressions. Seubert et al. (2010) found a greater insula activation as the response of a combination of a disgusted facial expression and an unpleasant smell. However, participants' reaction times were slower for disgusted and quicker for happy facial expressions in any olfactory context, regardless of its hedonic value.

A study by Kirk-Smith and colleagues (1983) demonstrated that performing a stressful task in a subliminal olfactory context afterwards leads to an evaluation of faces as being more anxious in the same context. However, this study has afterwards been critically discussed by an article in the same journal (Black & Smith, 1994) with regard to its unsound design and analysis. Rotton, Barry, Frey, and Soler (1978) exposed participants to ammonium sulfide (smelling like rotten eggs) in a room and asked them to rate pictures of other persons. Interestingly, evaluations suffered from the unpleasant smell of the room, meaning that the persons were evaluated more negatively, but only if people were told that they would not meet the persons afterwards. Additionally, participants spent less time in the polluted environment than in a control environment. A successive study tried to replicate these results while adding verbal descriptions of the persons to be rated. An effect of the polluted air was only found for moderate but not for extreme descriptions (Rotton, 1983). This indicates that extreme stimuli may not be influenced by polluted air, but moderately extreme stimuli might be prone to influence from the surrounding air. Besides, the reaction time advantage to happy facial expressions found in a neutral and a pleasant olfactory context disappears in an unpleasant olfactory context (Leppanen & Hietanen, 2003).

Baron (1997b) demonstrated that pleasant ambient fragrances lead to a higher likelihood of participants to pick up a fallen pencil (interpreted as pro-social behavior), but also to a more positive mood, suggesting a possible mediation of the influence of smells on social behavior via affective state. In line with this, a second study demonstrated that pleasant fragrances as well as a little gift increases the likelihood of participants volunteering to help the experimenter with an extra task (Baron & Thomley, 1994).

1.3.3 Explanatory Model of the Influence of Smells

As was nicely demonstrated in the experiment of Baron and Thomley (1994), the presentation of a pleasant smell alters the willingness of participants to help in an additional task. On the other hand, the donation of a small gift had the same effect as smelling something pleasant. The authors argue that the presentation of pleasant odors leads to a more positive affective state, which in turn could influence pro-social behavior. This argumentation could be generalized for all influences of smells on social interaction. As has been demonstrated above, hedonic odors are potent sources of positive or negative affect respectively. In turn, this positive or negative affect could serve as a facilitating or inhibiting factor in social interactions. The influence of hedonic odors on human social behavior could therefore be mediated by affective states. Whether a direct influence of smells also accounts for perceived changes in social interaction variables is yet to be shown. A schematic drawing of the hypothesized relationship is depicted in Figure 1.

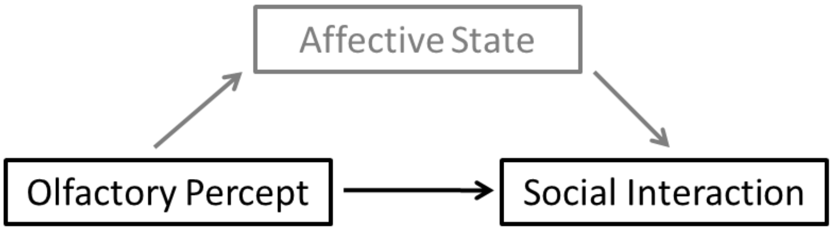

Figure 1: Hypothetical Model about a possible mediation of the influence of smells on social interactions.

The present thesis approaches this question by disentangling the influence of smells that are directly attributed to the social agent from the influence of contextually attributed smells. A potential direct influence of the smells on social interaction should result in larger effects of the hedonic smells in the social attribution, whereas an effect that is only mediated via affective state – or any other mediating factor – would result in equally large effects in both attributions.

1.4 Research Question and Hypotheses

Which is the influence of hedonic odors on social interactions? And how would odor attribution (person vs. context) mediate social interactions? This thesis aimed at exploring the interplay between odors and the evaluation of social stimuli and their processing. On the one hand, it compared the influence of unpleasant odors in contrast to pleasant ones on several indices such as verbal, psychophysiological, and behavioral measures. In a first study, the hedonic value of an initially neutral odor was changed by applying a context conditioning paradigm and by pairing the odor with an unpleasant unconditioned stimulus. In a second step, the influence of this threatening conditioned olfactory context (in contrast to an unpaired safety olfactory context) on the processing of emotional facial expressions was explored. In a third step and a different paradigm, it was investigated how odors which were initially evaluated as pleasant or unpleasant influenced the interaction with social agents displaying emotional facial expressions.

Another main goal of the thesis was to disentangle the influence of odors deriving directly from a social agent from the influence of a rather contextual odor. This was operationalized by implementing a VR paradigm, where virtual agents were placed in virtual offices. Social attribution was accomplished by placing two different agents alternately in the same office, one being associated with a pleasant and one with an unpleasant odor. The contextual attribution was accomplished by placing the same agent alternately in two virtual rooms, one room being associated with the pleasant and one with the unpleasant odor (Study 2 to Study 4).

I hypothesized the following:

(1) Odor valence (i.e., pleasant vs. unpleasant odors) should influence the processing and the evaluation of social stimuli independently of odor attribution, such that social stimuli paired with unpleasant odors are evaluated more negatively and are preferentially processed in comparison to pleasant odors. Specifically:

   a) Social stimuli presented in association with an unpleasant (or threatening) odor should be rated as less pleasant, more arousing, and less likable, compared to the social stimuli presented in association with the pleasant (or safety) odor. Next to a general influence of odors on evaluation and processing of social stimuli, different facial expressions should be distinctly influenced, such that the processing of the angry facial expression should be additionally boosted in combination with the unpleasant odor.
   b) Higher amplitudes of the LPP (Study 1 and 2), higher activity of the corrugator muscle (Study 1 and 2), and higher SCL (Study 1 to Study 4) are expected when exposed to unpleasant compared to pleasant odors. Next to a general influence of odors on the evaluation and processing of social stimuli, different facial expressions should be distinctly influenced by unpleasant compared to pleasant odors. Moreover, a flattening of the breathing curves (Study 2) and lower amplitudes of late components of the heart rate (Study 3 and 4) should be observed.
   c) Social behavior should be inhibited by the unpleasant compared to the pleasant odor, as reflected in greater distances kept between participants and virtual agents (Study 2 and 3) and less money offered to them (Study 4).

(2) The influence of hedonic odors on the processing of social stimuli should be stronger if the odors are associated with the social agent than if they are associated with the context (Study 2 to Study 4).

  a) Amplitudes of the LPP, corrugator activity, SCL, heart rate, ratings, and the behavioral measures (i.e., money distribution and distance to agents) are expected to display more accentuated differences in the social than in the contextual attribution. The interaction effect of odors and facial expressions should be especially pronounced in the social attribution condition.
  b) This holds true whether the attribution is manipulated between-subjects (Study 2) or within-subjects (Study 3 and Study 4).

(3) Social anxiety trait and contingency awareness should influence the processing of both facial cues and affective learning. These variables will be taken into account as exploratory between-subjects factors.

  a) High socially anxious participants should on the one hand display more pronounced emotional reactions towards all social cues as compared to low socially anxious participants, as reflected on measures of autonomic (i.e., SCL) and subjective arousal (i.e., ratings). On the other hand, this boosted arousal should lead to a reduced differentiation between different social cues, i.e., reduced differences between different facial expressions and the two odor conditions.
  b) Participants who are aware of the contingency (between odor and US in Study 1 and between odor and agent/room in Study 2 – 4) should display stronger effects than unaware participants on all verbal, psychophysiological, and behavioral dependent variables. This means that differences between unpleasant and pleasant odors should be larger in the subgroup of aware participants as well as that the differences between the attribution conditions should be especially pronounced in this subgroup.

2 Study 1: On Learned Affective Olfactory Contexts and Social Cues

The present study has, in a slightly changed form, been published in *Chemical Senses* (Kastner, Flohr, Pauli, & Wieser)[4].

2.1 Introduction

Odors play an important albeit subtle role in transferring information about the surrounding world. They serve as potent contextual cues to evoke associations of former experiences (Arshamian et al., 2013; Herz, 1996). If these experiences are aversive, an odor gains threatening value and constitutes an aversive context. This process can be regarded as a special kind of contextual conditioning. Context conditioning occurs if aversive events cannot be predicted by a specific cue, thus are unpredictable, and as a consequence become associated with the context (Davis, Walker, Miles, & Grillon, 2010; Mol, Baas, Grillon, van Ooijen, & Kenemans, 2007). The olfactory system is especially prone to evoke immediate emotional responses as it entertains direct connections to the limbic system without being gated through the thalamus (Gottfried, 2010). Odors are stimuli that are often present in the environment without being attributed to a special object or person, thus they frequently serve as transmitters for contextual information. Moreover, emotional judgments about odors highly depend on the personal learning history (Ayabe-Kanamura et al., 1998; Poncelet et al., 2010; Rouby et al., 2009; Schaal et al., 2000) so that the smell of lavender, for example, may be highly pleasant for one person, while evoking unpleasant feelings in another. Pairing of odors with USs has been shown to lead to augmented processing of these olfactory stimulants in cue conditioning paradigms (Åhs et al., 2013; Krusemark et al., 2013; Li et al., 2008). However, due to their special nature, i.e., being able to evoke affective states in a very direct way and often being rather vaguely present in the environment, odors seem to be perfectly suited for context conditioning. However, to my knowledge research on the effects and potentials of olfactory context conditioning on explicit and implicit variables to contexts is scarce. A study by Kirk-Smith and colleagues (1983) demonstrated that performing a stressful task in a subliminal olfactory context led to an evaluation of faces as being more anxious in the same context. Additionally, Epple and Herz (1999) as well as Herz et al. (2004) demonstrated that olfactory context conditioning was able to transfer frustrated behavior into another situation. Participants spent less time on a certain task

[4] The study has been designed and data have been collected, preprocessed and analyzed by Anna K. Kastner and Elena L. R. Flohr equally. Both participated to equal parts in the publishing process. The work was supervised by Paul Pauli and Matthias J. Wieser. It was noted in the paper that the work was part of Elena Flohr's dissertation project.

when they were exposed to the same olfactory context in which they had been frustrated before. Therefore, transmission of affective states via olfactory context conditioning seems to be successful; still, controlled paradigms of olfactory context conditioning inducing sustained anxiety are still to be implemented.

Contexts can be defined as background stimuli in which learning takes place. As such, one important characteristic is its long-term duration (Bouton, 2010). Thereby, a visual or situational context stimulus with a duration of 8.5 to 20 sec was previously shown to be sufficient to elicit context-related anxiety responses (Kastner, Pauli, & Wieser, 2015; Mol et al., 2007). Due to US unpredictability, the context later creates a chronic expectation of the aversive event and therefore a feeling of sustained anxiety (in contrast to phasic fear in cue conditioning; Davis et al., 2010). In a differential context conditioning paradigm, one paired context (CTX+) gains threatening value, while a second unpaired context (CTX-) becomes a signal for safety. Human context conditioning studies revealed that a threatening context compared to a safety context elicits startle potentiation (Baas, Nugent, Lissek, Pine, & Grillon, 2004; Glotzbach, Ewald, Andreatta, Pauli, & Mühlberger, 2012; Grillon, 2002; Vansteenwegen, Iberico, Vervliet, Marescau, & Hermans, 2008), increased skin conductance levels (Glotzbach-Schoon et al., 2013), enhanced steady-state visually evoked potentials (Kastner et al. 2015), and avoidance behavior as well as reports of increased anxiety and arousal and decreased valence ratings (Glotzbach et al., 2012; Grillon, Baas, Cornwell, & Johnson, 2006). Thus, due to the discussed theoretical implication, it seems reasonable to examine context conditioning with odors serving as contexts in the laboratory.

Since contextual stimuli are seldom observed in isolation and mostly serve as a surrounding environment, it is also of interest to investigate how facial stimuli might be processed within an olfactory context. This is even more relevant when considering that face processing within contexts is facilitated (Wieser & Brosch, 2012). Moreover, the effects of odor contexts on face processing seem interesting especially due to the ability of odors to evoke immediate emotional responses. Faces are of special importance for human beings, as the facial expression is an important source of information in communication and social interaction (Darwin, 1872; Dimberg & Thunberg, 1998; Öhman & Dimberg, 1978). Emotional faces were found to be processed preferentially compared to neutral ones in a plethora of studies (Phan & Wagner, 2004; Schupp et al., 2004). For example, Schupp and colleagues used angry, happy, and neutral faces in a free viewing paradigm and recorded ERPs. They found that EPN and LPP amplitudes were enhanced for angry compared to happy and neutral faces (Schupp et al., 2004). Moreover, in another study, emotional compared to neutral faces elicited higher N170, EPN, and LPP amplitudes (Bublatzky et al., 2014). Additionally, facial expressions are processed depending on the hedonic evaluation of the context such that the processing of faces presented within a threatening context was enhanced (Dunning et al., 2013; Righart & de Gelder, 2005; Rubin et al., 2012). A differential impact of the context can be observed on the perception of emotional faces, such that fearful faces elicit startle potentiation in a threat-of-shock context compared to neutral faces in the same context (Grillon & Charney, 2011).

Notably, so far, the impact of olfactory information on face processing has mainly been investigated using chemosensory anxiety signals (i.e., body odors) as context stimuli (Adolph et al. 2013; Rubin et al. 2012). Neutral as well as emotional faces elicited higher LPP amplitudes in the presence of a threatening body odor compared to a neutral body odor (Rubin et al., 2012), and chemosensory threat signals influence emotion perception in a hedonic-specific way (Zhou & Chen, 2009), such that ambiguous facial expressions were interpreted as more fearful in the context of threat odor. Additionally, chemosensory threat stimuli lead to higher arousal ratings of pictures (Adolph et al., 2013) and pleasant olfactory stimuli alter perceived attractiveness of neutral faces (Dematte et al., 2007). A recent study by Leleu et al. (2015) applied affective olfactory contexts (i.e., pleasant vs. unpleasant vs. no odor) on face processing. Recording ERP components (namely the P1), they were able to demonstrate that olfactory contexts facilitate the processing of faces independently of their emotional expression. Additionally, they found a differential effect of the unpleasant odor on the processing of happy and disgusted expressions, indicated by an enhanced P2 component for these facial expressions within a threatening context, while for other emotional expressions, no differences between the contextual odors were found. Forscher and Li (2012) demonstrated enhanced N170 and P1 amplitudes for subliminal fearful vs. neutral facial expressions within an aversive olfactory context, while in a pleasant olfactory context, no difference was found. However, this far, it is still unclear how initially neutral odors can modulate the processing of emotional faces after aversive olfactory context conditioning.

Thus, the present study has two aims: (1) to design an olfactory context conditioning paradigm showing that previously neutral odors may become contexts of anxiety and safety and (2) to investigate the impact of the threat vs. safety odor contexts on the processing of different facial expressions. In order to achieve these goals, differential context conditioning was performed using two originally neutral odors as to-be-conditioned contextual stimuli, both being presented for 20 sec. This duration was confirmed as sufficiently long to elicit sustained anxiety responses with visual stimuli (Kastner et al. 2015). One odor (anxiety context or CTX+) was associated with an aversive auditory stimulus (US) presented unpredictably, while the other odor (safety context or CTX-) was never presented in association with the US. After the conditioning phase, neutral, fearful, and angry faces were presented within both contexts.

This study assessed explicit (ratings of valence, arousal, sympathy, and anxiety) and implicit (SCL, ERPs) responses triggered by the contexts as well as the faces. On the implicit level, the SCL was assessed in order to obtain a continuous measure of autonomic arousal during the anxiety and safety context, while the LPP allowed observing fast (or phasic) changes in face processing. Specifically, I hypothesized that after context conditioning, the odor constituting the anxiety context triggers increased anxiety and arousal ratings and decreased valence ratings. In this vein, I also expected larger SCL and LPP amplitudes to the gray background screen, which signals the onset of the respective context when the anxiety odor was present. These variables should reflect enhanced processing of the CTX+. In addition, I expected that faces presented within the CTX+ are processed in a prioritized manner, which should be reflected by both implicit and explicit indices. Thus, faces presented within the olfactory anxiety context should be perceived as more anxiogenic, arousing, and unpleasant than faces within the safety context. Moreover, they should also evoke higher SCL and LPP responses. These effects should be especially pronounced when an angry face is presented. The contingency awareness between US and CS+ has been shown to play a role on conditioning studies with flavored drinks (Wardle, Mitchell, & Lovibond, 2007). It was therefore taken into account with respect to context processing. With respect to face processing, social anxiety was added as an additional factor.

2.2 Materials and Methods

2.2.1 Participants

Thirty-five subjects were recruited for the study via advertisements on a local online recruitment platform. To control for potential influence of odor perception capacity, a smell screening was performed. The screening version of the Sniffin' Sticks (Hummel, Konnerth, Rosenheim, & Kobal, 2001a) was used. This version uses 12 samples of the odor identification test of the Sniffin' Sticks battery (Hummel, Sekinger, Wolf, & Kobal, 1997). It contains 12 sticks filled with smelling liquids, which participants have to identify using a 4-answers-forced-choice test. A threshold of 9 out of 12 right classifications was set to make sure that subjects were able to perceive the applied odors. All participants who did not meet this threshold criterion were excluded from the study (n=7), resulting in 28 participants. Only female participants were investigated. The mean age was 25.46 years (ranging from 19 to 34 years). Participants received a payment of 10€ for their participation.

2.2.2 Stimuli and Apparatus

2.2.2.1 Pictures and Sound

As US, an unpleasant female scream was used (presentation duration was 1500 ms), presented at 95 dB, in order to increase the semantical "belongingness" between the facial stimuli and the US. This refers to the idea, that certain contingencies between an aversive outcome and a stimulus are easier learned than others (Hamm, Vaitl, & Lang, 1989). The scream was taken from the International Affective Digitized Sounds Database (IADS; Bradley and Lang (2007); sound number 276, FemaleScream2) and evaluated on 9-point Likert-scales by the participants as highly unpleasant (M = 1.57, SD = 1.35), highly arousing (M = 7.32, SD = 1.72), and anxiogenic (M = 6.25, SD = 1.99), all differing significantly from a medium level of valence ($t[27] = 13.49$, $p < .001$), arousal ($t[27] = 7.13$, $p < .001$), and from the lowest level of anxiety ($t[27] = 13.94$, $p < .001$). See procedures for anchor descriptions of the scales.

Emotional faces were selected from the Radboud Face Database (Langner et al., 2010). One picture for each facial expression (neutral, angry, and fearful) was selected, each showing the same female character (RfD90_14) in frontal position and displaying direct gaze, resulting in 3 facial stimuli. They were displayed centrally at 15.85 x 22.23 cm on a 17 inch computer screen, subtending a horizontal visual angle of 11.32° and a vertical angle of 15.82°. The pictures were presented using the software Presentation (Neurobehavioral Systems, Inc.). The distance between the screen and the participants was approximately 80 cm. Pictures were displayed on a gray background which also signalized the application of the odors (see below).

2.2.2.2 Olfactometer

An in-house built Lorig-olfactometer (Lorig, Elmes, Zald, & Pardo, 1999a) was used to deliver the odors. The olfactometer features an air compressor that pumps room air into the system. Room air is filtered and dehumidified by a mechanical filter and is not warmed by the olfactometer itself. Air flow through the apparatus amounts to 3l/min constantly, diameter of the Teflon tubes inside is 6 mm. The olfactometer allows the use of 7 different odor channels and one channel for inter-stimulus interval (ISI, defined as stimulation break, during which participants were supposed not to smell anything) passing through glass cylinders, where fluid and solid odor sources can be placed. The estimation of the concentration of the odors was controlled by using an external constant flow tube that delivers plain air. The flow of the constant flow tube and the odor flow tube adds up to 3l/min. The ratio between the constant flow and the flow that passes through the glass cylinders can be regulated to apply different odor concentrations. In the present experiment, two cylinders were filled with the odor fluids and one cylinder was filled with distilled water to be used in the intervals between odor applications. The substances were changed after every tenth participant completed the experiment. A breathing mask was used to present the odors to the participants. As the olfactometer itself was placed outside of the cabin where participants were seated, they were not able to hear the switching sounds of the valves. For a picture of the olfactometer I used, see Figure 2.

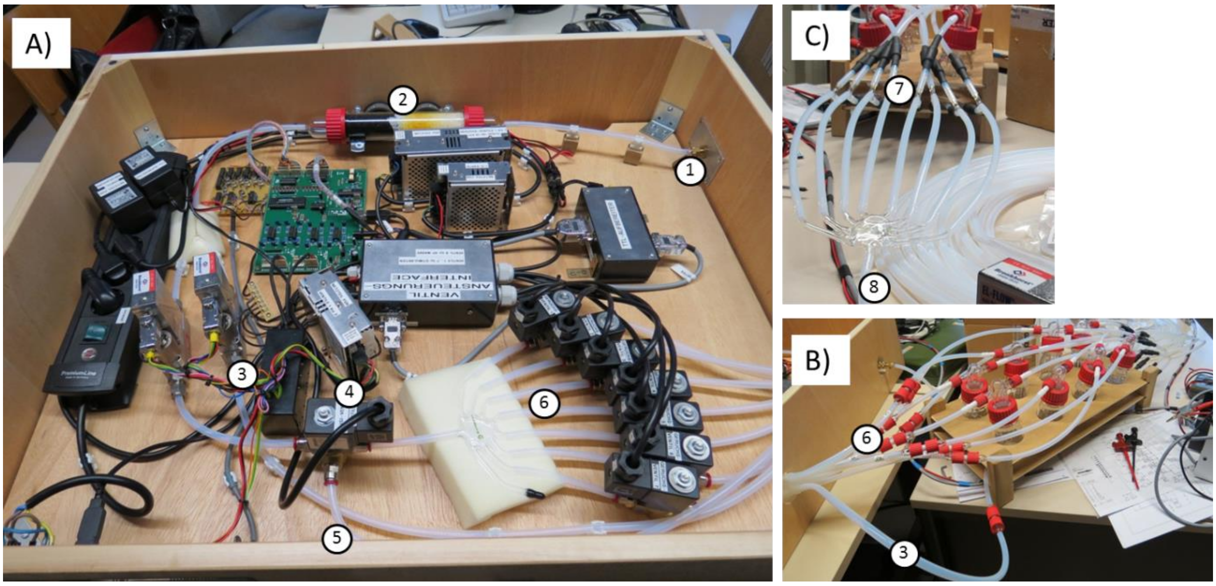

Figure 2: The olfactometer that was used in all of the experiments. A: Full view of the olfactometer (placed outside of the cabin). B and C: Glass tubes that contained the odorous substances (placed inside the cabin). Clean air was led into the system (1) and then filtered and dehumidified (2). At stage (3), the air flow was divided into an odor air flow (6) and a clean constant flow (3). A valve (4) is used to switch between 7 different odor channels (6) and one ITI channel (5) that is led through clean water. After being led through odorous substances, odor flow and constant flow reunite (7) and are led into the breathing mask (8).

2.2.2.3 Odors

Two different odors were used in the following dilutions: Phenylethylalcohol (PEA; 5% diluted in propane-1,2-diol) and Guaiacol (20% diluted in propane-1,2-diol). The concentrations (regulated via the ratio between the odor flow and the constant flow of the olfactometer) were 60% for the Guaiacol dilution and 90% for the PEA dilution in order to equalize the perceived intensities of the two odors. Participants reported to be able to differentiate between the two odors (they indicated a mean score of 3.32; *SD* = 1.27 on a scale from 1 – "*impossible to distinguish*" to 5 – "*very different*"). To control for the fast habituation of smell perception and to make long odor perception possible, an alternating odor presentation mode was applied. Namely, the olfactometer repetitively opened for one second and then closed for two seconds throughout odor presentation time (i.e., altogether 20 sec), while during closed odor channels the air flow passed through distilled water. This method creates a rather subtle background smell which was suitable for the present paradigm and has been applied for long smell stimulation duration in earlier experiments (Boyle et al., 2007).

2.2.3 Physiological Measurement

EEG-electrodes were applied to the scalp using an elastic head cap (BrainCAP, Munich, Germany) and oriented according to the international 10-20-system (Jasper, 1957). Seven Ag-AgCl-electrodes (Ø = 5mm) were attached according to the following positions: Cz, Pz, Oz, P3, P4, O1, and O2. The sensors Cz, Pz, P3, and P4 were of major interest for assessing the LPP, as these are the sensors commonly used to assess it (e.g., Schupp et al. 2000). Vertical eye movements and blink artifacts were recorded applying electrodes (Ø = 5mm) above and under the right eye.

Two Ag-AgCl-electrodes (Ø = 5mm) were placed centrally over the left eyebrow in order to assess activity of the *musculus corrugator supercilii* (Fridlund & Cacioppo, 1986). Two additional Ag-AgCl-electrodes (Ø = 5mm) were placed on the two mastoids representing reference (right) and ground (left) electrodes. Impedances were kept under 5 kΩ. Sampling rate was set to 1000 Hz, and no online-filters were applied.

Skin conductance was measured with two Ag-AgCl-Electrodes (Ø = 8 mm) filled with 0.05 molar sodium chloride electrolyte gel. The electrodes were placed on the non-dominant hand on the thenar and hypothenar eminences. Participants were requested to wash their hands in order to maximize the quality of skin conductance data. Data recording was performed using a V-Amp amplifier and the software Brain Vision Recorder Version 1.20 (Brain Products, Munich, Germany).

2.2.4 Procedure

The study was approved by the internal review board of the medical department of the University of Würzburg. The study complies with the Declaration of Helsinki for Biomedical Research involving Human Subjects.

Before the start of the physiological measurement and the application of the electrophysiological apparatus, participants gave their written informed consent and filled in a sociodemographic questionnaire as well as the “Social Phobia and Anxiety Inventory” (SPAI; Turner, Beidel, Dancu, & Stanley, 1989).

The experiment comprised two main experimental blocks (i.e., a conditioning and a test block, see Figure 3) that were separated by a break, during which participants were allowed to rest as long as they wanted. Ratings of the contextual odors and of the emotional faces were performed three times (before the conditioning block (t0), between conditioning and test block (t1), and after the test block (t2)). At t0, odors only and faces without odor presentation were rated by the participants. At t1 and t2, both odor contexts and separately all three faces in both contexts were rated. Ratings of valence, arousal, and anxiety were assessed for odors and faces; additionally, faces were rated for the perceived sympathy for the person shown on the picture. Contingency ratings were collected for odor contexts, represented by a question concerning the likelihood of the appearance of the US during odor presentation (on a 9-point scale ranging from 1 "*very unlikely*" to 9 "*highly likely*"). Ratings were reported using a keyboard on scales ranging from 1 ("*very unpleasant/low arousal/anxiety/sympathy*") to 9 ("*very pleasant/high arousal/anxiety/sympathy*"). First, participants were asked how pleasant, aroused, and anxious they felt while smelling the odor. In a second step, the same questions were posed while watching the facial stimuli together with odor presentation. Sympathy was assessed directly with focus on the person displayed on the picture. Rating scales were always presented in the same order. Odors and pictures to be rated also appeared in the same order. Thus, half of the participants rated the CTX+ first and half the CTX-.

The conditioning block consisted of 12 presentations of each contextual odor. Each trial started with a change of the background color of the screen from black to gray and stayed as such for 20 sec. Participants were instructed that the gray background indicated the presentation of an odor. During the 20 sec of gray screen, the olfactometer presented one of the odors in the way described above. Due to a prolongated rising time of odors of about 1500 ms, the olfactometer already opened two seconds before trial onset. During each presentation of one of the odors, one US was presented randomly between 4500 and 17000 ms after the onset of the gray screen (CTX+), while the second odor remained unpaired (CTX-), leading to a reinforcement rate of 100%. Assignment of the odors to CTX+ and CTX- was counterbalanced across participants. US presentation time was pseudo-randomized, in that it was made sure that it did not coincide with the opening and closing of the olfactometer. Each trial was followed by an inter-trial-interval (ITI) of 17 sec, during which participants saw nothing but a black screen, and the olfactometer did not emit any odor.

During the test block, the sequence was held as similar to the conditioning block as possible. Three presentations of the CTX+ were still paired with one US in order to avoid extinction (Garrison, Erdeniz, & Done, 2013). During odor presentation, one of the three facial expressions was presented three times, respectively 4000, 11000, and 17000 ms after trial onset (i.e., the gray screen). Faces were presented for 4000 ms each. Altogether, the test block consisted of 60 trials, 30 for the CTX+ and 30 for the CTX-. Every combination of context and facial expression (2 x 3) was presented 10 times. As there were 3 repetitions of each face within one context presentation, I had 30 repetitions of each combination of facial expression and context. For a schematic overview of the experimental procedure, see Figure 3.

The experiment lasted for approximately one hour. At the end of the experiment, participants completed a post-test questionnaire on the discriminability of the two odors.

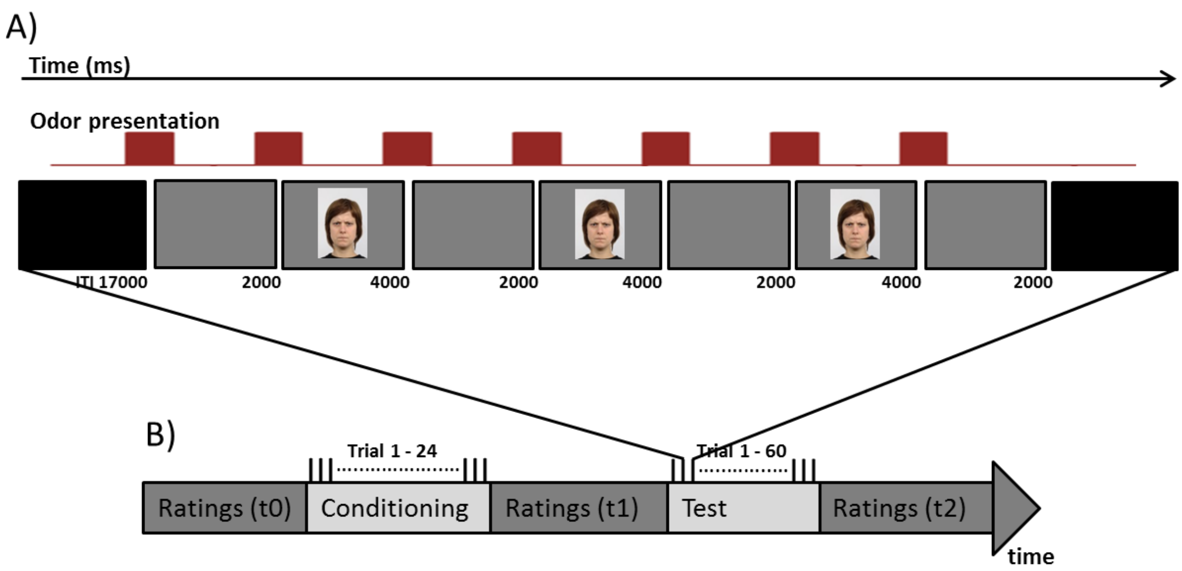

Figure 3: Schematic overview of the experimental procedure. Part B) represents the order of blocks within the experiment, whereas part A) represents one trial of the test block. ITI = Inter-trial Interval.

2.2.5 Data Processing and Statistical Analysis

Data preprocessing was performed using the software Vision Analyzer 2.0 (BrainVision, Munich, Germany). For calculation of Skin Conductance Level, a Butterworth high cutoff filter of 1 Hz was applied. The data were then segmented to the length of context presentation (i.e., 20 sec, the presentation of the gray screen) separately for the two blocks as well as to the duration of the faces (4000 ms, only in the test block). Afterwards, the data were baseline-corrected (average of 1000 ms before stimulus onset). The skin conductance level averaged over the duration of the segments and across all conditions was exported. A value of 1 was summated to the data, and they were then logarithmized. The three test trials during which an US was applied were excluded from further analysis. In the conditioning block, the data points of 7000 ms after US application were not included into further analysis of the context. The time-window when faces were presented (i.e., 4000 ms) was also excluded from analysis of the context.

EEG data were filtered using a Butterworth 0.01 Hz low-cutoff filter, a 35 Hz high-cutoff filter, and a 50 Hz notch filter. Ocular correction was applied using the parameters described by Gratton and Coles (1983), as implemented in Vision Analyzer. A baseline correction using the average of 100 ms before stimulus onset was applied. A semi-automatic artifact correction was applied, using the following parameters: a maximal voltage step of 50 µV, a maximal voltage difference of 200 µV, a maximal amplitude of 100 µV, a minimal amplitude of -100 µV, and a lowest allowed activity of 0.5 µV. Results of the artifact correction step were re-evaluated manually. The relative number of trials that remained after artefact correction did neither differ between the contexts in the conditioning ($t[26] = 0.44$, $p = .663$) nor in the test block ($t[26] = 0.07$, $p = .942$). After artifact correction, context onset data were averaged across the electrodes Cz and Pz. The relative number of kept trials after artefact correction for face-evoked LPPs did also not differ between conditions, as an ANOVA containing the factors face and context revealed (all ps > .097). Afterwards, face onset data were averaged across the electrodes Pz, P3, and P4. Both context- and face-elicited LPP amplitudes were scored as mean activity between 400 to 1000 ms after stimulus onset.

Electromyographic activity of the *musculus corrugator supercilii* was analyzed for face presentation. Data were filtered using a Butterworth low-cutoff filter of 30 Hz, a high-cutoff of 499 Hz, and a notch filter of 50 Hz. Afterwards, a moving average transformation (window size 125 ms) was applied as implemented in the software Vision Analyzer. Data were then segmented, and only the first of the three faces was included into further analysis. A baseline correction using the average voltage of 1000 ms before stimulus onset was applied. An automatic artifact rejection was then performed by rejecting trials with voltage steps over 30 µV and with activation over 8 µV during the baseline period. Activation was then averaged over all trials of the same condition. Averaged activity in the interval from 0 to 1000 ms after stimulus presentation was exported (Dimberg & Thunberg, 1998) and included into statistical analysis.

Psychophysiological and rating data were statistically analyzed using the software SPSS (Version 21, IBM Corp., Armonk, NY, US). For anxiety ratings of odors, only 16 datasets could be evaluated due to technical problems. For all of the other ratings, single missing data points were replaced by the mean rating of all participants of the respective condition. Ratings, SCL, and LPP for the contexts were analyzed calculating 2 x 2 (Context x Block) ANOVAs. For the analysis concerning the reactions to the faces, a 2 x 3 (Context x Facial expression) ANOVA was calculated for SCL, LPP, Corrugator muscle activity, and ratings. Pre-conditioning ratings were evaluated separately with paired *t*-tests to ensure that there was no difference between odors prior to conditioning. The ratings of the faces alone were subject to a repeated measure ANOVA with facial expression (angry vs. fearful vs. neutral).

Contingency ratings were compared between the two contexts using one-tailed paired *t*-tests for each block.

Moderating influence of social anxiety and the contingency awareness was taken into account. To obtain the factor awareness, participants who rated US occurrence probability in the CTX+ at t1 higher than in the CTX-, were classified as aware (*n* = 12). All others were classified as unaware (*n* = 16). This variable was added as a between-subjects factor into the analyses of context processing. A median split was performed with the values obtained in the SPAI (*Median* = 1.82), resulting in one group of high (HSA, *n* = 14) and one of low socially anxious (LSA, *n* = 14) participants. These groups were added as additional between-subjects factor into the analyses of face processing.

Marginally significant effects (.05 < *p* < .1) were further examined if they were hypothesis-driven. Significant effects were evaluated using post-hoc ANOVAS and paired *t*-tests. Multiple testing correction was not performed due to the pioneer character of the study regarding anxiety-inducing olfactory context conditioning in order to avoid missing interesting findings due to too conservative thresholds (Rotmann, 1990). If necessary, Greenhouse-Geisser correction of degrees of freedom was applied. A significance level of .05 was used for all analyses. For all analyses, the uncorrected degrees of freedom, the corrected p-values, the *GG-ε*, and the partial η^2 (η_p^2) are reported (Picton et al., 2000).

2.3 Results

2.3.1 Context Processing

2.3.1.1 Ratings

Ratings of the two contexts were collected prior to conditioning (t0), after the conditioning block (t1), and after the test block (t2). A paired *t*-test revealed no difference of the context odors at pre-conditioning as ratings did not differ in valence (*t*[27] = 0.37, *p* = .713), arousal (*t*[27] = 0.70, *p* = .492), and anxiety (*t*[15] = .85, *p* = .408) Mean ratings of this test are displayed in Table 1.

Table 1: Mean values and standard deviations of the ratings of the contextual odors before conditioning (t0)

Variable	**CTX+**	**CTX-**
Valence	5.76 (1.71)	5.88 (1.77)
Arousal	3.16 (1.86)	3.42 (1.94)
Anxiety	2.28 (1.67)	1.79 (0.98)

Repeated ANOVAs with the factor Context (CTX+, CTX-) and Block (t1, t2) were conducted for valence, arousal, and anxiety to examine conditioning effects on the explicit level. For valence ratings, I found a marginally significant main effect of Context (F[1, 27] = 3.28, p = .081, η_p^2 =.11) indicating that the CTX+ was perceived as slightly more unpleasant than the CTX- averaged over both conditioning and test block. The main effect of Block (F[1, 27] = 0.16, p = .694, η_p^2 =.01) as well as the interaction did not reach significance (F[1, 27] = 0.48, p = .496, η_p^2 =.02).

Similarly, a marginally significant main effect of Context for the arousal ratings (F[1, 27] = 3.40, p = .076, η_p^2 = .11) revealed increased arousal in response to the CTX+ compared to the CTX-, irrespective of the time point of the rating. No significant effects were found for the main effect of Block (F[1, 27] = 0.02, p = .895, η_p^2 <.01) and the interaction (F[1, 27] < 0.01, p = .959, η_p^2 <.01).

Anxiety ratings of the contexts only showed non-significant trends. The main effect of Context (F[1, 15] = 2.54, p = .132, η_p^2 = .15), Block (F[1, 15] = 2.44, p = .139, η_p^2 =.14), and the interaction (F[1, 15] = 3.03, p = .102, η_p^2 =.17) did not reach significance. Due to the author's a priori hypothesis regarding conditioning effects on all explicit ratings and due to the diminished sample size, I conducted planned paired t-tests for anxiety ratings after each block. These revealed, that the CTX+ was perceived as more anxiogenic than the CTX- after the conditioning block (t[15] = 2.21, p = .043) but not after the test block (t[27] = 0.37, p = .718). Valence, arousal, and anxiety ratings of the two contexts are displayed in Figure 4.

Perceived probability of US occurrence was marginally higher in the CTX+ than in the CTX- (main effect of Context: F[1, 27] = 3.82, p = .061, η_p^2 =.12) and higher in the conditioning than in the test block (main effect of Block: F[1, 27] = 5.38, p = .028, η_p^2 =.17). The interaction did not reach significance (F[1, 27] = 0.02, p = .879, η_p^2 <.01).

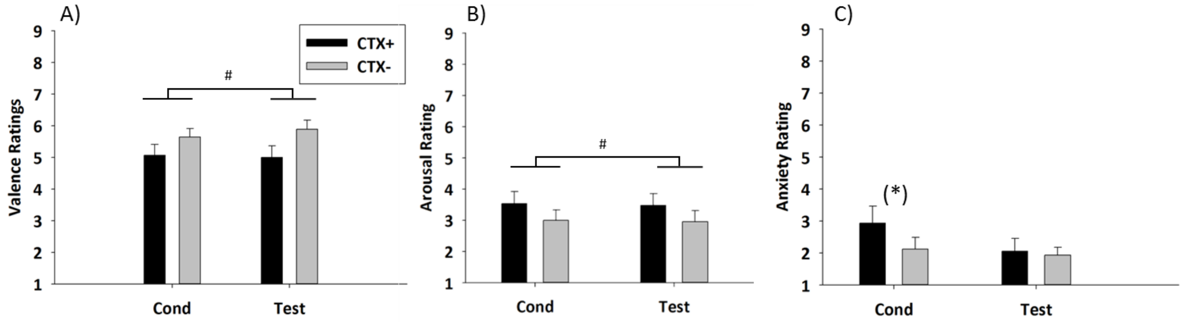

Figure 4: Odor ratings of valence, arousal, and anxiety after conditioning (t1) and after the test block (t2). Black bars represent the CTX+ and gray bars the CTX-. Error bars represent standard errors. The hash represents a significance level of .05 < p < .1.

2.3.1.2 SCL-Data

Regarding SCL, a repeated measures ANOVA returned a main effect of Context (F[1, 27] = 5.43, p = .027, η_p^2= .17). Thus, the CTX+ evoked higher SCL than the CTX- during both conditioning and test block, which is depicted in Panel A of Figure 5. The main effect of Block (F[1, 27] = 0.28, p = .599, η_p^2= .01) and the interaction (F[1, 27] = 1.45, p = .239, η_p^2= .05) did not reach significance.

2.3.1.3 EEG-Data

Regarding EEG data, a repeated measures ANOVA including the factors Context (CTX+ vs. CTX-) and Block (t1 vs. t2) was calculated. No significant main effects were revealed (Context: F[1, 27] = 1.30, p = .265, η_p^2= .05; Block: F[1, 27] = 1.10, p = .303, η_p^2= .04), but a marginally significant interaction of Block and Context (F[1, 26] = 3.60, p = .069, η_p^2 = .12). As mentioned before, due to my hypothesis, paired t-tests were conducted to compare the contexts in the conditioning and test block. While no difference between threat and safety context was found in the LPP during the conditioning block (t[26] = 0.42, p = .340), in the test block the LPP amplitudes in response to the CTX+ were significantly higher than in response to the CTX- (t[26] = 2.22, p = .018) (Figure 5, Panel B).

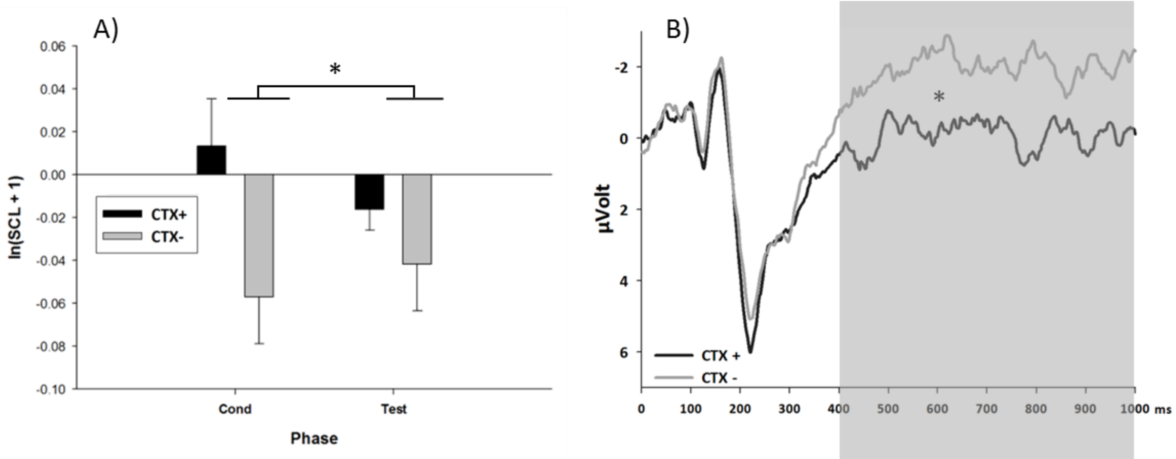

Figure 5: Panel A) displays mean skin conductance levels for the time of context presentation in both experimental blocks. Error bars represent standard errors. Panel B) represents the LPP for the onset of the contexts during the test block. The export window is represented by the gray area. Gray lines and bars represent the CTX-, while black lines and bars represent the CTX+.

2.3.1.4 Influence of Awareness of Contingency

Including the between-subjects factor Awareness into the analysis of the rating data did not reveal any significant interaction effect for the valence ratings (Context x Awareness: *F*[1, 26] = 0.15, *p* = .704, η_p^2 =.01; Block x Awareness: *F*[1, 26] = 0.13, *p* = .724, η_p^2 =.01; three-way interaction: *F*[1, 26] = 0.37, *p* = .549, η_p^2 = .01). However, a main effect of Awareness was found (*F*[1, 26] = 4.54, *p* = .043, η_p^2 = .15) indicating that aware participants rated both contexts as less pleasant than unaware participants. Concerning the ratings of arousal, a significant interaction of Block x Awareness was found (*F*[1, 26] = 6.12, *p* = .020, η_p^2 = .19), whereas the main effect of Awareness and the other interactions effects did not reach significance (Awareness: *F*[1, 26] = 0.08, *p* = .782, η_p^2 < .01; Odor x Awareness: *F*[1, 26] = 1.95, *p* = .175, η_p^2 = .07; three-way interaction: *F*[1, 26] = 1.90, *p* = .179, η_p^2 = .07). Post-hoc *t*-tests revealed that arousal ratings were higher at t1 than at t2 in the group of aware (*t*[11] = 3.93, *p* = .002) but not in the group of unaware participants (*t*[15] = 1.21, *p* = .244). For anxiety ratings, a significant interaction of Context x Awareness was found (*F*[1, 14] = 5.45, *p* = .035, η_p^2 = .28). All other effects did not reach significance (all *p*s > .236)). Post-hoc *t*-tests for the interaction revealed that the group of aware participants rated the CTX+ as more anxiogenic than the CTX- (*t*[8] = 2.75, *p* = .025). However, anxiety ratings did not differ between the contexts in the group of unaware participants (*t*[6] = 0.60, *p* = .573).

Inclusion of the between-subjects factor Awareness did not reveal any significant interactions for the SCL (Awareness: *F*[1, 26] = 0.93, *p* = .343, η_p^2 = .04; Context x Awareness: *F*[1, 26] = 0.30, *p* = .589, η_p^2

= .01; Block x Awareness: $F[1, 26] = 1.04$, $p = .317$, $\eta_p^2 = .04$; three-way interaction: $F[1, 26] = 0.50$, $p = .466$, $\eta_p^2 = .02$) or the LPP (Awareness: $F[1, 25] < 0.01$, $p = .976$, $\eta_p^2 < .01$; Context x Awareness: $F[1, 25] = 0.10$, $p = .751$, $\eta_p^2 < .01$; Block x Awareness: $F[1, 25] = 0.33$, $p = .571$, $\eta_p^2 = .01$; three-way interaction: $F[1, 25] = 2.59$, $p = .120$, $\eta_p^2 = .09$).

2.3.2 Face Processing

2.3.2.1 Ratings

Baseline-ratings of facial expressions alone were compared. Sympathy ratings showed a significant difference among the faces ($F[2, 54] = 8.83$, $p < .001$, $\eta_p^2 = .25$), with significantly higher sympathy ratings for the neutral compared to the angry face ($t[27] = 3.63$, $p = .001$) and for the fearful compared to the angry face ($t[27] = 3.81$, $p = .001$), while sympathy ratings between the neutral and the fearful face did not differ ($t[27] = 0.71$, $p = .483$). Neither differences in valence ratings ($F[2, 54] = 1.48$, $p = .237$, $\eta_p^2 = .05$, *GG-ε* = .79) nor in arousal ratings ($F[2, 54] = 2.63$, $p = .102$, $\eta_p^2 = .09$, *GG-ε* = .70) were found, while there was a main effect of Facial Expression in the anxiety ratings ($F[2, 54] = 3.39$, $p = .041$, $\eta_p^2 = .11$), revealing higher anxiety ratings for the fearful face compared to the neutral face ($t[27] = 2.64$, $p = .014$) and marginally higher compared to the angry face ($t[27] = 1.91$, $p = .067$), while no difference was found between the angry and the neutral face ($t[27] = 0.55$, $p = .590$). Mean ratings of all four variables are displayed in Table 2.

Table 2: Mean values and standard deviations of the ratings of the facial expressions before conditioning (t0)

Variable	Angry	Neutral	Fearful
Valence	3.75 (1.78)	4.36 (1.64)	3.86 (1.80)
Arousal	3.93 (2.09)	3.21 (2.15)	4.21 (2.28)
Anxiety	2.86 (2.01)	2.64 (1.91)	3.57 (2.30)
Sympathy	2.79 (1.50)	4.11 (1.77)	3.86 (1.56)

Ratings of valence, arousal, anxiety, and sympathy before and after the test block were analyzed with 2 x 2 x 3 repeated measures ANOVAs including the factors Context (CTX+, CTX-), Block (t1,t2), and Facial Expression (neutral, angry, fearful). Analysis of sympathy ratings revealed a main effect of Facial Expression ($F[2, 54] = 18.94$, $p < .001$, $\eta_p^2 = .41$), an interaction of Block and Context ($F[1, 27] = 14.26$, $p = .001$, $\eta_p^2 = .35$), as well as an interaction of Context and Facial Expression ($F[2, 54] = 5.08$, $p = .009$, $\eta_p^2 = .16$). The main effect of Block was marginally significant ($F[1, 27] = 4.09$, $p = .053$, $\eta_p^2 =$

.13), indicating that sympathy ratings tended to drop from t1 to t2, as well as the interaction of Context x Facial Expression x Block (F[2, 54] = 2.98, p = .059, η_p^2 = .10). The main effect of Context (F[1, 27] = 0.85, p = .364, η_p^2 = .03) as well as the interaction of Facial Expression x Block (F[2, 54] = 0.69, p = .473, η_p^2 = .03, *GG-ε* = .78) did not reach significance. The interaction of Block and Context showed lower sympathy ratings for all faces at t1 in the CTX+ compared to the CTX- (t[27] = 3.99, p < .001), while the difference between the contexts was only marginal after the test block (t2) (t[27] = 1.99, p = .057). Moreover, the interaction of Context and Facial Expression showed reduced sympathy ratings for the angry and the fearful compared to the neutral face in the CTX+ (t[27] = 6.67, p < .001; t[27] = 2.94, p = .007 respectively) as well as lower sympathy ratings for the angry face compared to the fearful face in the CTX+ (t[27] = 4.29, p < .001). However, for sympathy ratings in the CTX-, only the angry face elicited significantly less sympathy than the neutral face (t[27] = 4.26, p < .001). The angry face was also the only face which received differential sympathy ratings between CTX+ and CTX- (t[27] = 2.82, p = .009), with significantly reduced sympathy ratings in the threat context. Figure 6 illustrates the mean sympathy ratings for all faces in both contexts averaged over t1 and t2.

Regarding the valence ratings, a main effect Context (F[1, 27] = 13.81, p = .001, η_p^2= .34) and a main effect Facial Expression (F[2, 54] = 23.44, p < .001, η_p^2 = .47) were found, whereas the main effect of Block did not reach significance (F[1, 27] = 13.81, p = .001, η_p^2= .34). Moreover, an interaction of Context and Facial Expression (F[2, 54] = 8.08, p = .001, η_p^2= .23), an interaction of Block and Facial Expression (F[2, 54] = 4.40, p = .017, η_p^2= .140), and an interaction of Context and Block (F[1, 27] = 8.00, p = .009, η_p^2= .23) were found. These were further qualified by a three-way interaction of Context, Block, and Facial Expression (F[2, 54] = 3.44, p = .039, η_p^2 = .11). Post-hoc t-test revealed that faces within the anxiety context were evaluated as more unpleasant than in the safety context after the test block (t[27] = 4.42, p < .001) and that the valence ratings for all faces within the anxiety context were significantly decreased after the test block compared to before (t[27] = 2.07, p = .049). Additionally, within the CTX+, the angry face was perceived as more unpleasant compared to the fearful (t[27] = 2.63, p = .014) and the neutral face (t[27] = 5.97, p < .001), while the fearful face was rated as more unpleasant than the neutral one (t[27] = 4.26, p < .001). Within the CTX-, the fearful face compared to the angry face was rated as less pleasant (t[27] = 2.17, p = .039) and the angry face as more unpleasant than the neutral face (t[27] = 3.64, p = .001). When comparing how the valence ratings of each face changed between the contexts, only the valence ratings for the angry face were perceived differently depending on the context, with more negative ratings in the CTX+ compared to the CTX- (t[27] = 5.49, p < .001).

Overall, next to a general decrease in valence ratings for all faces when perceived in the CTX+, a differential influence of the context on the evaluation of facial expressions was found, with an especially pronounced negative evaluation of the angry face in the anxiety context.

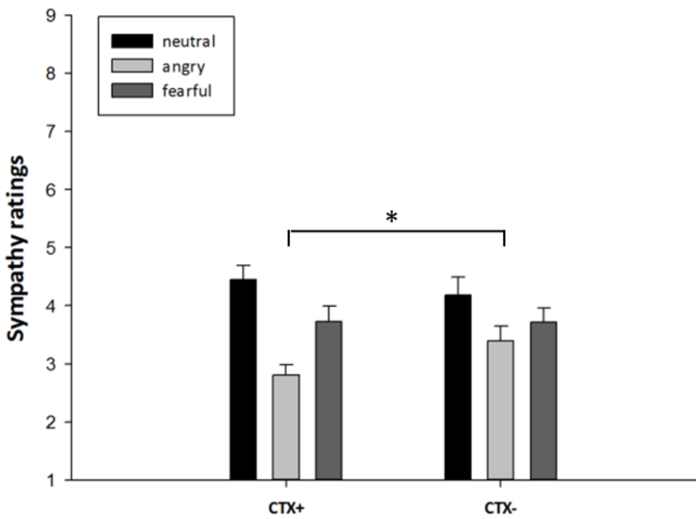

Figure 6: Sympathy ratings of the faces in the odor contexts averaged over both experimental blocks. Error bars represent standard errors.

Regarding arousal ratings, a marginally significant main effect of Context (F[1, 27] = 3.65, p = .067, η_p^2 = .12) revealed higher arousal ratings for the CTX+ compared to the CTX-. Moreover, a significant main effect of Facial Expression was found (F[2, 54] = 12.66, p = .001, η_p^2 = .32, *GG-ε* = .57). Paired *t*-tests showed higher arousal ratings for the angry and the fearful face compared to the neutral face (t[27] = 2.68, p = .012 and (t[27] = 3.70, p = .001), respectively, and higher arousal ratings for the fearful compared to the angry face (t[27] = 4.23, p < .001). All other effects did not reach significance (Block: F[1, 27] = 0.39, p = .537, η_p^2 = .01; Context x Facial Expression: F[2, 54] = 0.68, p = .461, η_p^2 = .03, *GG-ε* = .70; Context x Block: F[1, 27] = 0.31, p = .580, η_p^2 = .01; Facial Expression x Block: F[2, 54] = 1.18, p = .318, η_p^2 = .04; three-way interaction: F[2, 54] = 1.08, p = .347, η_p^2 = .04).

For anxiety ratings, a main effect of Block (F[1, 27] = 4.30, p = .048, η_p^2 = .14), a significant interaction of Context and Block (F[1, 27] = 5.55, p = .026, η_p^2 = .17), and a significant interaction of Block and Facial Expression (F[1, 26] = 7.44, p = .004, *ηp2* = .22, *GG-ε* = .73) were found. Anxiety ratings for the faces between conditioning (t1) and test block (t2) only differed in the CTX-, with higher anxiety ratings at t2 compared to t1 (t[27] = 3.11, p = .004), and differed marginally between the contexts at t1, with higher anxiety for faces in the CTX+ compared to the CTX- (t[27] = 1.93, p = .06). All other effects did not reach significance (Context: F[1, 27] = 0.61, p = .442, η_p^2 = .02; Facial Expression: F[2, 54] = 0.96, p = .376, η_p^2 = .03, *GG-ε* = .81; Context x Facial Expression: F[2, 54] = 1.24, p = .289, η_p^2 = .04, *GG-ε* = .69; three-way interaction: F[2, 54] = 0.05, p = .955, η_p^2 < .01).

2.3.2.2 SCL-Data

The skin conductance level in response to the faces showed a marginally significant main effect of Context (F[1, 27] = 3.50, p = .072, η_p^2 = .12), with higher SCL for all faces when perceived in the CTX+. Moreover, a marginally significant interaction of Context and Facial Expression (F[2, 54] = 3.11, p = .053, η_p^2 = .10, *GG-ε* = .75) was found. The main effect of Facial Expression did not reach significance (F[2, 52] = 0.03, p = .928, η_p^2 < .01, *GG-ε* = .73). Mean SCL data in response to the faces in both contexts are illustrated in panel A of Figure 7. As this interaction was part of my main interest, post-hoc paired t-tests were used to follow up this interaction. When comparing the faces with each other within both contexts, only the fearful face differed marginally significantly from the neutral and the angry face within the CTX- (t[27] = 1.85, p = .075; t[27] = 1.85, p = .075 respectively), with increased SCL for the fearful face. Moreover, only the neutral face showed differential SCL between contexts (t[27] = 2.38, p = .025), with increased SCL in the threat context. A similar trend could be found for the angry face (t[27] = 1.93, p = .065).

2.3.2.3 EEG-Data

Regarding the LPP evoked by the onset of facial expressions, a marginally significant main effect of Context (F[1, 26] = 3.23, p = .084, η_p^2 = .11) was found. The difference between the two contexts is shown in panel B of Figure 7. The LPP amplitude was augmented in the threat context compared to the safety context. Moreover, a main effect of Facial Expression (F[2, 52] = 3.94, p = .025, η_p^2 = .13) revealed differences between the neutral and the angry face (t[26] = 1.80, p = .083) and the neutral and the fearful face, (t[26] = 2.12, p = .043). The interaction of Context x Facial Expression did not reach significance (F[2, 52] = 0.65, p = .527, η_p^2= .02).

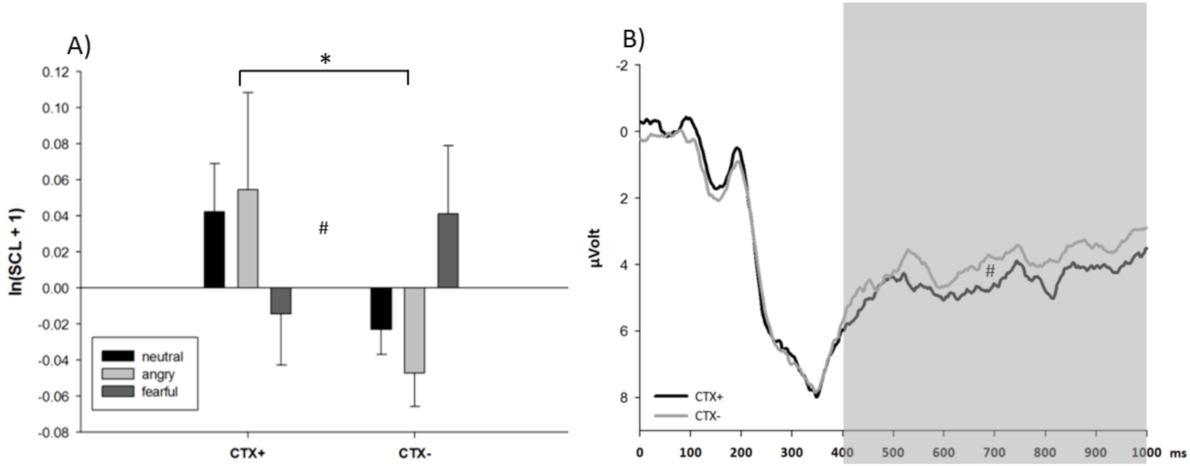

Figure 7: Reactions to facial expression in odor contexts. Panel A) displays the SCL during the presentation of the faces in both contexts. Panel B) displays the LPP as reaction to the onset of the faces averaged over the three facial expressions to illustrate the main effect of context. The export window is represented by the gray area. Error bars represent standard errors. The hash stands for a significance threshold of .05 < p < .1.

2.3.2.4 Corrugator Activity

The ANOVA with the factors Context x Facial Expression did neither reveal any significant main effects (Context: $F[1, 27] = 0.06$, $p = .811$, $\eta_p^2 < .01$; Facial Expression: $F[2, 54] = 0.14$, $p = .773$, $\eta_p^2 = .01$, *GG-ε* = .67) nor did the interaction reach significance ($F[2, 54] = 0.73$, $p = .412$, $\eta_p^2 = .03$, *GG-ε* = .55).

2.3.2.5 Influence of Social Anxiety

Including the between-subjects factor of Social Anxiety into rating data did not reveal any significant interaction for the sympathy ratings (all *p*s > .076) or valence (all *p*s > .171). However, for arousal ratings, a significant main effect of Social Anxiety was found ($F[1, 26] = 4.97$, $p = .035$, $\eta_p^2 = .16$), classified by the fact that HSA participants gave higher ratings of arousal than LSA participants. All other interactions with the factor Social Anxiety did not reach significance (all *p*s >.129).

Including the factor Social Anxiety into the analyses did not reveal any significant interactions with the SCL (all *p*s >.314), the LPP (all *p*s >.099), or corrugator activity (all *p*s >.059).

2.4 Discussion

In the present study, aversive context conditioning was applied to initially neutral odors, leading to an olfactory anxiety context and a safety context. Subsequently, pictures displaying different facial expressions were presented within both olfactory contexts in order to examine the influence of threat contexts on face processing.

Olfactory context conditioning was successfully implemented as reflected on explicit as well as implicit measurements. The anxiety context showed a tendency towards higher anxiety and arousal ratings as well as more negative valence ratings compared to the safety context. Additionally, the SCL was augmented in the CTX+ during both conditioning and test block, indicating an increased tonic autonomic arousal due to the chronic expectation of the US (i.e., a desperate female scream). This effect seemed to be rather long-lasting as it appeared in both conditioning and test block. The finding that the CTX+ leads to a state of higher alertness was further supported by the EEG data showing increased amplitudes of the LPP at the onset of the CTX+ during the conditioning block. This can be interpreted as preferential processing of the threat context compared to the safety context.

Processing of faces was enhanced while an odor signaling a threatening environment was present, as indicated by explicit variables and cautiously supported by implicit variables. Valence and sympathy ratings revealed that independently of facial expressions, faces were evaluated more negatively and less likeable when perceived within the CTX+ than in the CTX-. This suggests a general influence of the surrounding context on the evaluation of faces. Additionally, it was found that the difference between threat and safety contexts was especially pronounced when an angry face was presented. As a potentially threatening cue, the angry face seems to gain importance when additionally contextual threat information is available. Regarding arousal ratings, all facial expressions were rated as more arousing when presented within the CTX+. Therefore, threatening contextual information seems to boost reported arousal. Applied as a measure of a stronger emotional state, anxiety ratings for all faces were elevated in the CTX+ after the conditioning block, but this difference diminished during the test block. Faces that are perceived within a threatening context therefore elicit higher reports of anxiety and arousal. On the implicit level, SCL and LPP showed a trend towards increased responses for all facial expressions within the CTX+. Consequently, faces within a threatening context are processed preferentially and evoke higher psychophysiological arousal, thereby extending the rating results. Additionally, skin conductance level was further modulated by angry and neutral faces such that they evoked higher responses when presented in the CTX+. Similarly to subjective measures, a threatening or ambiguous stimulus obtains even more pronounced threatening value when this information is supported by a threatening context.

The present study is the first to explore the impact of olfactory context conditioning on the perception of social cues in a controlled laboratory setting. Olfactory stimuli seem to be perfectly suitable as contextual stimuli as they are permanently present sensory features of daily situations.

Often they are not attributable to a certain object in the environment and therefore correspond to the definition of a context (Bouton, 2010). Also, the results suggest long-lasting effects of context conditioning when using odors as the impact of threat learning was still observed in and after the test block. Whether these effects would still show an impact that extends the duration of one experimental session cannot be answered by the present data. Nevertheless, the results of the present study could be taken as a model for PTSD where impacts of aversively conditioned odors are often observed years after the traumatic event (Vermetten & Bremner, 2003). PTSD patients suffer from their traumatic memory as soon as objects with traumatic content are encountered. When re-experiencing traumatic cues, a previously neutral stimulus paired with these traumatic cues might gain aversive value itself (Wessa & Flor, 2007). In the present study, the processing of unrelated faces was influenced by threatening odors that had been aversively conditioned before. More research would be needed in order to examine the influence of former aversive experience paired with olfactory contexts to extend current models of PTSD.

In the present study, context conditioning effects remained stable over time, such that faces presented in the test block did not disrupt preferential processing of the CTX+ but were integrated in the context and gained from its motivational significance. Preferential processing of threatening objects (i.e., angry faces) within threatening contexts has been shown before (Adolph et al., 2013; Grillon & Charney, 2011; Wieser, Pauli, Reicherts et al., 2010). Fearful faces in comparison to angry faces, however, can be interpreted in a more ambiguous way, especially because gaze direction plays a pivotal role for face processing (Graham & Labar, 2012; Wieser & Brosch, 2012). While for angry faces a direct gaze would hold the most threatening information, the opposite would be true for fearful faces (Adams, Gordon, Baird, Ambady, & Kleck, 2003; Adams & Kleck, 2003a, 2005). An angry person, looking directly at the perceiver would indicate a threat for the perceiver, while when looking away, it would indicate a threat for someone else. The opposite is true for fearful facial expressions. Someone looking behind you showing a fearful expression would indicate a danger right next to you, while the same person looking directly at you would not indicate potential danger for you. In the present study, only faces with a direct gaze were included, which might explain why angry faces were processed preferentially compared to fearful faces.

Next to the increased LPP amplitudes in response to faces in the threatening context, a general increase of the LPP was observed for the gray screen indicating the onset of the anxiety context. Therefore, the question arises whether the effects shown are really specific for socially relevant stimuli or whether the expectation of an aversive event leads to a more general sensitization due to higher alertness (i.e., general hypervigilance). This would be in accordance with the *defense cascade* *model*, stating a general facilitation of perceptual processing in an early stage of defensive behavior, associated with the state of anxiety (Fanselow, 1994). Passive viewing paradigms, as the one used in the present study, mirror these early defense stages, and therefore my results (i.e., more pronounced processing of faces within the CTX+) seem to be in line with the model. However, it seems beneficial to extend the present paradigm in a way that a broader spectrum of emotional expressions should be included in the future. It seems possible that the difference between angry, fearful, and neutral facial expressions was too small to reflect differential influences of the two contexts, especially because neutral facial expression are ambiguous and tend to be interpreted negatively (Somerville et al., 2004; Yoon & Zinbarg, 2007, 2008). An inclusion of happy faces or the inclusion of averted vs. direct gaze as an additional factor would possibly broaden the emotional spectrum and lead to a higher sensitivity of the paradigm.

Furthermore, it seems remarkable that baseline differences between facial expressions were only found for sympathy and anxiety ratings but not for arousal and valence ratings. It can be speculated that this was due to the nature of the questions I asked. While valence and arousal ratings asked about the emotional state of participants elicited by the pictures, sympathy ratings rather led participants to an evaluation of the picture itself. It seems possible that facial expressions alone were not strong enough as a stimulus to influence the emotional state per se (Bradley et al., 2001; Britton, Taylor, Sudheimer, & Liberzon, 2006; Wangelin, Bradley, Kastner, & Lang, 2012). This could also be an explanation as to why no effects were found on corrugator activity and no influence of social anxiety was found. The latter one also points in the direction that to some extent the effects of the present study were not social in nature (and would therefore also not be influenced by social anxiety).

When talking about odors as contexts, the potential influence of perceptual awareness needs to be taken into account. In general, it seems that the amygdala, as an important structure of fear processing, is activated by both supra- and subliminal conditioned stimuli (Critchley, Mathias, & Dolan, 2002). In a study about the influence of odors on social preferences, effects of subliminal odors were shown to be even stronger than effects with odors that were perceived consciously (Li et al., 2007). In the present study, I used supraliminal odors. In accordance with the previous studies (Li et al., 2007), possibly, context conditioning with subliminal contextual odors might be at least as strong as in the present study, if not stronger. The application of subliminal stimuli as contextual odors would be an interesting topic of upcoming research. On the other hand, the influence of the awareness of the contingency between US and CTX+ only mediated the effect of the odors on ratings of anxiety. Participants that were able to consciously report the contingency reported higher ratings of anxiety in the CTX+ than in the CTX-, whereas unaware participants did not. However, on all other variables, only weak or no effects of contingency awareness could be found.

Altogether, the present results support the conclusion that odors are highly suitable as contextual stimuli, and olfactory context conditioning can be implemented to create contexts of sustained anxiety. Moreover, cues presented within the threatening context gain significance and are processed preferentially. Evaluation of cues with inherent emotional significance (i.e., threatening facial expressions) is boosted even more with contextual threat. Two major questions remained for future research. The present study nicely demonstrated the influence of a threatening odor on face processing as it was obtained by a foregoing conditioning procedure. Most of the odors humans are exposed to in daily life are, however, not new and therefore not neutral to them. It would therefore be of interest to explore the influence of initially pleasant or unpleasant odors on face processing and other variables of social interaction. In a second step, it would be interesting to explore the influence of a personally attributable smell in contrast to a contextual one as it was done in the present study. It seems possible to obtain even larger effects if odors are not administered contextually but in accordance to an interaction partner.

3 Study 2: On the Attribution of Smells: Between-Subjects Manipulation

3.1 Introduction

Aside from a lot of research on the influence of odors on human behavior and preferences transmitted via the endocrine system (i.e., by means of human pheromones), purely olfactory cues have been proven to influence human beings, for example by serving as potential elucidators of positive or negative affective state respectively. This has been demonstrated on various subjective variables, like ratings, and objective variables, like evoked potentials of the EEG, facial EMG, and the SCL (Bensafi et al., 2002a; Bensafi et al., 2002). In addition to the influence on affective state, olfactory stimuli have an influence on the processing of different social variables. In fact, pleasant odors increase helping behavior (Baron, 1997b), and wearing perfumes has been shown to alter chances of success in job interviews (Baron, 1983). Besides, it could be demonstrated that smells influence face processing. For instance, facial stimuli presented within an unpleasant olfactory context are rated as less attractive than when they are presented within a pleasant odor (Dematte et al., 2007). Similarly, the LPP (Bensafi et al., 2002) and the SCL (Hermann et al., 2000, 2002) are enhanced during presentation of facial stimuli within an unpleasant olfactory context. Moreover, in conditioning studies using facial stimuli as CSs, hedonic odors have been demonstrated as appropriate USs for the acquisition of both aversive and appetitive conditioned responses (Gottfried et al., 2002a; Todrank et al., 1995). Furthermore, emotional facial expressions seemed to be distinctively processed depending on the olfactory context. Therefore, fearful facial expressions gained importance from unpleasant olfactory contexts as indicated by enhanced N170 and P1 amplitudes to these expressions within an unpleasant odor (Forscher & Li, 2012). However, other researchers found differential effects for disgusted rather than for fearful faces (Leleu et al., 2015; Seubert et al., 2010). Thus, if and how a specific influence of smells on the processing of some facial expressions can be found is not conclusively resolved.

Nonetheless, Baron and Thomley (1994) nicely demonstrated that the reception of a small gift had the same effect on pro-social behavior as the presentation of a pleasant smell. Thus, participants were more prone to volunteer for an extra task to help the experimenter. The authors conclude that such effects may be mediated by the impact of smell or a gift on the positive affective state. In other words, when exposed to a pleasant smell, affective state would most probably become more positive (as has been demonstrated on multiple accounts, Croy et al., 2011; Glass et al., 2014), and that would in turn increase pro-social behavior. Similar findings have been demonstrated for interpersonal trust by Underwood et al. (1977). From the body of existing literature, it cannot be concluded whether the influence of smells on the processing of social stimuli is only mediated via affective state evoked by smells or whether there is more specific influence that evokes from the attribution to the social counterpart. In the first study of this thesis, I demonstrated the influence of a threatening compared to a neutral odor context on the processing of facial stimuli displaying emotional expressions. Processing of facial stimuli was facilitated within the threatening olfactory context, as was reflected on both subjective and physiological variables. However, in my first study, I could not conclude whether such effect was due to the odor being contextually perceived or to the odor being related to the facial stimuli.

In the second study, I therefore tried to disentangle the influence of personally attributable smells from that of contextually attributable smells. I tried to tease apart such attributions by means of instructions and the experimental logic. Thereby, in the social attribution, participants were confronted with one out of two virtual agents which were always standing in the same room. One was paired with a pleasant, while the other one was paired with an unpleasant smell. For the contextual attribution, participants were always confronted with the same person that stood in one out of two rooms. One room was paired with the pleasant and the other one with the unpleasant smell. The paradigm was established in VR, as this tool allowed creating different environments and combines the advantages of laboratory settings (i.e., high controllability of the experiment and thus high internal validity) with those of field studies (i.e., a more or less naturalistic setting leading to high external validity; Diemer, Alpers, Peperkorn, Shiban, & Mühlberger, 2015). Due to these advantages, VR has gained more and more attention in the past years (Andreatta et al., 2015), and attempts to administer smells in virtual environments have been made (Baus & Bouchard, 2010). The review by Baus and Bouchard (2010) points out the possibilities for practical application of odors in virtual environments due to strong interactions between odors and other senses. They report that, so far, this approach has mostly been implemented in the therapy of PTSD and drug addiction (Baus & Bouchard, 2010).

The study aimed at describing the impact of hedonic odors as well as its attribution to either the interaction partner or the environment. During the experiment, one group of participants learn the association between two virtual agents and a pleasant or unpleasant odor respectively, while for another group of participants two virtual rooms were paired with the odors. EDA, corrugator activity, breathing volume, and the LPP were recorded as learning indices at the onset of dynamic happy, neutral, or angry facial expressions performed by the agents. Additionally, ratings were collected. At the end of the experiment, participants underwent a behavioral task, during which measures of interpersonal space (i.e., how distant they kept from the agent) and approach time (i.e., how long it took them to approach the agent) were collected.

The unpleasant smell was hypothesized to evoke higher LPPs, SCL, and corrugator activity as well as smaller breathing volume and larger distances to the agents, shorter time to approach them, and lower ratings of valence, sympathy, and “homelikeness”[5] combined with higher ratings of arousal. Next to this general influence of hedonic odors on the evaluation and processing of social stimuli, a specific influence on the processing of some facial expressions was expected. This would be reflected on some expressions being more influenced by the presented odors than others. It has been shown that neutral or ambiguous expressions tend to be more easily influenced by contextual factors (Wieser & Brosch, 2012). I therefore hypothesized that agents performing a neutral facial expression should gain more emotional significance from the odors they were paired with than when performing the angry and happy facial expressions. All of these effects were hypothesized to be more pronounced in the social than in the contextual attribution group. Finally, the influence of social anxiety as measured by the SPAI (Turner et al., 1989) and contingency awareness (whether participants were able to consciously recall which agent/room was paired with which odor) were taken into account as possible influencing variables.

3.2 Methods

3.2.1 Participants

In total, 124 female participants were recruited for the study. Seven participants were excluded due to technical problems or due to low smell abilities and one because of circulatory problems. The manipulation of the attribution of odors was done between-subjects in two groups. Finally, I considered 59 participants for the social attribution group (mean age 23.17, SD = 5.71) and 58 for the contextual attribution group (mean age 22.98, SD = 4.39). Professional qualification was compared and did not differ between the groups ($X^2[3] = 6.00$, $p = .111$). Additional characteristics were compared between the groups using t-tests for parametric and X^2-tests for non-parametric testing. Statistics are reported in Table 3.

[5] In the following, the term “homelikeness” is used to refer to the question of “how much would you like to spend time in this room?”

Table 3: Descriptive variables of both groups. Standard Deviations are represented in brackets. Characteristics are defined as follows: Scores in the smell screening as measured with the Sniffin' Sticks Screening Version (Hummel et al., 2001a), subjective smell abilities as rated in the sociodemographic questionnaire, social anxiety as measured with the SPAI ((Turner et al., 1989), presence in the virtual environment (as measured with the I-group Presence Questionnaire IPQ (Schubert, 2003), positive and negative affect before and after the experiment as measured with the Positive and Negative Affect Scale PANAS (Krone, Egloff, Kohlmann, & Tausch, 1996), and the number of EDA-nonresponders (see 4.2.5 Statistical Analysis), the number of valid datasets in the distance measurement (see 4.2.5 Statistical Analysis), number of HSA participants, number of participants that were fully aware of the contingency between the odors and the virtual objects (see 4.2.5 Statistical Analysis), and the number of smokers as indicated in the sociodemographic questionnaire.

Variable	**Social Attribution**	**Contextual Attribution**	**Test values**
Age	23.17 (5.71)	22.98 (4.39)	$t[115] = 0.20$, $p = .842$
Smell Screening	10.12 (0.81)	10.93 (0.90)	$t[115] = 5.14$, $p < .001$
Subjective Smell Abilities	4.29 (0.89)	4.40 (0.79)	$t[115] = 0.69$, $p = .489$
Presence (IPQ)	2.75 (1.52)	2.64 (1.46)	$t[115] = 0.39$, $p = .696$
PANAS PA (pre)	26.75 (5.39)	31.78 (5.85)	$t[115] = 4.84$, $p < .001$
PANAS NA (pre)	13.47 (4.02)	12.07 (2.25)	$t[115] = 0.30$, $p = .023$
PANAS PA (post)	22.78 (6.46)	21.83 (5.83)	$t[115] = 0.84$, $p = .404$
PANAS NA (post)	12.76 (4.04)	12.88 (3.74)	$t[115] = 0.16$, $p = .872$
Social Anxiety	1.97 (0.80)	2.08 (1.04)	$t[115] = 0.67$, $p = .506$
HSA	$n = 29$	$n = 29$	$X^2[1] = 0.08$, $p = .972$
Aware	$n = 46$	$n = 39$	$X^2[1] = 1.69$, $p = .193$
EDA nonresponder	$n = 12$	$n = 7$	$X^2[1] = 1.47$, $p = .225$
***N* in distance measurement**	$n = 49$	$n = 52$	$X^2[1] = 1.72$, $p = .189$
Smoker	$n = 12$	$n = 8$	$X^2[1] = 1.96$, $p = .193$

3.2.2 Stimuli and Apparatus

3.2.2.1 Virtual Reality

The virtual environment was built with Source Software Development Kit (SDK; Valve Corporation, Bellevue, USA). To control the experiment and to define the experimental sequence, the software CyberSession-Research Version 5.4.20 (VT+ GmbH, Würzburg, Germany) was used. The virtual environment consisted of two offices and an anteroom or corridor, which have been used previously (Andreatta et al., 2015; Glotzbach et al., 2012). The offices were similar in shape, illumination, number of windows, and the distribution of colors. They differed in the color of the carpet and in the furniture, the pictures on the walls and the view through the window. The VR was presented via a head-mounted display (resolution 800 x 600 pixel; eMagin, Hopewell Junction, USA) fixed on the participants' heads. VR presentation was not stereoscopic, and no perspective adaption was implemented. Participants were able to move freely in the virtual environment by means of a gamepad.

Two virtual agents were singularly placed in the middle of an office. The agents represented two adult male persons that are easily distinguished (VT+ GmbH, Würzburg, Germany). The agents showed either happy, neutral, or angry facial expressions. The facial expressions were developed using the software Face Poser, which is part of Source SDK (Valve Corporation, Bellevue, USA). Facial expressions were dynamic and lasted for 2500 ms. Each expression took approximately 500 ms to rise. Different facial muscles were involved in the virtual performance of each expression to represent them as ecologically valid as possible (Weyers, Mühlberger, Hefele, & Pauli, 2006). The agent was looking at the participant while the expression was performed. For pictures of the emotional expressions and the different agents and rooms, see annex.

3.2.2.2 Olfactory Stimulation

Two pleasant and two unpleasant odors were used. The choice of the odors and the dilution in propane-1,2-diol was based on the pilot study (see annex). Each participant received one pleasant and one unpleasant odor, adding up to 4 possible combinations of pleasant and unpleasant odors. Combinations of odor delivery were counterbalanced among participants. The same olfactometer as in Study 1 and the pilot study was used.

In order to control odor properties such as valence, arousal, and intensity, ratings were collected at the beginning of the experiment. Ratings revealed that pleasant odors were rated as more pleasant ($t[114] = 14.58$, $p < .001$) and less arousing ($t[114] = 6.53$, $p < .001$) than unpleasant ones. Only a marginally significant difference was found for intensity ratings of the two odor categories ($t[114] = 1.93$, $p = .056$), indicating that unpleasant smells were perceived as slightly more intense than pleasant smells. Mean values are presented in Table 4.

Table 4: Mean ratings of valence, arousal, and intensity of the different odors at t0. Values in brackets represent standard deviations

Substance	**Valence**	**Arousal**	**Intensity**
Pleasant smells	6.34 (1.75)	3.10 (1.76)	6.21 (2.19)
Unpleasant smells	3.38 (1.74)	4.11 (1.95)	6.64 (1.86)

3.2.3 Physiological Measurements

For recording of the EEG, EMG, and SCL the same protocol as in Study 1 was used. Before the start of the experiment, EDA-nonresponders were identified. Participants were asked to inhale deeply. If they did not show a drift of the SCL (of at least 5 µS), they were classified as nonresponder and not included into the analysis concerning skin conductance level.

For this study I additionally recorded participants' breathing volume. To this purpose, a breathing belt (BrainVision, Munich, Germany) was fixed around the participants' chest. No online-filters were applied. All physiological data were recorded using a V-Amp amplifier and the software Vision Recorder Version 1.20 (BrainVision, Munich, Germany). Sampling rate was set to 500 Hz.

3.2.4 Procedure

The whole experiment was planned as a between-subjects design. The social attribution group was examined before the contextual attribution group with about half a year difference. Time window of data collection was during summer in the social attribution and during winter and early spring for the contextual attribution. The experiment consisted of three blocks during which physiological responses were collected. After the third physiological block, participants underwent a behavior block, during which approach to the virtual agents was assessed. Before and after each block, ratings for the valence, arousal, sympathy (for the social attribution), or homelikeness (for the contextual attribution) were recorded. For a schematic picture of the experimental procedure, see Part B of Figure 8.

3.2.4.1 Manipulation of the attribution of smells

Social vs. contextual attribution of the smells was manipulated between-subjects. The social attribution was performed by using one room and two different agents. One agent was paired with the pleasant odor, and the other agent was associated with the unpleasant odor. In the contextual attribution, this procedure was kept as similar as possible, but one agent and two rooms were used. The agent appeared in both rooms in separate trials. One of the rooms was paired with the pleasant and the other with the unpleasant odor. Odors and agents/rooms were counterbalanced among participants (for a short description of the balancing strategy, see annex).

Additionally to the logic of the experimental manipulation, the attribution was instructed before the start of the experiment through the information form, on the screen directly before the start, and verbally by the experimenter. For exact instructions, see annex. Specifically, for the social attribution, participants were told that they were going to enter a room where they would meet one of two agents, each of whom would exude either a pleasant or an unpleasant odor. For the contextual attribution, participants were instructed that they were going to enter one of two rooms, each of which would exude the odor. Notably, these instructions were meant to provoke participants to specifically attribute the odors to the agents vs. the offices. Notably, the exact contingency, i.e., which agent/room was associated with which odor, was not instructed.

This manipulation method had the advantage that both groups could be treated in a very similar manner. Namely, the odor presentation started at the same time (i.e., when entering the office, see 4.2.4.2 Physiology Blocks) for both attributional groups, so there was no difference in exposure time to the odors or in any other physical variables (duration of trials, ITIs, luminance, etc.).

3.2.4.2 Physiology Blocks

Before the physiology blocks, participants underwent three training trials during which they were passively guided into an office without any agent in it and were told that they should practice inhalation when they passed the doorstep of the room. If they reported not having been successful, this part of the experiment was repeated until they were able to do so. All participants reported to be successful after the first training session.

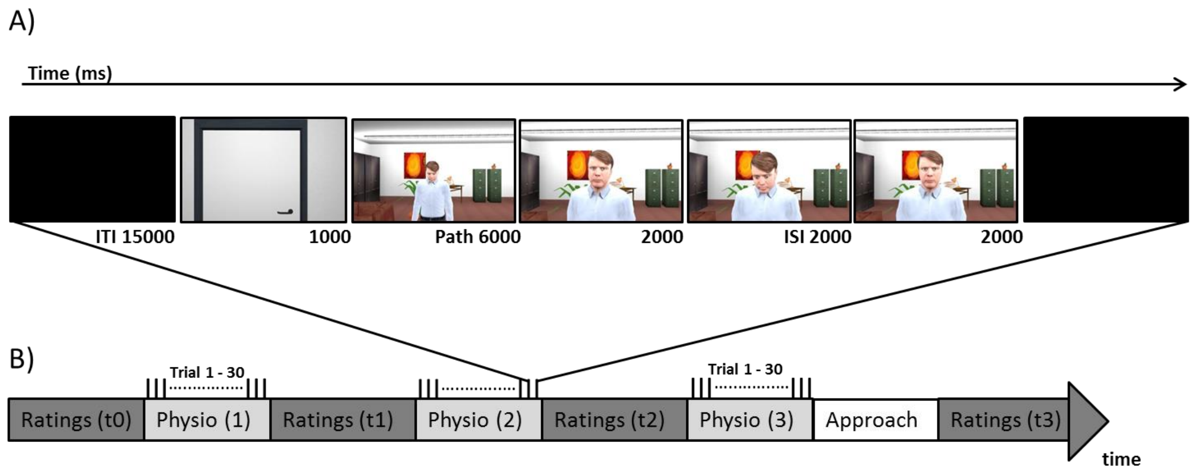

Figure 8: Overview over the experimental procedure. Part B) represents the presentation order of the different experimental phases. Part A) represents one trial of the physiology blocks with one exemplary agent in an exemplary room. ITI = Inter-trial interval, ISI = Inter Stimulus Interval.

Each trial of a physiology block started with participants standing in the corridor in front of the office's door. The door was closed at the beginning of the trial and opened as soon as the participants were passively guided into the room. It took approximately 1 sec before participants were passing the doorstep. In front of the participants, approximately in the middle of the office, a virtual agent was standing and looking towards the floor. A pre-recorded path guided participants until they stood at a distance of approximately 1.20 m from the agent. The passive approach lasted about 6 sec in total. Odor delivery started when the door was opened. Participants were instructed to inhale when entering the room. Notably, the odor took about 1 sec to rise in the breathing mask, and consequently, participants smelled the odor about when they entered the room and throughout the whole trial, i.e., 12 sec.

When they stopped in front of the agent, it raised its head and looked at them. Participants stood in front of the agent for approximately 6 sec, and the agent showed the emotional facial expression twice for 2 sec. Between the two expression performances, the agent looked at the floor once again for 2 sec. The trial then faded out, the olfactometer was closed and a new trial began after an ITI of about 15 sec.

During each block, participants entered the room 30 times (i.e., 30 trials). Within each block, each agent/room was associated 15 times with the odor. Happy, neutral, and angry facial expressions of each agent were presented 10 times in each block (5 times associated with the pleasant and 5 times with the unpleasant odor). Notably, for EEG-recording, 30 repetitions of each condition were conducted since in each trial, the emotional expression was repeated twice. See part A) of Figure 8 for an overview of the trial structure.

3.2.4.3 Rating Data

At t0, participants were asked to rate the valence, arousal, and intensity (ranging from 1 "*very faint"* to 9 "*very strong"*) of the two odors they were going to smell. To this purpose, odors were presented for 6 sec while the words "please sniff" appeared on the screen. Afterwards, these words were replaced by the rating scales.

Between the three physiology blocks (t1 and t2) as well as before (t0) and after the physiology blocks (t3), participants were asked to rate the agents and offices. To this purpose, the agents and the rooms were presented for 2 and 4 sec, respectively. The picture then faded out and a 9-point Likert scale appeared on the screen. Participants told the experimenter their ratings, who noted them. First, the room alone was rated for valence on a scale ranging from 1 ("*very unpleasant"*) to 9 ("*very pleasant"*) and arousal ranging from 1 ("*very calm"*) to 9 ("*very excited"*). Additionally, the agents, showing the three emotional expressions, were afterwards rated on valence, arousal, and sympathy, by means of a Likert scale ranging from 1 ("*not likable at all"*) to 9 ("*very likable"*). In the contextual attribution, rooms were additionally rated on "homelikeness" that was assessed by the question of how much they would like to be in the rooms, on a scale ranging from 1 ("*not at all*") to 9 ("*very much").* In this regard, valence and arousal ratings served as general evaluations of the whole situation (as the questions of how pleasant/aroused participants felt was asked), whereas the ratings of sympathy and homelikeness were used to assess a more direct evaluation of the agents and rooms.

In this experimental part, the social attribution group received a different procedure from the contextual attribution group. In other words, participants in the social attribution group rated the room and the two agents separately in each of the 4 rating blocks (t0 – t3). Thus, the agents were placed in front of a black background (and not inside the room) performing the three facial expressions. The rooms on the other hand, were presented without agents. In contrast, the contextual attribution group rated the rooms and the agents separately in each of the rating blocks, but the agents did not perform the emotional expressions. Notably, at t0 and t3, the agent and the rooms were rated while the agent was standing in the rooms and performing the emotional expression.

During the last rating session at the end of the experiment (t3), participants were additionally asked to complete an awareness task, during which they were exposed to the odor again. Afterwards, the question "*Where did this odor exude from during the experiment?*" and pictures of the room-agent combinations that was used in this respective run (i.e., one room and two agents for the social attribution vs. one agent and two rooms for the contextual attribution) appeared on the screen. Again, participants indicated their response by telling it to the experimenter. For pictures of the contingency ratings, see annex.

3.2.4.4 Approach Session

Trials of the approach block were held as similar as possible to the trials of the physiology blocks, the only difference being that participants were able to actively move in the virtual environment by means of a gamepad. Participants were initially instructed to approach the agent as close as they were comfortable with and then to indicate their final position by pressing a button.

Again, one trial started with the participant standing in front of the closed door of the office. The respective odor was delivered when the office's door was opened. The agent, standing in the middle of the office, kept looking down towards the floor while participants were approaching it. After the button press, the image was faded out, odor delivery was stopped and a new trial began after the ITI lasting 15 sec. During the approach session, each agent-odor combination was presented 3 times resulting in 6 trials.

3.2.4.5 Questionnaires and test batteries

When arriving at the lab, participants were tested for their smelling abilities using the screening version of the Sniffin' Sticks battery (Hummel et al., 2001b). The cut-off criterion was set at 9 out of 12 right answers in this test. Thereby included participants then filled in a sociodemographic questionnaire, the PANAS (Krone et al., 1996), and the SPAI (Turner et al., 1989).

The IPQ (Schubert, 2003) was filled in at the end of the experiment to assess the presence participants experienced during exposure to the virtual environment together with a post-experiment PANAS. For the sociodemographic questionnaire, see annex.

3.2.4.6 Breathing Calibration

To be able to calculate breathing volume, a calibration of the breathing belt was conducted at the beginning of each experimental session before electrodes were placed. Participants inhaled and exhaled six times from a breathing bag which contained around 800 ml of air while wearing a nose clip. The signal to inhale (3000 ms) and exhale (3000 ms) was given using the software Presentation (Neurobehavioral System Inc.). The commands appeared in white in the middle of a black screen (font size 20). This procedure was repeated twice, separated by a break, resulting in 12 breathing cycles in total. The signal was recorded by a breathing belt (BrainVision, Munich, Germany) that was fixed around the participants' chests. The exact holding capacity of the breathing bag was measured afterwards in order to be able to calculate the breathing volume of the trials of the calibration block. This amount was afterwards taken into account when data were evaluated. Missing data of content of the breathing bag were replaced by the mean holding capacity of all breathing bags.

3.2.5 Data Preprocessing and Statistical Analysis

Data preprocessing was performed using the software Vision Analyzer 2.0 (BrainVision, Munich, Germany). The exclusion of 19 EDA-nonresponders resulted in 98 datasets for the analysis of skin conductance level, namely 47 in the social and 51 in the contextual attribution group. A high-pass filter of 0.1 Hz was applied to the data, and the 1000 ms before the start of the trial were taken for baseline-correction. Averaged SCL was processed separately for the *approaching time* (i.e., the time between door opening and the end of the passive path, in total 6 sec) and the *social encounter* (i.e., the time when the agent looked at the participant and performed the emotional facial expression, in total 6 sec). SCL data were additionally exported separately for the three blocks in order to be able to follow changes over the time course of the experiment. Raw data were then logarithmized (SCL + 1) and averaged for each condition.

Preprocessing of EEG data started with the application of a 0.01 Hz low cutoff-filter, a 35 Hz high-cutoff filter, and a 50 Hz notch-filter. An Independent Component Analysis (ICA, Makeig, Bell, Jung, and Sejnowski, (1996)) ocular correction was then applied to the data. For baseline correction, 100 ms before the start of the facial expression were used. Artifact rejection was performed semi-automatically, applying a maximal voltage step of 50 µV, a maximal difference within an interval of 200 µV, minimal amplitude of -100 µV and maximal amplitude of 100 mV and the lowest allowed activity of 0.5 µV. Data were then averaged within every condition through the three blocks and over the 4 electrodes. For the LPP, a time window of 400 to 800 ms was exported.

For offline analysis of the EMG signal, I first subtracted the electric signal of the two electrodes from each other. Afterwards, a 30 Hz low cutoff, a 249 Hz high-cutoff, and a 50 Hz notch filter were applied. A moving average (window size 125 ms) and a baseline correction using 1000 ms before trial-onset were then applied to the data. Automatic artifact correction was used, applying a maximal allowed difference of 30 µV in one trial and rejecting trials that showed more than 8 µV activity during baseline. EMG activity of each condition was then averaged over trials of one condition and exported for each of the three blocks separately. As the facial expression took around 500 ms to rise, the period from 500 to 1500 ms after facial expression onset was exported for statistical analysis (Dimberg & Thunberg, 1998). Only the first of the two times the agent looked towards participants was used for EMG analysis in order to avoid overlapping effects, resulting in 5 trials per condition and block.

Due to technical issues during breathing calibration, only 111 datasets could be included in the breathing data analysis. To be able to calculate breathing volume, I first applied a moving average correction with a window size of 50 ms to the data. Afterwards, peaks of inhalation and exhalation were automatically detected. Inhalation was defined as the first peak from 0 to 5000 ms after olfactometer onset and exhalation as the last minimum before the inhalation peak (search window -2000 to 5000 ms), as a breathing cycle lasts for approximately 6 sec (Keller, 2011). Breathing data were then manually corrected, thereby keeping the same criteria for peak detection and marking the first inhalation after smell presentation and the exhalation directly before. Amplitudes of these peaks were afterwards exported separately per condition. The same was done for the data of the breathing calibration, except that the inhalation or exhalation peak was defined directly after the respective command was presented. This resulted in a mean breathing calibration value (mean difference between inhalations and exhalations) that corresponded to the respective content of the breathing bag. Final breathing volume was afterwards calculated by subtracting exhalation amplitudes from mean inhalation amplitudes. Breathing calibration was taken into account by dividing the content of the breathing bag by the mean breathing calibration value and then multiplying this factor by the resulting breathing amplitude of each odor condition.

For approach measurements, the distance between participants and agents was calculated by comparing coordinates of both of their positions. Trials during which participants walked behind the agents (and therefore were no longer able to see them and to estimate the distance) were excluded from further analysis. Due to this and to further technical problems, datasets of 16 participants could not be included into statistical analysis. Horizontal and vertical distances between agent and participant were put into Pythagorean Theorem (as both legs of the resulting triangle), resulting in the distance (as being the hypotenuse of this triangle). I also considered the time participants needed to move towards the agent. To this purpose, the starting time of the trial was subtracted from the time point when participants pressed the joystick button.

Social Anxiety and Awareness were taken into account as influencing factors to the investigated variables. The between-subjects factor of social anxiety was constructed with the values of the SPAI (Turner et al., 1989). A median split (Median = 2.04) was calculated over the whole sample, resulting in a group of low socially anxious and one of HSA participants. The between-subjects factor of awareness was constructed by the help of the contingency ratings. Participants that indicated the right source for both of the odors were classified as “aware”, whereas all other participants were classified as "unaware". Both distribution of aware and socially anxious participants did not differ between the groups (see

Table 3). Both factors were included as between-subjects factors into separate overall-ANOVAs of the different variables. Significant interactions are listed separately at the end of the results section.

Due to differences in the experimental setup, ratings were analyzed separately for the social and the contextual attribution group. For the ratings of the agents alone (social attribution) or within the office rooms (contextual attribution), three separate 4 x 2 x 3 ANOVAs were calculated for valence, arousal, and sympathy. ANOVAs contained the factors block (t0 to t3), odor (pleasant vs. unpleasant), and facial expression (happy vs. neutral vs. angry). To test significant interactions post-hoc repeated measures ANOVAs and *t*-tests were calculated. In case of significant interactions of Odor x Facial Expression, the block t0 was left outside of the follow-up ANOVAs, as ratings at t0 were recorded before any pairing with the odors had occurred. In case of significant effects including the factor block, only differences between the subsequent blocks and between t0 and all later stages were calculated. For the ratings of the room alone in the contextual attribution, 2 (odor) x 4 (block) ANOVAs were calculated for valence, arousal, and homelikeness ratings. In case of a significant interaction, post-hoc *t*-tests were conducted to compare ratings of each time point separately between the two odors. Additionally, ratings of t0 and t1 were compared within each of the two odor conditions to explore changes between time points before and after the first pairing of odors and rooms.

The SCL for the approach phase as well as the breathing volume was analyzed applying a 2 x 3 x 2 ANOVA with the factors Odor x Block x Attribution. The SCL during the social encounter and the activity of the *musculus corrugator supercilii* were analyzed by a 2 x 3 x 3 x 2 ANOVA with the factors Odor x Facial Expression x Block x Attribution. For the LPP, a 2 x 3 x 2 ANOVA was applied. It contained the factors Odor x Facial Expression x Attribution. For approach behavior, distance and time of the 3 repetitions were compared using 2 x 2 ANOVAs (Odor x Attribution). In case of a significant interaction with the factor attribution, post-hoc ANOVAs (and follow-up paired *t*-tests) were calculated within each of the two groups. The same was done in case of interactions with the factor block.

Marginally significant effects ($.05 < p < .1$) were further examined if they were hypothesis-driven. In any other cases, no post-hoc tests were applied to effects with $p > .05$. For moderating variables, only significant results were further tested, as the whole analysis was considered exploratory in nature. In case of a violation of the sphericity assumption, Greenhouse-Geisser -corrected degrees of freedom were used. The significant level for all statistical tests was set at p = .05 (two tailed). Estimated effect sizes (η_p^2) and Greenhouse-Geisser epsilon (*GG-ε*) are reported.

3.3 Results

3.3.1 Ratings of Social Attribution

3.3.1.1 Sympathy Ratings of Agents

The 2 x 3 x 4 ANOVA with the factors Odor x Facial Expression x Block revealed a significant main effect of Odor (F[1, 58] = 32.71, p < .001, η_p^2 = .36; the agent paired with the unpleasant odor was rated as less likable than the one paired with the pleasant odor), a significant main effect of Facial Expression (F[2, 116] = 88.63, p < .001, η_p^2 = .60, *GG-ε* = .70; the agent performing the happy facial expression was rated as more likable than when performing a neutral facial expression (t[58] = 2.95, p = .005) which in turn was rated more likable than the angry facial expression (t[58] = 12.15, p < .001) and a significant interaction of Odor x Block (F[3, 174] = 15.84, p < .001, η_p^2 = .21, *GG-ε* = .78). Additionally, a marginally significant interaction of Odor x Facial Expression (F[2, 116] = 2.83, p = .071, η_p^2 = .05, *GG-ε* = .86) was found. The main effect of Block (F[3, 174] = 1.29, p = .280, η_p^2 = .02, *GG-ε* = .70) and all other interactions did not reach significance (Facial Expression x Block: F[6, 348] = 1.47, p = .186, η_p^2 = .03; Odor x Facial Expression x Block: F[6, 348] = 0.79, p = .582, η_p^2 = .01).

Post-hoc testing of the interaction of Odor x Block revealed that the agent, which was paired with the unpleasant odor, did not differ from the one paired with the pleasant odor at t0 (t[58] = 0.83, p = .408), but it was rated as less likable at all later stages (t1: t[58] = 6.53, p < .001; t2: t[58] = 5.18, p < .001; t3: t[58] = 5.68, p < .001). Ratings of the agent that was paired with the unpleasant odor were lower at all later stages of the experiment compared to t0 (t1: t[58] = 4.23, p < .001; t2: t[58] = 2.62, p = .011; t3: t[58] = 2.19, p = .032). Ratings at later stages did not differ from each other (t1 vs. t2: t[58] = 1.49, p = .142; t2 vs. t3: t[58] = 0.77, p = .444). Sympathy ratings of the agent that was paired with the pleasant odor increased at all later stages compared to t0 (t1: t[58] = 4.44, p < .001; t2: t[58] = 2.77, p = .007; t3: t[58] = 3.91, p < .001). Ratings at t3 were higher than at t2 (t[58] = 2.14, p = .037), whereas the comparison of t2 to t1 did not reach significance (t[58] = 1.91, p = .062). See panel A of Figure 10 for a graphical display of the interaction.

For further exploration of the interaction of Odor x Facial Expression, the block t0 was left out of the analysis. The ANOVA revealed significant main effects of Odor (F[1, 58] = 41.58, p < .001, η_p^2 = .42) and Facial Expression (F[2, 116] = 76.82, p < .001, η_p^2 = .57) as well as a significant interaction of Odor x Facial Expression (F[2, 116] = 3.55, p = .042, η_p^2 = .06, *GG-ε* = .81). All other effects did not reach significance (all *p*s > .059). Post-hoc *t*-tests revealed that the interaction was due to the following pattern: The agent paired with the unpleasant odor was rated as less likable than the agent paired with the pleasant odor, independently of the facial expression performed (all *p*s < .001). The agent that was paired with the pleasant odor was rated as most likable when performing a happy facial expression, followed by the neutral one (happy > neutral: $t[58] = 3.43$, $p = .001$) that was in turn followed by the angry facial expression (neutral > angry: $t[58] = 9.61$, $p < .001$). However, the agent paired with the unpleasant odor did not provoke a difference in sympathy ratings for the happy and the neutral facial expression ($t[58] = 1.05$, $p = .297$). Nonetheless, both of them were rated as more likable than the angry facial expression (happy: $t[58] = 7.77$, $p < .001$; neutral: $t[58] = 10.20$, $p < .001$). See Figure 9 for a graphical display of this interaction.

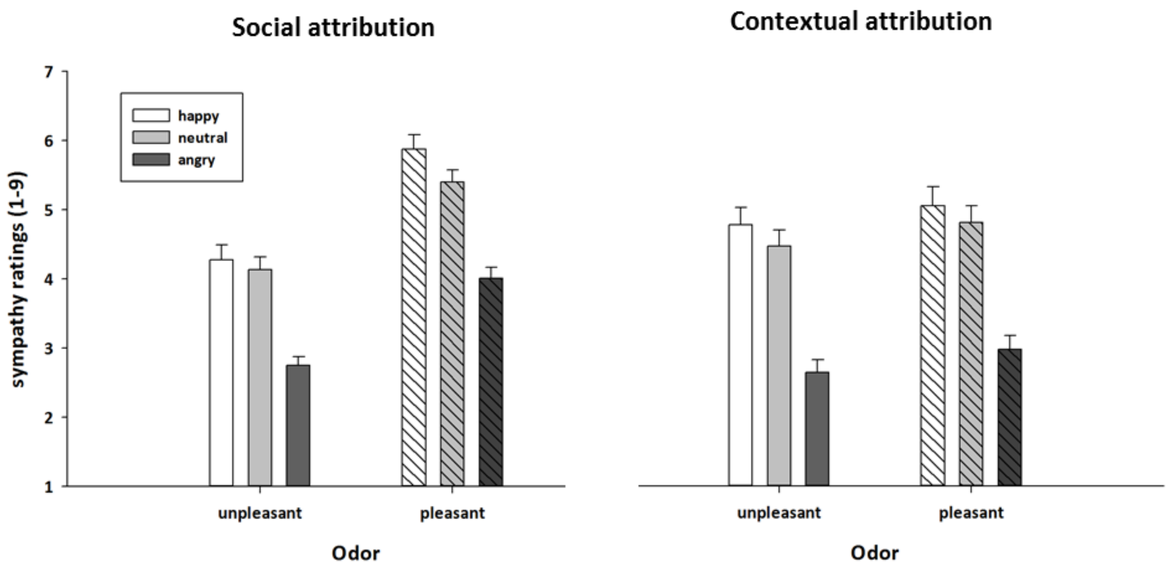

Figure 9: Sympathy ratings of both attribution groups are displayed. Ratings before the pairing of agent/rooms with the odors have not been included. Asterisks for significant differences are not shown because of too many significant differences. The white bars represent happy, the light gray bars neutral, and the dark gray bars angry facial expressions. Striped bars represent the ratings of agents paired with a pleasant odor and bars without stripes agents paired with an unpleasant odor. Error bars represent standard errors.

3.3.1.2 Valence Ratings of scenes with agents

The 2 x 3 x 4 ANOVA with the factors Odor x Facial Expression x Block returned significant main effects of Odor ($F[1, 58] = 21.75$, $p < .001$, $\eta_p^2 = .27$; indicating that agents paired with the pleasant odor were rated as more pleasant) and Facial Expression ($F[2, 116] = 84.03$, $p < .001$, $\eta_p^2 = .59$, *GG-ε* = .70; indicating that the happy facial expression was perceived as more pleasant than the neutral one ($t[58] = 2.18$, $p = .034$) that in turn was perceived as more pleasant than the angry facial expression ($t[58] = 12.62$, $p < .001$)). The main effect of Block was not significant ($F[3, 174] = 0.50$, $p = .652$, η_p^2 =

.01, *GG-ε* = .85). Additionally, a significant interaction of Odor x Block (*F*[3, 174] = 6.86, *p* = .001, η_p^2 = .11, *GG-ε* = .85) and a marginally significant interaction of Odor x Facial Expression (*F*[2, 116] = 2.57, *p* = .081, η_p^2 = .04) were found. All other interactions did not reach significance (Facial Expression x Block: *F*[6, 348] = 1.37, *p* = .227, η_p^2 = .02; Odor x Facial Expression x Block: *F*[6, 348] = 0.48, *p* = .795, η_p^2 = .01, *GG-ε* = .84).

Post-hoc testing of the interaction of Odor x Block showed that the two agents did not differ at t0 (*t*[58] = 1.26, *p* = .212), but at all later stages of the experiment, the agent paired with the pleasant odor was rated as more pleasant than the agent paired with the unpleasant odor (t1: *t*[58] = 4.62, *p* < .001; t2: *t*[58] = 3.55, *p* = .001; t3: *t*[58] = 4.63, *p* < .001). Valence ratings of the agent paired with the unpleasant odor showed a significant decrease from t0 to t1 (*t*[58] = 2.64, *p* = .011). Ratings at t2 (*t*[58] = 1.94, *p* = .057) and t3 (*t*[58] = 1.78, *p* = .080) were marginally lower in comparison to t0. All other comparisons did not reach significance (all *p*s > .180). Valence ratings for the agent that was paired with the pleasant odor increased from t0 to t1 (*t*[58] = 2.76, *p* = .008), decreased from t1 to t2 (*t*[58] = 2.29, *p* = .026) and increased from t2 to t3 (*t*[58] = 2.07, *p* = .043). Ratings at t3 were significantly higher than at t0 (*t*[58] = 2.24, *p* = .029), but ratings at t2 did not differ from t0 (*t*[58] = 0.82, *p*=< .417). See panel B of Figure 10.

For further exploration of the interaction of Odor x Facial Expression, t0 was left outside of the analysis. The post-hoc ANOVA revealed significant main effects of Odor (*F*[1, 58] = 23.96, *p* < .001, η_p^2 = .29) and Facial Expression (*F*[2, 116] = 76.71, *p* < .001, η_p^2 = .60). The interaction of Odor x Facial Expression did not reach significance (*F*[2, 116] = 2.33, *p* = .102, η_p^2 = .04). All other effects were not significant either (all *p*s > .059). This interaction was therefore not further explored.

3.3.1.3 Arousal Ratings of scenes with agents

The 2 x 3 x 4 ANOVA for the ratings of arousal revealed a significant main effect of Odor (*F*[1, 57] = 10.17, *p* = .002, η_p^2 = .15; indicating that arousal ratings were higher for the agent paired with the unpleasant odor) and Facial Expression (*F*[2, 114] = 22.63, *p* < .001, η_p^2 = .28; further classified by the fact that agents performing the angry facial expression were rated as more arousing than agents performing the happy (*t*[58] = 5.05, *p* < .001) or the neutral face (*t*[58] = 5.80, *p* < .001), whereas the latter two did not differ (*t*[58] = 1.00, *p* = .322)) and an interaction of Odor x Block (*F*[3, 171] = 4.02, *p* = .010, η_p^2 = .07, *GG-ε* = .86). The main effect Block (*F*[3, 171] = 1.45, *p* = .239, η_p^2 = .03, *GG-ε* = .75) and all other interactions (Odor x Facial Expression: *F*[2, 114] = 1.03, *p* = .359, η_p^2 = .03; Facial

Expression x Block: $F[6, 342] = 1.27$, $p = .269$, $\eta_p^2 = .02$; Odor x Facial Expression x Block: $F[6, 3,42] = 0.83$, $p = .522$, $\eta_p^2 = .01$, $GG\text{-}\varepsilon = .79$) did not reach significance.

The interaction of Odor x Block was further classified by the fact that agents did not differ at t0 ($t[58] = 0.75$, $p = .458$) and t2 ($t[58] = 1.64$, $p = .107$), whereas the agent paired with the unpleasant odor was rated as more arousing at t1 ($t[58] = 3.97$, $p < .001$) and t3 ($t[58] = 2.32$, $p = .024$) than the agent paired with the pleasant odor. Ratings of the agent that was paired with the unpleasant odor increased from t0 to t1 ($t[58] = 2.05$, $p = .045$) but decreased from t1 to t2 ($t[58] = 2.40$, $p = .022$). All other comparisons did not differ (all *p*s > .424). Arousal ratings for the agent that was paired with the pleasant odor showed a marginally significant drop from t0 to t1 ($t[58] = 1.75$, $p = .086$). All other comparisons were not significant (all *p*s > .180). For a graphic display of arousal ratings, see panel C of Figure 10.

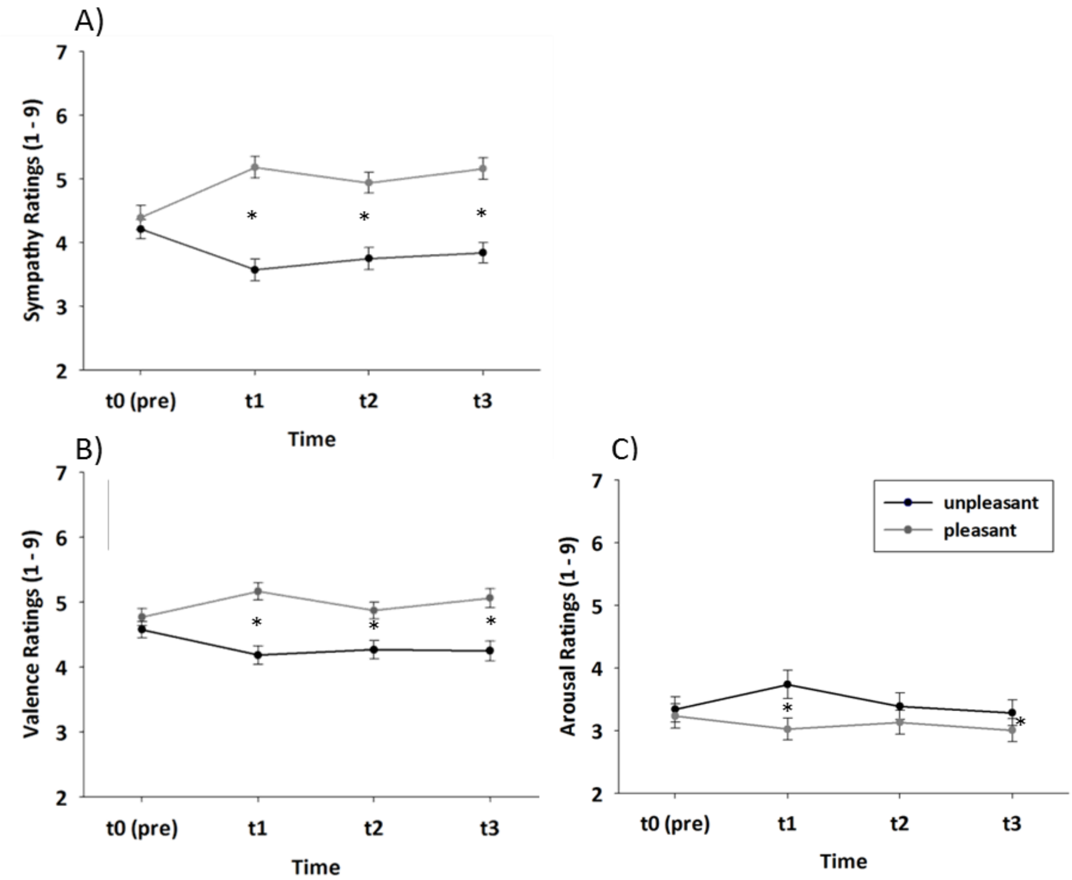

Figure 10: Ratings of agents in the social attribution group. Panel A displays sympathy ratings, panel B valence ratings, and panel C arousal ratings. Gray lines represent agents paired with the pleasant odor and black lines agents paired with the unpleasant odor. Error bars represent standard errors.

3.3.2 Ratings of Contextual Attribution

3.3.2.1 Ratings of the context

The 2 x 4 ANOVA of the ratings of valence revealed significant main effects of Odor (F[1, 57] = 31.00, p < .001, η_p^2 = .35; indicating that rooms that were paired with an unpleasant odor were rated as less pleasant) and Block (F[3, 171] = 25.24, p < .001, η_p^2 = .31, *GG-ε* = .85; further classified by the fact that valence ratings dropped from t0 to t1 (t[57] = 4.94, p < .001) and from t1 to t2 (t[57] = 3.65, p = .001), but not from t2 to t3 (t[57] = 0.22, p = .829)). Furthermore, the interaction of Odor x Block was significant (F[3, 171] = 3.99, p = .012, η_p^2 = .07, *GG-ε* = .88). Post-hoc *t*-tests of this interaction revealed that valence ratings dropped from t0 to t1 in both odor conditions (unpleasant: t[57] = 5.17, p < .001; pleasant: t[57] = 2.34, p = .023). Additionally, rooms paired with an unpleasant odor were rated as less pleasant at every block (t0: t[57] = 3.35, p = .001; t1: t[57] = 4.18, p < .001; t2: t[57] = 4.28, p < .001; t3: t[57] = 4.96, p < .001) as compared to rooms paired with a pleasant odor. To additionally test for the source of the interaction, differences between pleasant and unpleasant odor pairings were compared between the blocks. It was found that differences between the two rooms were larger after conditioning than before (t1 > t0: t[57] = 2.44, p = .018; t2 > t0: t[57] = 2.47, p = .017; t3 > t0: t[57] = .280, p = .007). Differences at all later blocks did not differ from each other (all *p*s > .570). See panel A of Figure 11.

For ratings of arousal, significant main effects of Odor (F[1, 57] = 10.66, p = .002, η_p^2 = .16; indicating that rooms paired with an unpleasant odor were rated as more arousing than rooms paired with a pleasant odor) and Block (F[3, 171] = 21.00, p < .001, η_p^2 = .27, *GG-ε* = .86; further classified by the fact that arousal ratings increased from t0 to t1 (t[57] = 5.15, p < .001) but only marginally from t1 to t2 (t[57] = 1.78, p = .081) and not further from t2 to t3 (t[57] = 0.55, p = .584)) and a significant interaction of Odor x Block (F[3, 171] = 4.74, p = .005, η_p^2 = .08, *GG-ε* = .86) were found. Post-hoc *t*-tests for the interaction revealed that arousal ratings increased from t0 to t1 for both rooms (unpleasant: t[57] = 5.67, p < .001; pleasant: t[57] = 2.78, p = .007). At t0, arousal ratings did not differ between odors (t[57] = 0.28, p = .780), but at all later blocks, rooms paired with an unpleasant odor, were rated as more arousing than rooms paired with a pleasant odor (t1: t[57] = 3.72, p < .001; t2: t[57] = 2.77, p = .008; t3: t[57] = 2.45, p = .017). See panel B of Figure 11 for a graphical display.

For ratings of homelikeness, significant main effects of Odor (F[1, 57] = 26.14, p < .001, η_p^2 = .31; indicating that participants reported higher willingness to spend time in the room paired with the pleasant odor compared to the unpleasant odor) and Block (F[3, 171] = 15.46, p < .001, η_p^2 = .21; classified by the fact that homelikeness ratings dropped from t0 to t1 (t[57] = 2.81, p = .007) and from t1 to t2 (t[57] = 3.24, p = .002), but not from t2 to t3 (t[57] = 0.15, p < .882)) and a significant interaction of Odor x Block (F[3, 171] = 5.86, p = .001, η_p^2 = .09, GG-ε = .88) were found. Post-hoc t-tests showed that homelikeness ratings dropped from t0 to t1 for the room that was paired with the unpleasant odor (t[57] = 3.34, p = .001), but not for the one paired with the pleasant odor (t[57] = 0.94, p = .354). Homelikeness ratings of the rooms did not differ at t0 (t[57] = 1.65, p = .105). However, at all later blocks, the participants were more willing to spend time in the room paired with the pleasant than with the unpleasant odor (t1: t[57] = 3.57, p = .001; t2: t[57] = 4.61, p < .001; t3: t[57] = 5.59, p < .001). See panel C of Figure 11.

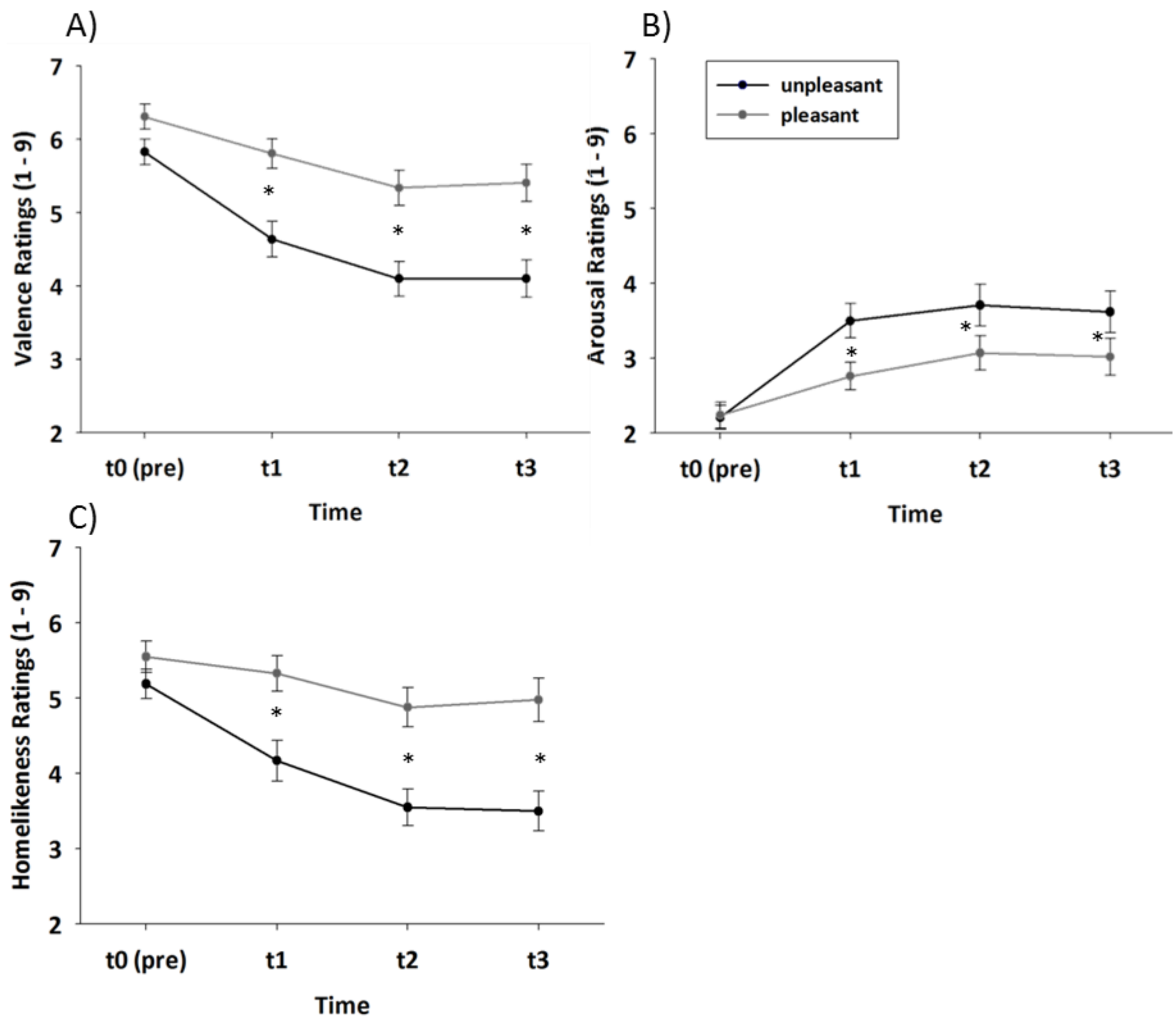

Figure 11: Ratings of the rooms in the contextual attribution group. Panel A displays valence ratings, panel B arousal ratings, and panel C homelikeness ratings. Gray lines represent rooms paired with the pleasant odor and black lines rooms paired with the unpleasant odor. Error bars represent standard errors.

3.3.2.2 Sympathy Ratings of Agents in Contexts

For sympathy ratings, the 2 x 3 x 2 ANOVA revealed significant main effects of Odor (F[1, 56] = 4.38, p = .041, η_p^2 = .07; indicating that agents in a room paired with a pleasant odor were rated as more likable than in a room paired with an unpleasant odor), Facial Expression (F[2, 112] = 68.82, p < .001, η_p^2 = .55, *GG-ε* = .87; agents performing the happy facial expression were rated as more likable than agents performing the neutral facial expression (t[57] = 2.51, p = .015) that in turn were rated as more likable than agents performing the angry facial expression (t[57] = 10.31, p < .001)), and Block (F[1, 56] = 11.11, p = .002, η_p^2 = .17; indicating that sympathy ratings dropped from t0 to t3). Additionally, the interaction of Odor x Block was significant (F[1, 56] = 4.16, p = .046, η_p^2 = .07). All other interactions did not reach significance (Odor x Facial Expression: F[2, 112] = 0.06, p = .946, η_p^2 < .01; Facial Expression x Block: F[2, 112] = 1.17, p = .188, η_p^2 = .03; Odor x Facial Expression x Block: F[2, 112] = 0.07, p = .933, η_p^2 < .01). For the interaction of Odor x Facial Expression (in contrast to the social attribution group), see Figure 9.

Post-hoc t-tests for the interaction of Odor x Block revealed that at t0, sympathy ratings did not differ between the odors (t[57] = 0.22, p = .829), but at t3, agents in a room that was paired with a pleasant odor were rated as more likable than in a room paired with an unpleasant odor (t[57] = 2.86, p = .006). However, sympathy ratings dropped from t0 to t3 in the unpleasant odor condition (t[57] = 3.40, p = .001) and marginally significant in the pleasant odor condition (t[57] = 2.00, p = .051).

3.3.2.3 Homelikeness Ratings of Contexts with Agents

The 2 x 3 x 2 ANOVA for the ratings of homelikeness revealed significant main effects of Odor (F[1, 56] = 12.02, p = .001, η_p^2 = .18; indicating that participants felt more willingness to spend time in a room paired with a pleasant odor than in a room paired with an unpleasant odor), Facial Expression (F[2, 112] = 53.00, p < .001, η_p^2 = .49, *GG-ε* = .80; participants reported marginally more willingness to spend time in a room with an agent performing a happy than a neutral facial expression (t[57] = 1.93, p = .059) and more with an agent performing a neutral than an angry facial expression (t[57] = 9.68, p < .001)), and Block (F[1, 56] = 19.59, p < .001, η_p^2 = .26; indicating that homelikeness dropped from t0 to t3). Additionally, the interactions of Odor x Block (F[1, 56] = 10.43, p = .002, η_p^2 = .16) and Facial Expression x Block were significant (F[2, 112] = 4.16, p = .022, η_p^2 = .07, *GG-ε* = .91). Neither the interaction of Odor x Facial Expression (F[2, 112] = 0.22, p = .804, η_p^2 < .01) nor the three-way interaction reached significance (F[2, 112] = 0.34, p = .711, η_p^2 = .01).

Post-hoc *t*-tests of the interaction of Odor x Block showed that at t0, the rooms did not differ in homelikeness (t[57] = 0.30, p = .767), but at t3, rooms paired with a pleasant odor were rated as more homelike than rooms paired with an unpleasant odor (t[57] = 3.91, p < .001). This was mainly due to ratings dropping from t0 to t3 for the unpleasant (t[57] = 4.99, p < .001) but not for the pleasant odor (t[57] = 1.51, p = .137).

Post-hoc *t*-tests to further explore the nature of the interaction of Facial Expression x Block revealed that homelikeness of a room with a happy agent was higher than with a neutral agent at t0 (t[57] = 3.48, p = .001) but not at t3 (t[57] < 0.01, p > .999). In turn, homelikeness of a room with an agent performing an angry facial expression was lower than with an agent performing a neutral facial expression in both blocks (t0: t[57] = 7.39, p < .001; t3: t[57] = 7.80, p < .001). Additionally, ratings of homelikeness dropped from t0 to t3 for the angry (t[57] = 4.26, p < .001) and the happy facial expression (t[57] = 4.53, p < .001) and only marginally for the neutral facial expression (t[57] = 1.98, p = .052).

3.3.2.4 Valence Ratings of combined scenes

For the 2 x 3 x 2 ANOVA of valence ratings of the agents within the context, significant main effects of Odor (F[1, 57] = 8.03, p = .006, η_p^2 = .12; indicating agents in rooms that were paired with the pleasant odor were rated as more pleasant than paired with an unpleasant odor), Facial Expression (F[1, 57] = 8.48, p = .005, η_p^2 = .13; classified by the fact that happy facial expression was rated as marginally more pleasant than the neutral facial expression (t[57] = 1.74, p = .086) which in turn was rated as more pleasant than the angry facial expression (t[57] = 9.73, p < .001)) and Block (F[2, 114] = 58.54, p < .001, η_p^2 = .51, *GG-ε* = .83; agents were rated as more pleasant at t0 than at t3) were found as well as a significant interaction of Odor x Block (F[1, 57] = 5.16, p = .027, η_p^2 = .08) and of Facial Expression x Block (F[2, 114] = 4.58, p = .015, η_p^2 = .07, *GG-ε* = .89). The interaction of Odor x Facial Expression did not reach significance (F[2, 114] = 0.21, p = .813, η_p^2 < .01), but the three-way interaction indeed did (F[2, 114] = 3.47, p = .035, η_p^2 = .06).

To test for the origin of the three-way interaction, two 2 x 3 ANOVAs with the factors Odor x face were conducted separately for each block. At t0, a main effect of Facial Expression was found (F[1, 57] = 36.69, p < .001, η_p^2 = .39, *GG-ε* = .82), as well as a marginally significant interaction of Odor x Facial Expression (F[2, 114] = 2.53, p = .084, η_p^2 = .04). This interaction was not tested further as I did not have any a priori hypothesis concerning this effect. The main effect of Odor did not reach significance (F[2, 114] = 0.02, p = .887, η_p^2 < .01).

At t3, significant main effects of Odor (F[1, 57] = 12.38, p = .001, η_p^2 = .18; agents in rooms paired with an unpleasant odor were rated as less pleasant) and Facial Expression (F[2, 114] = 60.35, p < .001, η_p^2 = .51, GG-ε = .89) were found. The main effect of facial expression was explained by agents performing angry facial expression being rated as less pleasant than both the neutral (t[57] = 10.22, p < .001) and the happy expression (t[57] = 8.11, p < .001), whereas the latter two did not differ (t[57] = 0.27, p = .786). The interaction of Odor x Facial Expression did not reach significance at t3 (F[2, 114] = 1.03, p = .359, η_p^2 = .02).

3.3.2.5 *Arousal Ratings of combined scenes*

The 2 x 3 x 2 ANOVA with the factors Odor, Facial Expression, and Block for arousal ratings of the agents in context revealed a significant main effect of Facial Expression (F[2, 114] = 17.75, p < .001, η_p^2 = .24, GG-ε = .84). It was classified by the angry facial expression being rated as more arousing than both the neutral (t[57] = 5.59, p < .001) and the happy (t[57] = 4.00, p < .001) facial expression, while the latter two did not differ (t[57] = 0.98, p = .333). Additionally, the main effect Odor (F[1, 57] = 3.50, p = .066, η_p^2 = .06; indicating that agents in the room paired with the unpleasant odor were rated as more arousing than agents in rooms paired with a pleasant odor) and the interaction of Odor x Block (F[1, 57] = 3.13, p = .082, η_p^2 = .05) were marginally significant. All other interactions and the main effect of Block did not reach significance (Block: F[2, 114] = 0.08, p = .784, η_p^2 < .01; Odor x Facial Expression: F[2, 114] = 2.20, p = .116, η_p^2 = .04; Facial Expression x Block: F[2, 114] = 0.12, p = .886, η_p^2 < .01; Odor x Facial Expression x Block: F[2, 114] = 0.34, p = .672, η_p^2 = .01, GG-ε = .83). Exploratively tested, the interaction of Odor x Block was further classified by the fact that agents in the rooms paired with different odors did not differ in their arousal ratings at t0 (t[57] = 0.20, p = .839), but at t3, agents in the room that was paired with the unpleasant odor were rated as more arousing (t[57] = 2.19, p = .032). Agents in both rooms did not change significantly from t0 to t3 in their arousal ratings (all ps >.294).

3.3.3 Late Positive Potential

The 2 x 3 x 2 ANOVA with the factors Odor x Facial Expression x Attribution revealed significant main effects of Odor (F[1, 115] = 4.43, p = .038, η_p^2 = .04; indicating that the LPP was higher in the unpleasant odor than in the pleasant one (Figure 12, panel A)), Facial Expression (F[2, 230] = 22.51, p < .001, η_p^2 = .16, GG-ε = .93; classified by the fact that the LPP amplitude was higher for the angry (t[116] = 5.19, p < .001) and the happy facial expression (t[116] = 5.51, p < .001) than for the neutral one, whereas the first two did not differ from each other (t[116] = 0.35, p = .728)), and Attribution (F[1,115] = 5.37, p = .022, η_p^2 = .05; indicating that the LPP amplitude was higher in the contextual than in the social attribution group). Furthermore, the interaction of Facial Expression x Attribution turned out to be significant (F[2, 230] = 4.07, p = .021, η_p^2 = .03, GG-ε = .93), whereas the other two-way interactions (Odor x Facial Expression: F[2, 230] = 0.030, p = .730, η_p^2 < .01, GG-ε = .94; Odor x Attribution: F[1,115] = 0.21, p = .648, η_p^2 < .01) and the three-way interaction (F[2, 230] = 0.51, p = .589, η_p^2 < .01, GG-ε = .94) did not.

The interaction of Facial Expression x Attribution was further tested by comparing the facial expressions within each attribution group separately. Within both groups, the happy and the angry facial expression resulted in larger LPP amplitudes than the neutral facial expression (happy/angry > neutral: all ps < .027), while the first two did not differ from each other in both groups (happy vs. angry: all ps > .230). Comparisons between the two attribution groups for each facial expression revealed that the contextual attribution group showed larger LPPs than the social attribution group to the angry (t[115] = 2.93, p = .004) and the happy facial expression (t[115] = 2.08, p = .040), whereas the LPP did not differ between two groups when the neutral facial expression was performed (t[115] = 1.01, p = .318).

3.3.4 Skin Conductance Level

3.3.4.1 Approaching Part

For the approach part, the 2 x 3 x 3 ANOVA returned a significant main effect of Block (F[2, 188] = 8.34, p = .001, η_p^2 = .08, GG-ε = .86), indicating that SCL decreased from block 1 to block 2 (t[95] = 2.02, p = .046) and from block 2 to block 3 (t[95] = 2.60, p = .011). Additionally, a marginally significant interaction of Odor x Block (F[2, 188] = 2.69, p = .740, η_p^2 = .03, GG-ε = .93) was found. No other main effects (Odor: F[1, 94] = 1.26, p = .265, η_p^2 = .01; Attribution: F[1, 94] = 0.30, p = .587, η_p^2 < .01) or other interactions (Odor x Attribution: F[1, 94] = 0.98, p = .325, η_p^2 = .01; Block x Attribution: F[2, 188] = 0.43, p = .651, η_p^2 = .01; Odor x Block x Attribution: F[2, 188] = 1.90, p = .153, η_p^2 = .02) reached significance. Further exploration of the interaction revealed that in block 2, the SCL was higher when an unpleasant than when a pleasant odor was presented (t[95] = 2.31, p = .023). This pattern was partly explained by the fact that in the pleasant odor, the SCL decreased from block 1 to block 2 (t[95] = 2.12, p = .036), whereas in the unpleasant odor, it decreased from block 2 to block 3 (t[95] = 3.01, p = .003). All other comparisons did not reach significance (all ps > .215). For the interaction of Odor x Block, see panel B of Figure 12.

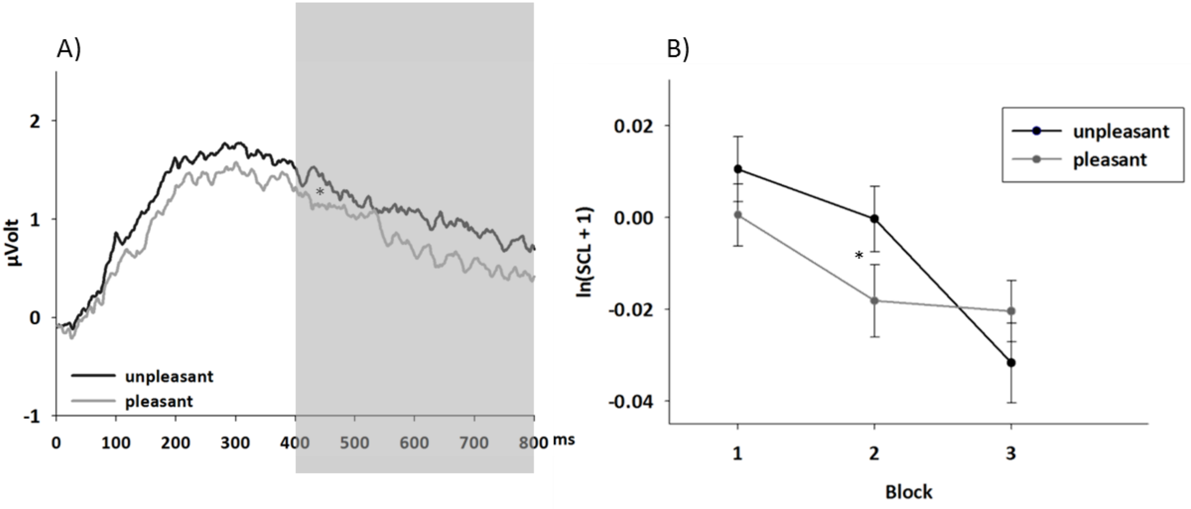

Figure 12: The main effect of odor on the late positive potential (A) and the interaction of Odor x Block on the skin conductance level (B) are displayed. Gray bars/lines represent the condition of pleasant and black bars/lines the condition of unpleasant odors. Error bars represent standard errors. The export window of the LPP amplitude is represented by the gray area.

3.3.4.2 Social Encounter Part

For the social encounter part, the 2 x 3 x 3 x 2 ANOVA revealed a marginally significant main effect of Odor (*F*[1, 93] = 2.91, *p* = .091, η_p^2 = .03; indicating that SCL was higher when an unpleasant than when a pleasant odor was presented), Block (*F*[2, 186] = 17.26, *p* < .001, η_p^2 = .16, *GG-ε* = .91; indicating that the SCL dropped from the first compared to the other two blocks (t2: *t*[95] = 4.80, *p* < .001; t3: *t*[95] = 4.38, *p* < .001), whereas the latter two did not differ (*t*[95] = 0.01, *p* = .994)), and Attribution (*F*[1, 93] = 5.64, *p* = .020, η_p^2 = .06; classified by the fact that the SCL was higher in the contextual than in the social attribution group). Additionally, a marginally significant interaction of Odor x Facial Expression x Attribution (*F*[2, 186] = 2.46, *p* = .088, η_p^2 = .03) and an interaction of Odor x Facial Expression x Block (*F*[4, 372] = 2.45, *p* = .051, η_p^2 = .03, *GG-ε* = .92) were found. All other effects did not reach significance (all *p*s > .220).

Explorative post-hoc testing of the interaction of Odor x Facial Expression x Attribution with a 2 x 3 ANOVA considering the factors Odor and Facial Expression was performed by calculating in each attributional group separately. In the social attribution group, a marginally significant interaction (*F*[2, 88] =2.64, *p* = .077, η_p^2 = .06) was found, whereas the main effects of Odor (*F*[1, 44] = 2.57, *p* = .116, η_p^2 = .06) and Facial Expression (*F*[2, 88] = 0.38, *p* = .687, η_p^2 = .01) did not reach significance. The marginal interaction was mainly driven by the fact that the SCL was higher in the unpleasant than in the pleasant odor when a neutral facial expression was performed (*t*[44] = 2.41, *p* = .020), but when a happy (t[44] = 1.61, p = .114) or angry facial expression (t[44] = 0.52, p = .605) was performed, no significant differences were revealed. Additionally, facial expressions did not differ from each other within the pleasant or unpleasant odor (all ps > .145). In the contextual attribution group, neither main effects (Odor: F[1, 50] = 0.40 , p = .528, η_p^2 = .01; Facial Expression: F[2, 100] = 0.35, p = .668, η_p^2 = .01, GG-ε = .85) nor the interaction effect (F[2, 100] = 0.17, p = .855, η_p^2 < .01) reached significance. For a graphic display of the interaction, see Figure 13.

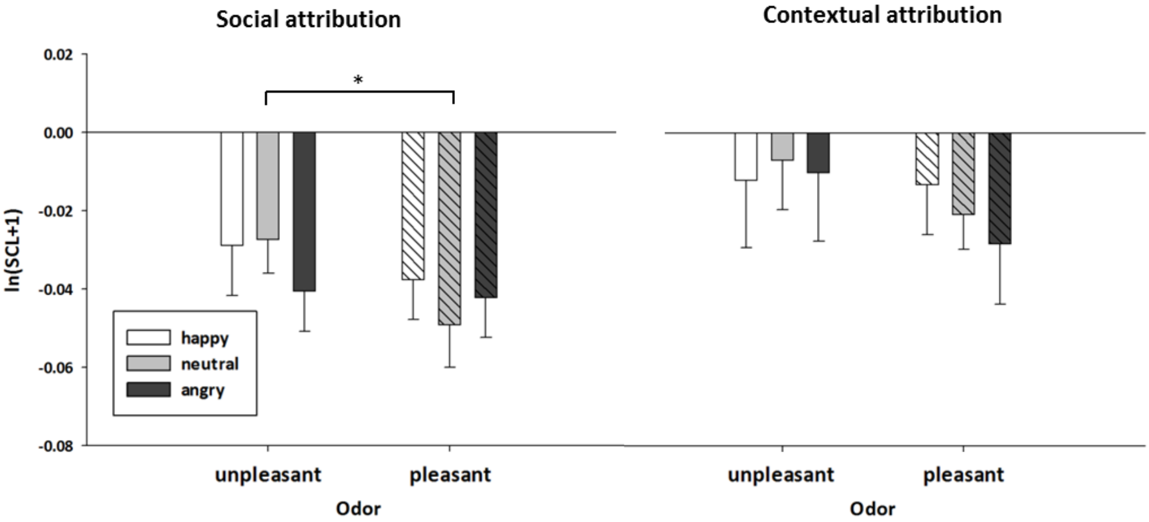

Figure 13: The interaction of Odor x Attribution x Facial Expression is displayed. The white bars represent happy, the light gray bars neutral, and the dark gray bars angry facial expressions. Striped bars represent the skin conductance level during the encounter with agents paired with a pleasant odor and bars without stripes during the encounter with agents paired with an unpleasant odor. Error bars represent standard errors.

The interaction of Odor x Facial Expression x Block was exploratively examined by calculating three 2 x 3 ANOVAs with the factors Odor and Facial Expression, one for each block. In the first block, a significant main effect of Odor was found (F[1, 95] = 7.33, p = .008, η_p^2 = .07), indicating that the SCL was higher when an unpleasant than when a pleasant odor was presented. The main effect Facial Expression did not reach significance (F[2, 190] = 0.05, p = .952, η_p^2 < .01). Additionally, the interaction of Odor x Facial Expression was significant (F[2, 190] = 5.43, p = .005, η_p^2 = .05). Post-hoc t-tests revealed that the interaction was mainly driven by the SCL being higher in the unpleasant than in the pleasant odor when a happy (t[95] = 2.72, p = .008) or a neutral facial expression was performed (t[95] = 2.96, p = .004) and did not differ when an angry face was performed (t[95] = 0.99, p = .323). Additionally, when a pleasant odor was presented, the angry facial expression elicited higher SCL than the happy (t[95] = 2.49, p = .015) or the neutral facial expression (t[95] = 2.79, p = .006). The latter two and all facial expressions in the unpleasant odor did not differ from each other (all ps > .105). In block 2 and block 3, no significant effects were found (all ps > .436). For the interaction of Odor x Facial Expression in block 1, see Figure 14.

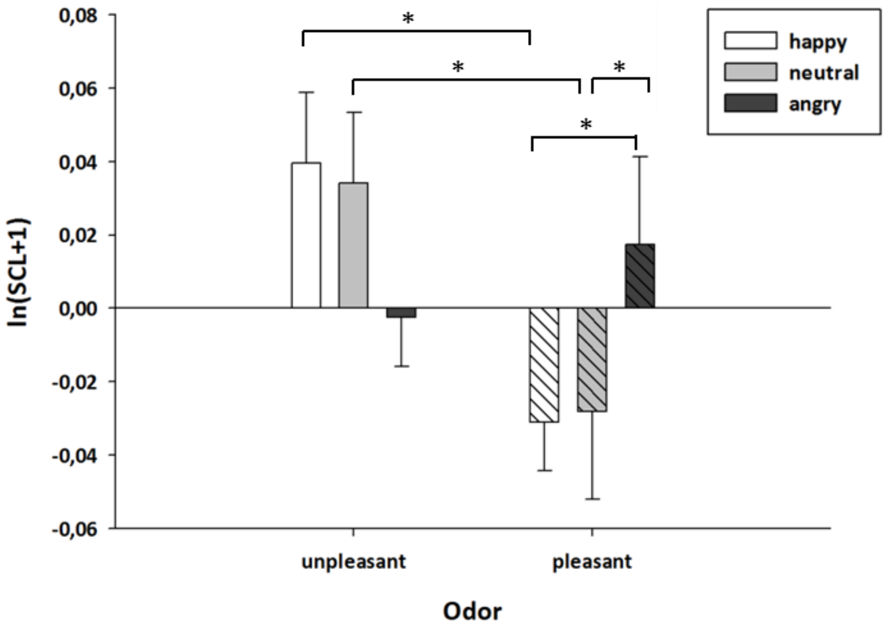

Figure 14: Skin conductance level during social encounter. The interaction of Odor x Facial Expression in block 1 is displayed. The white bars represent happy, the light gray bars neutral, and the dark gray bars angry facial expressions. Striped bars represent the skin conductance level during the encounter with agents paired with a pleasant odor and bars without stripes during the encounter with agents paired with an unpleasant odor. Error bars represent standard errors.

3.3.5 Corrugator

The 2 x 3 x 3 x 2 ANOVA revealed a significant main effect of Attribution (F[1, 114] = 6.63, p = .011, η_p^2 = .05), indicating that corrugator activity in the social attribution group was lower than in the contextual attribution group. All other main effects did not reach significance (Odor: F[1, 144] = 0.50, p = .824, η_p^2 < .01; Facial Expression: F[2, 228] = 0.11, p = .882, η_p^2 < .01, *GG-ε* = .91; Block: F[2, 228] = 0.24, p = .790, η_p^2 < .01). However, a significant three-way interaction of Facial Expression x Block x Attribution (F[4, 456] = 2.54, p = .046, η_p^2 = .02) and a marginally significant three-way interaction of Odor x Facial Expression x Attribution (F[2, 228] = 2.63, p = .080, η_p^2 = .02, *GG-ε* = .90) were found. All other interactions did not reach significance (all ps > .115).

The interaction of Facial Expression x Block x Attribution was exploratively investigated by two ANOVAs of Facial Expression x Block separately for each group. In the social attribution group, no significant effects were found (main effect Facial Expression: F[2, 114] = 0.22, p = .775, η_p^2 < .01; *GG-ε* = .88; main effect Block: F[2, 114] = 0.12, p = .891, η_p^2 < .01; interaction of Facial Expression x Block: F[4, 228] = 0.51, p = .731, η_p^2 = .01). In the contextual attribution group, no significant main effect Facial Expression (F[2, 114] = 0.99, p = .367, η_p^2 = .02) or Block (F[2, 114] = 1.14, p = .318, η_p^2 = .02;

GG-ε = .87) was found, but a significant interaction of Facial Expression x Block (F[4, 228] = 2.82, p = .039, η_p^2 = .05; *GG-ε* = .77). Separate t-tests within each block revealed higher corrugator activity for happy than for neutral (t[57] = 2.46, p = .017) and angry (t[57] = 2.42, p = .019) facial expressions in block 1. In block 2, corrugator activity was higher for angry than for happy facial expressions (t[57] = 2.52, p = .015). All other comparisons did not reach significance (all ps > .064).

Post-hoc testing of the three-way interaction revealed a marginally significant interaction of Odor x Facial Expression in the social attribution group (F[2, 116] = 2.85, p = .070, η_p^2 = .05; *GG-ε* = .86). The main effects Odor (F[1, 58] = 0.82, p = .369, η_p^2 = .01) and Facial Expression (F[2, 116] = 0.21, p = .782, η_p^2 < .01; *GG-ε* = .88) were not significant. The two-way interaction was further classified by significantly lower corrugator activity for happy than for neutral facial expression when the agent exuded a pleasant odor (t[58] = 2.07, p = .043) and marginally higher corrugator activity when the agent performed a neutral facial expression for the pleasant vs. the unpleasant odor (t[59] = 1.77, p = .081). All other comparisons did not reach significance (all ps > .140). In the contextual attribution, no significant effects were found (main effect Odor: F[1, 57] = 1.77, p = .189, η_p^2 = .03; main effect Facial Expression: F[2, 114] = 0.99, p = .376, η_p^2 = .02; interaction: F[2, 114] = 0.42, p = .620, η_p^2 = .01; *GG-ε* = .84). See Figure 15 for a graphical display of the interaction.

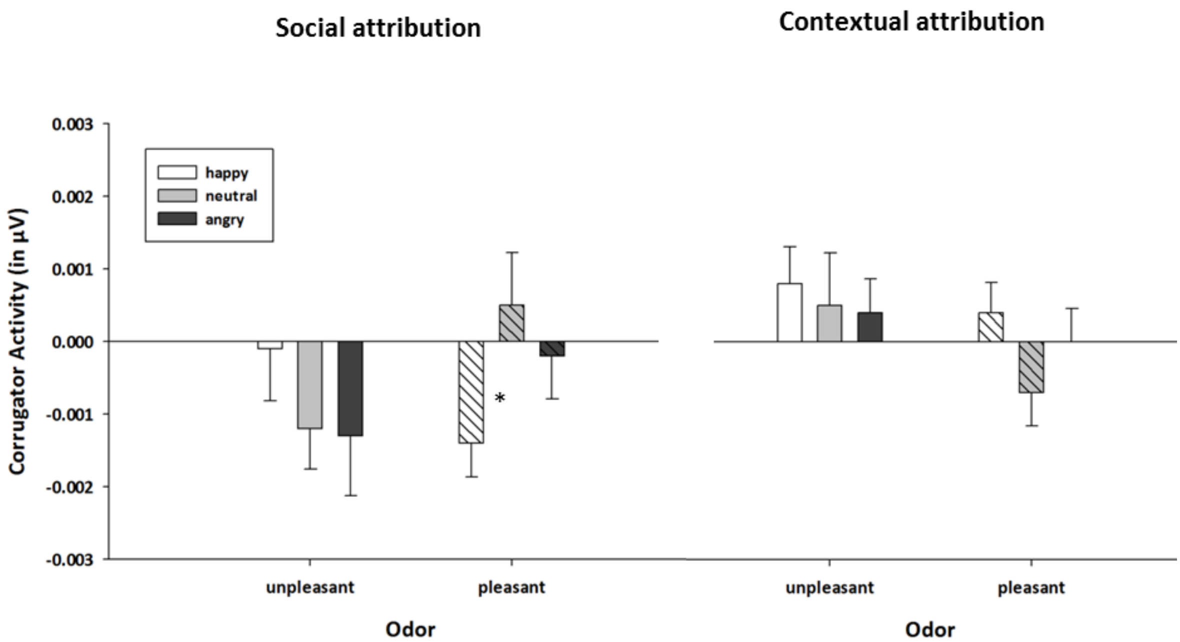

Figure 15: Corrugator activity for both attribution groups is displayed. The white bars represent happy, the light gray bars neutral, and the dark gray bars angry facial expressions. Striped bars represent corrugator activity during the encounter with agents paired with a pleasant odor and bars without stripes during the encounter with agents paired with an unpleasant odor. Error bars represent standard errors.

3.3.6 Approach Behavior

3.3.6.1 Distance

For the distance between participants and agents, the 2 x 2 ANOVA returned only a significant main effect of Odor (*F*[1, 99] = 14.13, *p* < .001, η_p^2 = .12). Participants kept larger distances to the agents when an unpleasant smell was presented than when a pleasant smell was presented. The main effect Attribution (*F*[1, 99] = 0.62, *p* = .433, η_p^2 = .01) and the interaction (*F*[1, 99] = 1.20, *p* = .276, η_p^2 = .01) did not reach significance.

3.3.6.2 Approach Time

For the time participants spent approaching the agents, the 2 x 2 ANOVA returned a marginally significant main effect of Odor (*F*[1, 99] = 3.87, *p* = .052, η_p^2 = .04), indicating that participants tended to spend less time approaching the agents when an unpleasant smell compared to a pleasant smell was presented. The main effect Attribution (*F*[1, 99] = 0.18, *p* = .671, η_p^2 < .01) and their interaction (*F*[1, 99] = 0.30, *p* = .588, η_p^2 < .01) did not reach significance. See Figure 16 for a graphical display of distance and time.

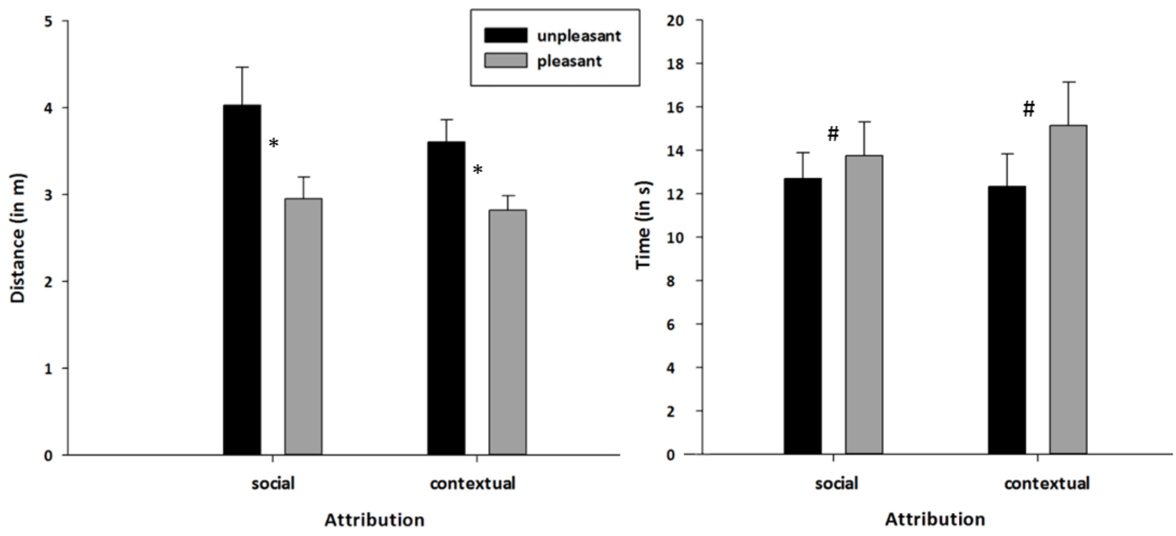

Figure 16: Graphical display of the main effect of Odor on the distance participants kept to the agent and the time they spent approaching. Note that larger numbers in the left panel stand for larger distance and therefore less approaching behavior. Black bars represent the condition of unpleasant and gray bars of pleasant odors. Error bars represent standard errors.

3.3.7 Breathing Volume

The ANOVA revealed a significant main effect of Odor (F[1, 109] = 10.99, p < .001, η_p^2 = .09), indicating that breathing volume was larger when a pleasant odor than when an unpleasant odor was presented. Additionally, a significant main effect of Block was found (F[2, 218] = 20.83, p < .001, η_p^2 = .16, GG-ε = .80). Post-hoc t-tests indicated that the breathing volume dropped from block 1 to block 2 (t[110] = 5.13, p < .001) and block 3 (t[110] = 5.07, p < .001), whereas breathing volumes in block 3 were only marginally lower than in block 2 (t[110] = 1.97, p = .052). The main effect of Attribution (F[1, 109] = 0.68, p = .411, η_p^2 = .01) as well as the interactions did not reach significance (Odor x Attribution: F[1, 109] = 1.44, p = .233, η_p^2 = .09; Odor x Block: F[2, 218] = 1.70, p = .188, η_p^2 = .02, GG-ε = .92; Attribution x Block: F[2, 218] = 1.33, p = .266, η_p^2 = .01, GG-ε = .80; three-way interaction: F[2, 218] = 0.20, p = .803, η_p^2 < .01, GG-ε = .92).

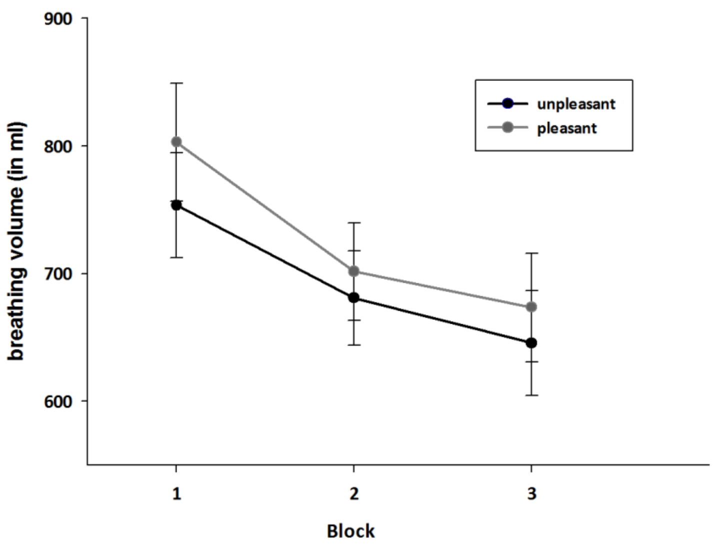

Figure 17: Breathing volumes when exposed to the pleasant or unpleasant odor are displayed throughout the three experimental blocks. Gray lines represent the breathing volume during exposure to the pleasant and black lines during exposure to the unpleasant odor. Error bars represent standard errors.

3.3.8 Influence of Moderating Variables

No significant correlation between the distribution of high and low socially anxious participants and aware and unaware participants could be found ($X^2{}_1$ = 0.13, p = .720).

3.3.8.1 Social Anxiety

In the social attribution group, for sympathy ratings, a significant interaction of Odor x Social Anxiety was found (F[1, 57] = 6.34, p = .015, η_p^2 = .10). All other effects did not reach significance (all ps > .191). The interaction was due to the following effects: Both groups rated the agent paired with the pleasant odor as more likable than the agent paired with the unpleasant one (low: t[28] = 5.71, p < .001; high: t[29] = 2.63, p = .014). Sympathy ratings did not differ between the groups for the agent paired with the pleasant odor (t[57] = 1.15, p = .256), but for the agent paired with the unpleasant one. LSA participants declared even lower sympathy than HSA participants (t[57] = 2.17, p = .034).

For valence ratings, the interaction of Odor x Social Anxiety was significant (F[1, 57] = 5.75, p = .020, η_p^2 = .09) and the four-way interaction showed a trend towards significance (F[6, 342] = 1.91, p = .092, η_p^2 = .03, GG-ε = .84). All other effects did not reach significance (all ps >.207). Post-hoc t-tests for the interaction revealed that agents paired with a pleasant odor were rated as more pleasant than when paired with an unpleasant odor by the group of LSA participants (t[28] = 5.03, p < .001). However, this difference was only marginally significant in the group of HSA participants (t[29] = 1.81, p = .081). The group of LSA participants rated agents that were paired with a pleasant smell marginally more pleasant than the HSA group (t[57] = 1.74, p = .087). For agents paired with an unpleasant smell (t[57] = 1.18, p = .245), this difference was not significant.

For arousal ratings, the interaction of Facial Expression x Social Anxiety (F[2, 112] = 5.30, p = .006, η_p^2 = .09) as well as the interaction of Facial Expression x Block x Social Anxiety (F[6, 336] = 2.67, p = .037, η_p^2 = .04) were significant. Additionally, a significant main effect of Social Anxiety was found (F[1, 56] = 12.68, p = .001, η_p^2 = .19), indicating that HSA participants rated agents as more arousing than LSA ones (all other effects: p > .192). Post-hoc t-tests of the interaction of Facial Expression x Social Anxiety revealed that this difference was also found for each facial expression separately (all ps < .002). Besides, the angry facial expression was rated as more arousing than the two other ones by both social anxiety groups (all ps < .018), whereas the other two expressions did not differ from each other (all ps > .181). Post-hoc ANOVAs for the interaction of Facial Expression x Block x Social Anxiety revealed a significant main effect of Facial Expression in the LSA group (F[2, 56] = 5.35, p = .007, η_p^2 = .16). All other effects did not reach significance within the LSA group (all ps > .451). In the HSA group, however, a significant main effect of Facial Expression (F[2, 58] = 19.70, p < .001, η_p^2 = .40) as well as a significant interaction of Facial Expression x Block (F[6, 147] = 2.17, p = .048, η_p^2 = .07) were found. The main effect of Block was not significant (p = .263). Post-hoc t-tests for this interaction revealed that at t0, the facial expressions did not differ from each other (all ps > .191), whereas at all later blocks, the angry face was rated as more arousing than the other two (all *p*s < .037). At t3, the happy facial expression was additionally rated as more arousing than the neutral one (p = .028). Arousal ratings at subsequent blocks did not differ from each other for any of the three facial expressions (all *p*s > .141).

In the contextual attribution, no significant interactions were found with the factor Social Anxiety for valence ratings (all *p*s > .145), arousal ratings (all *p*s > .241), and homelikeness ratings (all *p*s > .269). For sympathy ratings, a significant interaction of Odor x Social Anxiety (F[1, 55] = 5.24, p = .026, η_p^2 = .09) and a marginally significant interaction of Facial Expression x Block x Social Anxiety (F[2, 110] = 2.78, p = .061, η_p^2 = .05) were found. All other effects did not reach significance for sympathy ratings (all *p*s > .232). The interaction of Odor x Social Anxiety was explained by the fact that agents in rooms that were paired with a pleasant odor were rated as more likable than in a room that was paired with an unpleasant odor in the group of LSA (t[28] = 3.12, p = .004), but not in the group of HSA participants (t[28] = 0.06, p = .915). Sympathy ratings did not differ between the groups, neither for the pleasant (t[56] = 1.02, p = .309) nor for the unpleasant odor (t[56] = 0.08, p = .939).

The consideration of the factor Social Anxiety as an additional between-subjects factor into the ANOVA of Odor x Facial Expression x Attribution did not reveal any significant interaction with social anxiety for the LPP (all *p*s > .183) or the SCL during approach (all *p*s > .233). For the SCL during the social encounter phase, consideration of the factor Social Anxiety as an additional between-subjects factor revealed marginally significant interactions of Facial Expression x Social Anxiety (F[2, 182] = 2.37, p = .096, η_p^2 = .03) and of Odor x Facial Expression x Block x Social Anxiety (F[4, 364] = 2.43, p = .053, η_p^2 = .03). All other interactions with the factor Social Anxiety were not significant (all *p*s > .100).

For activation of the *musculus corrugator supercilii*, the consideration of the factor Social Anxiety as an additional between-subjects factor did not reveal any significant interaction with this factor (all *p*s > .135). For approach behavior, the between-subjects factor Social Anxiety in both distance measurement and approach time did not reveal any significance (all *p*s > .138) Including the factor Social Anxiety into the analysis of breathing volumes did not reveal any significant interaction with this factor (all *p*s > .256).

3.3.8.2 Awareness

In the social attribution group, for the interactions of the factor Awareness with sympathy ratings, a significant interaction of Odor x Awareness was found (F[1, 57] = 5.60, p = .036, η_p^2 = .08), as well as marginally significant interactions of Odor x Block x Awareness (F[3, 171] = 2.70, p = .062, η_p^2 = .05,

GG-ε = .77) and Odor x Facial Expression x Block x Awareness (F[6, 342] = 1.87, p = .086, η_p^2 = .03). Post-hoc tests for the interaction of Odor x Awareness revealed that agents that were paired with a pleasant odor were rated as more likable than agents paired with an unpleasant odor by the group of aware participants (t[45] = 5.84, p < .001) but not by the group of unaware participants (t[12] = 1.23, p = .243). Agents that were paired with the unpleasant odor were rated as less likable by the group of unaware participants compared to the aware group (t[57] = 2.51, p = .015), whereas no difference was found for agents that were paired with the pleasant odor (t[57] = 0.42, p = .674).
A significant interaction of Odor x Awareness was found for valence ratings (F[1, 57] = 4.87, p = .031, η_p^2 = .08). The interactions of Odor x Block x Awareness (F[3, 171] = 2.48, p = .072, η_p^2 = .04, *GG-ε* = .87), Odor x Facial Expression x Awareness (F[2, 114] = 2.58, p = .081, η_p^2 = .04) as well as the four-way interaction (F[6, 342] = .189, p = .095, η_p^2 = .03, *GG-ε* = .85) were marginally significant. All other effects did not reach significance (all ps >.132). Post-hoc tests for the interaction of Odor x Awareness revealed that agents that were paired with a pleasant odor were rated as more pleasant than agents paired with the unpleasant odor by the group of aware participants (t[45] = 5.18, p < .001) but not by the group of unaware participants (t[12] = 0.34, p = .738). The two groups differed neither for the pleasant (t[57] = 1.56, p = .125) nor for the unpleasant odor (t[57] = 1.14, p = .261). No significant interactions with the factor Awareness were found for arousal ratings (all ps > .124).

In the contextual attribution group, a significant interaction of Odor x Awareness was found (F[1, 56] = 4.13, p = .047, η_p^2 = .07) for valence ratings. The interaction of Facial Expression x Block x Awareness was marginally significant (F[2, 112] = 2.65, p = .082, η_p^2 = .05, *GG-ε* = .89). All other effects did not reach significance (all ps > .292). Post-hoc t-tests for the interaction of Odor x Awareness revealed that agents standing in a room that was paired with a pleasant odor were rated as more pleasant only for the group of aware participants (t[38] = 3.37, p = .002), but not for unaware ones (t[18] = 0.00, p = 1.000). Ratings did not differ between the groups for pleasant (t[56] = 0.87, p = .388) or unpleasant odors (t[56] = 0.26, p = .795). No significant interactions with the factor Awareness were found for arousal ratings (all ps > .244) and sympathy ratings (all ps > .164). For ratings of homelikeness, a significant interaction of Odor x Awareness was found (F[1, 55] = 5.19, p = .027, η_p^2 = .09). All other effects were not significant (all ps > .115). Post-hoc tests revealed that aware participants preferred to spend time in a room that was paired with a pleasant odor (t[38] = 3.38, p < .001), whereas no difference was found between the odors for unaware participants (t[18] = 0.37, p = .718). The homelikeness ratings did not differ between the groups for pleasant (t[56] = 0.60, p = .552) or for unpleasant odors (t[56] = 1.01, p = .319).

No significant interactions with the awareness were found for the LPP (all *p*s > .152), the SCL during approach (all *p*s > .123), or during the social encounter (all ps > .143). For corrugator activity, however, inclusion of the factor Awareness revealed a significant interaction of Odor x Block x Awareness (*F*[2, 224] = 6.12, *p* = .003, η_p^2 = .05). All other interactions with the factor Awareness did not reach significance (all *p*s > .264). The interaction is further classified by significant interactions of Odor x Block in the aware (*F*[2, 62] = 3.30, *p* = .044, η_p^2 = .10) as well as in the unaware group (*F*[2, 166] = 5.19, *p* = .008, η_p^2 = .06, *GG-ε* = .93). However, the pattern was opposite in both groups. While in the aware group, corrugator activity rose over blocks for the unpleasant odor (block 1 < block 2: *t*[84] = 2.06, *p* = .043; block 1 < block 3: *t*[84] = 2.11, *p* = .038) and tended to drop for the pleasant odor (block 1 > block 3: *t*[83] = 1.95, *p* = .054), in the unaware group, it tended to drop for the unpleasant odor (block 1 > block 3: *t*[31] = 1.83, *p* = .078).

For approach behavior, the between-subjects factor Awareness in both distance measurement and approach time did not reveal any significant interactions or main effects (all *p*s > .250). Adding the factor Awareness into the analysis of breathing volume did not reveal any significant effects (all *p*s > .147).

3.4 Discussion

The present study investigated the influence of an initially pleasant or unpleasant odor on the processing and evaluation of social stimuli in a virtual reality paradigm. Additionally, it was explored whether the direct attribution of the odor to the social agents played a major role in this influence by either establishing a social attribution (i.e., to the virtual agent) or a contextual attribution (i.e., to the virtual rooms where the social encounter took place). Changes in processing and evaluation were depicted on different physiological, behavioral, and subjective variables. Physiological variables were recorded in three consecutive blocks, while the virtual environment and the hedonic odors were presented simultaneously. The same was true for behavioral data, except that those data were recorded in a separate approach block at the end of the experiment. Subjective ratings were collected in-between the physiology blocks, while agents and rooms were rated without the odor being presented, thereby constituting the test block of the learning paradigm established here. As the paradigm consisted of three factors (odor, attribution, and emotional facial expression) and as olfactory stimulation requires long inter-stimulus intervals in order for the nose to recover and to prevent habituation, the factor attribution was, in this first experiment, manipulated between-subjects in order to avoid too long lasting experimental sessions, resulting in two experimental groups.

Presentation of agents in rooms together with an unpleasant compared to a pleasant odor led to preferential processing as reflected in enhanced LPP amplitudes and enhanced SCL. The LPP has been shown to reflect motivational processes (Schupp et al., 2000), while the SCL is more often found to be arousal-modulated (Bradley et al., 2001; Glass et al., 2014; Löw et al., 2008). With regard to olfactory stimuli, enhanced motivational processes and autonomic arousal would most probably occur simultaneously. Unpleasant odors are characterized by a greater risk of harm to the organism of the perceiver (Auffarth, 2013). This potential risk would result in enhanced avoidance motivation following the perception of these bad smells (i.e., higher LPP) and in a similar vein on higher autonomic arousal (i.e., higher SCL). The prioritized processing was also reflected on the subjective ratings and the breathing volume during presentation of the odors. In fact, unpleasant odors were shown to evoke higher general arousal ratings paralleling the SCL findings. Conceivably, participants inhaled less deeply when an unpleasant compared to a pleasant odor was presented. These effects suggest a general preferential processing of unpleasant vs. pleasant odors independently of their attribution.

Strikingly, pairing unpleasant odors with agents or rooms resulted in attenuated approach behavior towards the agent in an additional behavioral task at the end of the experiment. Supportively, participants spent less time approaching the agent when an unpleasant smell compared to a pleasant one was presented. In other words, participants felt comfortable with a greater distance to the virtual agents when an unpleasant than when a pleasant smell was presented, regardless of odor attribution. These results are in line with the *equilibrium theory* by Argyle and Dean (1965). They suggest a compensatory function of the adjustment of interpersonal distances. Thus, when violating the personal space of others, people would tend to adjust additional factors to compensate for this violation (e.g., smiling). Respectively, if surrounding variables lead to a less pleasant evaluation of the interaction partner or the situation (as in the present study), distances would be flexibly adjusted.

Furthermore, results indicated that olfactory conditioning of virtual agents and rooms was successful as reflected in all subjective rating scales. Agents and rooms that were paired with an unpleasant odor were rated as less pleasant, less likable/homelike and more arousing than agents or rooms paired with a pleasant odor, while they did not differ in ratings before conditioning. This difference was not only due to the fact that pairing with an unpleasant odor resulted in more negative ratings, but also that pairing with pleasant odors resulted in more positive evaluations compared to the baseline. These results are in line with previous studies on olfactory conditioning (Gottfried et al., 2002a; Hermann et al., 2002; Todrank et al., 1995) and confirmed the notion that olfactory cues are suitable reinforcers in olfactory aversive and appetitive conditioning. Whether olfactory conditioning can also be reflected on physiological variables is hard to answer by the present data, as the respective variables were only recorded during physiology blocks, when agents/rooms and odors were presented simultaneously. One would expect an increase in influence on the physiological variables throughout the course of the experiment due to learning factors. However, no significant changes over time were found. In contrast, if there were any effects to be found, they tended to be larger in the first block than in the subsequent ones (as was true for the SCL). Conditioning responses are often found to be largest in the first trials, i.e., when the consequences of a stimulus are still unexpected (*prediction error,* Garrison et al., 2013; McHugh et al., 2014; O'Doherty, Dayan, Friston, Critchley, & Dolan, 2003). In contrast, during later stages of the experiment, participants knew about the associations between rooms/agents and odors, which could be responsible for the flattening of the learning curve. Additionally, the effect of odors on physiological variables could have suffered from habituation throughout the long experiment (Flohr et al., 2015; Hudry et al., 2001; Poellinger et al., 2001). Which of these speculations is true, or if most of the effects I found on the physiology might be due to the simultaneous presentation of odors and agents in rooms rather than to learned association between agents/rooms and odors cannot be answered by the present data.

An interacting effect of hedonic odors and the processing of emotional facial expressions could only be observed on some variables. On the SCL, it could be shown that the influence of the unpleasant vs. the pleasant odors was strongly mediated by the facial expression of the agents. Differentiation between the odors was only found for neutral or happy facial expressions during the first block (see Figure 14). This could be due to happy and neutral facial expressions being more easily influenced by a present hedonic odor, while angry facial expressions were preferentially processed and therefore not influenced by pleasant vs. unpleasant odors. A similar pattern was found for sympathy ratings (at least in the social attribution group). Pairing of agents with an unpleasant odor led to less distinction among facial expressions, but this effect only concerned neutral and happy facial expressions. Supposedly, angry facial expressions as a potential threatening cue recruit more processing resources than neutral or happy facial expressions, and the latter two are therefore more prone to the influence of surrounding stimuli. Supportively, unpleasant olfactory stimuli are potentially noxious to the organism and thus signal threat. It seems plausible that in such conditions of potential danger, angry facial expressions are still able to catch the participants' attention, but neutral or happy facial expressions are not. It has been argued before that neutral or ambiguous facial expressions are more likely to be influenced by surrounding stimuli (Wieser & Brosch, 2012). This assumption is further supported by the results of the corrugator activity. Again, presentation of the unpleasant odor flattens the differences among facial expressions, such that modulation of corrugator activity as a function of facial expression is only found when presented together with a pleasant and not with an unpleasant odor (and only in the social attribution group). However, the only modulation that was found was a larger relaxation of the corrugator muscle when the agent was smiling compared to the neutral facial expression (indicating positive valence). No corrugator activity potentiation was found when the agent performed an angry facial expression. Surprisingly, for the neutral and the happy facial expression, corrugator activity was higher in the pleasant than in the unpleasant odor, in contrast to what is commonly found in the literature (Delplanque et al., 2009). Contrarily to what would have been expected when speaking about recruitment of attentional resources due to the potentially threatening nature of unpleasant olfactory stimuli, the effects of the LPP did not show any specific modulation of hedonic smells on face processing.

Results of the attribution manipulation were only found on some measures. SCL and corrugator activity have been found to exhibit changes only in the social attribution group. The same was true for the differential influence of odors on the evaluation of some facial expressions as reflected on the sympathy ratings. The interaction of odor and reactions of different facial expressions is interpreted as social interaction, as this interaction would not be found in non-human objects. This interaction was only found in the social attribution group. It is possible that odors which are contextually attributed are not related to the virtual agents and therefore do not result in specific changes of the influence on emotional expressions. In sum, the attribution of the odors to the social agents resulted in larger effects of odors on the processing and evaluation of social stimuli. Why these effects did not display on all variables is to be investigated by future research.

With respect to the moderating variables, I found the following effects. Interactions with social anxiety were only observable on the ratings and not on the physiological or behavioral variables. Thus, the LSA participants of the social attribution group showed larger rating differences between unpleasant and pleasant odors than the HSA participants of the same attribution group. The same effect was found in the contextual attribution group but only for sympathy ratings. Additionally, it was shown that the group of HSA participants gave generally higher arousal ratings when evaluating the agents. These effects indicate that the HSA participants experienced states of higher arousal when being exposed to the virtual agents. It seems plausible that the fact of being exposed to a social stimulus outperformed the fact of whether the agents were paired with a pleasant or an unpleasant odor. This could have led to the observation that the difference between odors disappeared in the group of HSA participants. The effect of HSA participants not differing between facial stimuli is commonly found in the literature (Mühlberger et al., 2009). It is interpreted as general enhanced salience of facial stimuli in HSA participants leading to a reduced differentiation between emotional facial expressions. The study by Mühlberger et al. (2009) shows this effect of reduced differentiation on the LPP.

With respect to contingency awareness, some effects were found on the ratings. Participants that were aware of the contingency between odors and rooms/agents showed larger differences between the two odor conditions on valence and sympathy ratings in the social attribution group and on sympathy and homelikeness ratings in the contextual attribution group. It seems logical that participants who were able to verbally report the contingency after the experiment also displayed a clearer differentiation between the odors on the subjective variables. Concerning the physiological and behavioral measurements, results are very scarce. Only the corrugator activity data showed an interaction with awareness. Namely, aware participants displayed an increase of corrugator activity throughout the experiment for unpleasant odors, whereas unaware participants decreased in corrugator activity. These findings point towards successful learning of odor (un-)pleasantness in the aware but not in the unaware group.

In this study, the present paradigm was used for the first time. The question arises whether characteristics of the virtual environment are suitable for this kind of experimental manipulation. As the virtual office rooms have been successfully used before (Andreatta et al., 2015) and were matched for multiple subjective and objective variables, it is very likely that they constitute a useful manipulation of a daily virtual environment. Of greater interest when talking about social behavior are the application of the social agents and the emotional facial expressions. So far, the agents were not used in any published study, and the facial expressions were specifically created for the present paradigm. The results of the subjective ratings and the LPP suggest that facial expressions were perceived as intended, and this was additionally supported by the fact that perception of facial expressions differed for HSA vs. LSA participants. The present results mimic the results of a study by Mühlberger et al. (2009), who were able to demonstrate that real and artificial facial expressions elicit equal manipulations of the LPP (i.e., larger LPP amplitudes for emotional than for neutral facial expressions). However, in the present study, no facial mimicry could be observed on activity of the corrugator muscle. Studies on facial mimicry by using dynamic virtual faces are scarce. Weyers et al. (2006) demonstrated that dynamic faces do not differ from static ones when it comes to facial mimicry. The results of the present study are in line with their results as Weyers et al. (2006) also did not find corrugator activity potentiation but relaxation of this muscle during the presentation of happy faces. The results of the SCL showed differential effects concerning odors' impact on facial expressions. Still, modulations of subjective and objective responses to emotional facial expression were found on some variables.

Some potential influencing factors have to be taken into account when interpreting the results. The question arises whether the difference between the two hedonic odors was also due to appetitive effects of the pleasant odor or whether the effects merely reflected aversive effects as contrasted to the appetitive odor. A control condition with either a neutral or no odor would be needed in order to answer this question. The lack of this control condition was due to the already long duration of the experiment. The literature on appetitive effects of odors is contradictory. Some authors also found effects for pleasant odors vs. clean air (Cook et al., 2015), while some did not (Dematte et al., 2007). What remains as a fact is that the impact of aversive odors is stronger than the impact of appetitive ones, most possibly due to their potentially threatening character. Additionally, the present study involved the drawback that ratings of agents were not directly comparable between the groups as in the social attribution group, agents were rated without any context (in front of a black background), whereas in the contextual group, agents were rated in the virtual office rooms. The separate analysis of the results in the two groups was therefore done explanatorily and not based on statistical reasons. This is a drawback originating from the planning phase of the experimental design and should be overcome in future experiments.

A second question that comes into mind when interpreting the results is the origin of the effects I found in the additional approach part. One has to take into account that in this special part of the experiment, participants were able to decide themselves how long a trial would last and thereby how long they would be exposed to the unpleasant odor. It can therefore not be decided by the present data whether the results were really due to participants not wanting to approach the agents any further or whether they wanted to get rid of the unpleasant odor as quickly as possible. However, this ostensible drawback supports the notion of what I wanted to catch with this measure, namely a measure that is as ecologically valid as possible. When interacting with a person that exudes an unpleasant smell, human beings would most probably want both to get rid of the smell and to avoid the person exuding it.

Thirdly, a result that is somewhat surprising is the continuously higher activity on all physiological variables in the contextual attribution group. As this was not at all reflected on any subjective or behavioral measure, it was most probably due to physical reasons. As data of the two groups were collected one after another, this could be due to seasonal reasons or characteristics of the applied hardware. In line with this was the finding that the contextual attribution group reached higher scores in the Smell Screening. This is most probably also due to physical reasons as the test battery was changed between the social and the contextual attribution group (as it expires after a certain time). It is thus possible that the sticks were just more intense for the contextual than for the social attribution group. These results are not paralleled by the intensity ratings of the odors[6]. The contextual attribution group even reported lower arousal ratings than the social attribution group.

Another prominent factor concerning the results is the question of conscious odor processing. In an intriguing study on olfactory conditioning (Li et al., 2007) hedonic odors were found to guide social preferences only if presented subconsciously. Conscious perception of the odors degraded the conditioning effect. In the present study, all odors were present at a consciously perceivable concentration. Contrarily to the study by Li and colleagues, I found strong evidence for successful olfactory conditioning with supraliminally presented odors. Moreover, 72% of the participants were able to consciously report the contingency between agents/rooms and odors. This might not have been the case if odors had been presented subliminally. Adding the factor awareness into the analyses only revealed small effects of influence, but they all resulted in stronger effects for participants that were aware of the contingency than for participants that were not. Within these considerations one has to remember that odors were rated for valence, arousal, and intensity before the start of the experiment. This procedure could have drawn the participants' attention to odor hedonics and might thereby have left them even more conscious about the methods applied. Nonetheless, compared with the study of Li et al. (2007), I found similar results although participants were aware of odor presentation, contingency between the odor and its source, and most probably even odor hedonics.

In summary, the present study proved to be suitable for the manipulation of different odors and their influence on different social variables. The experiment is, to my knowledge, the first to investigate the influence of odors on variables of social interaction and preferences in a VR setting. The VR and the facial expressions I set up were suitably implemented in the experiment. Even calculation of the LPP was possible with the present experimental setup, although facial expressions did not have a distinct stimulus onset but the agents lifting their head and looking at the participant. Moreover, it could be shown that unpleasant vs. pleasant odors influence social interaction on different variables, as was reflected on a general effect of odor hedonics as well as by a specific effect of hedonics on face processing. The impact of odor attribution was demonstrated on some variables but not on others and therefore remains open for specification in future research.

[6] This approach was not reported above as it was not in the main focus of the study. It could be shown that there were no interactions of Odor x Attribution or main effects of Attribution for valence ratings (all *p*s > .069) or intensity ratings (all *p*s > .139). There was a significant main effect of Attribution for arousal ratings ($F[1, 113] = 5.23$, $p = .024$, $\eta_p^2 = .04$), indicating that the social attribution group reported higher arousal ratings for both odors. The interaction of Odor x Attribution was not significant ($F[1, 113] = 0.53$, $p = .468$, $\eta_p^2 = .01$).

4 Study 3: On the Attribution of Smells: Within-Subjects Manipulation

4.1 Introduction

In my previous study, I established an experimental paradigm in VR, which allowed disentangling the influence of smells attributed to a social agent from the influence of a contextually attributed smell on social interaction. The conditions were manipulated between-subjects, thus resulting in two experimental groups. It was shown that the simultaneous presentation of an odor and a virtual agent led to shifts in evaluative ratings in line with the hedonic value of the odor. Additionally, the combined presentation of a virtual agent with an unpleasant odor resulted in larger LPP amplitudes and higher SCL than the combination of an agent with a pleasant odor. On the behavioral level, it could be demonstrated that agents in combination with unpleasant odors were less approached than those in combination with pleasant odors. Differential effects of odors on the processing of emotional facial expressions performed by the agents were found on sympathy ratings, EDA, and corrugator activity. Greater effects for the social attribution of smells were demonstrated on the EDA, the corrugator activity, and subjective ratings, but not on other physiological or behavioral variables.

The present study was meant to establish the paradigm for a more ecologic use (i.e., within-subjects) and to explore possible changes due to distinct awareness about odor attribution. Moreover, the previous study suffered from two major drawbacks which will be overcome by the present study. First, the between-subjects paradigm was designed in a way that made it difficult to directly compare the ratings of the two groups. Thus, the social attribution group rated the agents separately, meaning in front of a black background outside of the room, whereas the contextual attribution group rated both rooms and agent separately, but in this case the agent was presented inside the rooms. Therefore, the current study tries to overcome this limitation by assessing ratings in both attributional conditions in a similar way: Valence and arousal ratings will be given as overall judgments of the whole situation, i.e., the combination of agents and rooms. Sympathy ratings will be used to assess the evaluation of the virtual agents, while “homelikeness” ratings are meant to evaluate the rooms.

The second drawback concerns the approach task. In fact, in the previous study participants were allowed to decide how close they wanted to move toward the agents. They then could initiate the end of the trial by pressing a joystick button. Even though this approach is fairly ecologically valid, it makes it difficult to disentangle whether the large distance kept from the agents (i.e., less approach) when the unpleasant odor was presented is due to participants not wanting to further approach the agents or rather to the attempt to get rid of the unpleasant smell quickly. In daily life, approaching someone and being exposed to his/her smell for a long time goes hand in hand. Therefore, the present study tries to solve this confusion by prompting participants to withdraw from agents instead of approaching them. As a consequence, greater distance to the agents and more time exposed to the unpleasant odor would then be reversely proportional. This approach was meant to allow drawing conclusions about effects being due to smell exposure or approach behavior per se.

Moreover, I decided to collect heart rate and SCL, ratings of valence, arousal, sympathy and “homelikeness”, interpersonal distance to the agents as well as time spent on withdrawal behavior, like in the previous study. LPP, corrugator activity, and breathing volume were not further collected, because they appeared not to be sensitive enough for detecting factors mediating social interactions. Furthermore, I decided to only show the agent displaying a neutral facial expression during the physiology blocks. This has the advantage of reducing the paradigm’s duration. However, during the rating blocks, happy, neutral, and angry facial expressions were performed by the agents. It was hypothesized that ratings of both agents and rooms would vary according to the valence of the associated odors. Additionally, the SCL was supposed to be higher during presentation of the unpleasant odors, whereas heart rate was supposed to vary according to the *defense cascade model* (Fanselow, 1994) while participants were passively approaching the agent. Odors were supposed to modulate the pattern of heart rate deceleration and following acceleration according to their perceived valence. I expected heart rate data to exhibit a weaker deceleration followed by a stronger acceleration during the presentation of the pleasant compared to the unpleasant odor as has been shown by Löw et al. (2008). Finally, interpersonal distance was supposed to be influenced by the presented odors. Distance should be larger to agents combined with an unpleasant odor, and withdrawal time should be longer in comparison to the pleasant odor. Besides a general influence of the hedonic odors, a differential influence on neutral and happy facial expressions was hypothesized according to the results of the previous study. I expected both the happy and the neutral facial expression to be influenced more strongly by odor valence than the angry facial expression. Moreover, effects were supposed to be larger in the social attribution condition than in the contextual attribution condition. Social anxiety and awareness of contingency between agents/rooms and odors was taken into account as a potential modulating variable.

4.2 Methods

4.2.1 Participants

Thirty-two female participants took part in the study. The same inclusion criteria as in the previous studies were applied. One participant had to be excluded because of technical problems, resulting in 31 participants (mean age = 21.42 years; *SD* = 1.95) for the analysis. All participants reached a minimum of 9 out of 12 correct answers in the Smell Screening (*M* = 10.77; *SD* = 0.99, (Hummel et al., 2001b). They rated their subjective smell abilities as medium (*M* = 4.23; *SD* =0.72). On the SPAI (Turner et al., 1989), the participants reached an average score of 2.00 (*SD* = 0.77) and on the IPQ (Schubert, 2003) of 2.77 (*SD* = 1.38). Prior to the experiment, participants reported a mean negative affect of 12.52 (*SD* = 2.53) and a mean positive affect of 28.42 (*SD* = 5.74) on the PANAS (Krone et al., 1996). Positive affect diminished during the experiment ($t[30] = 2.11$, $p = .043$, $m_{post} = 26.13$, $SD_{post} = 5.17$), whereas the negative affect did not change ($t[30] = 0.13$, $p = .893$, $m_{post} = 12.16$, $SD_{post} = 3.63$). Three participants reported to be smokers. Seven participants were classified as EDA-nonresponders (for criteria see below), resulting in *n* = 25 for the analysis skin conductance level. Due to specific technical problems with the distance measurement, only 28 participants could be included into the analysis of this variable. Nineteen participants were fully aware of the contingency between the odors and the agents/rooms.

4.2.2 Stimuli and Apparatus

4.2.2.1 Virtual Reality

The VR characteristics were the same as in Study 2. The virtual environment now consisted of three office rooms and a corridor, one extra room was added to the two rooms of the previous experiment. Again, the rooms were distinguishable by the color of the carpet, the furniture and the view through the windows. The virtual agents represented three adult male persons that are easily distinguished (VT+ GmbH, Würzburg, Germany). They stood in the middle of the offices. Participants were handed a gamepad that was used to move in the virtual environment. The same facial expressions as the ones developed for the previous experiment were used, built with the software Face Poser, which is part of Source SDK (Valve Corporation, Bellevue, USA). Facial expressions were dynamic and lasted for 2500 ms. The expression took approximately 500 ms to rise. Different facial muscles were involved in each expression to represent them as ecologically valid as possible (Weyers et al., 2006). The agent was looking at the participant while the expression was performed.

4.2.2.2 Olfactory Stimulation

The same two pleasant and two unpleasant odors in the same dilutions as in the previous study were used. Each participant received one pleasant and one unpleasant odor in each of the two attribution conditions, resulting in four possible combinations of pleasant and unpleasant odors. As the attribution conditions were balanced within participants, every participant received every odor either in the social or in the contextual attribution block.

In order to monitor odor properties, valence, arousal, and intensity ratings that were conducted at the beginning of the experiment were compared between pleasant and unpleasant odors using paired *t*-tests. Ratings revealed that pleasant odors were rated as more pleasant ($t[30] = 12.09$, $p < .001$) and less arousing ($t[30] = 4.11$, $p < .001$) and more intense ($t[30] = 3.19$, $p = .003$) than unpleasant ones. For mean ratings, see Table 5.

Table 5: Mean ratings of valence, arousal, and intensity for pleasant and unpleasant smells. Values in brackets represent standard variations.

Substance	**Valence**	**Arousal**	**Intensity**
Pleasant smells	7.21 (1.04)	3.47 (1.70)	7.42 (0.82)
Unpleasant smells	3.42 (1.57)	4.56 (1.52)	6.95 (1.03)

4.2.3 Physiological Measurements

Physiological data were recorded using the software Vision Recorder 1.20 (BrainVision, Munich, Germany). Two adhesive heart rate electrodes fixed directly under the right clavicle and on the lowest rib on the left side were used to assess an electrocardiogram. Impedances were held under 5 µV to minimize noise on the heart rate signal. For measurement of the SCL and identification of EDA-nonresponder, the same hardware and criteria as in Study 2 were applied.

4.2.4 Procedure

4.2.4.1 Manipulation of the attribution of smells

Social vs. contextual attribution was manipulated in a blocked design. For the social attribution block, two agents, both standing in the same office room, were paired with two odors, one with a pleasant and one with an unpleasant odor. In the contextual attribution block, one agent standing in two office rooms which were each paired with either a pleasant or an unpleasant odor were used.

Additionally, attribution to either the agents or the rooms was instructed at the beginning of each block using the same instructions as in the previous experiment. The four possible combinations of pleasant and unpleasant odors (two pleasant x two unpleasant odors) were balanced over participants as well as the order of the two attribution blocks, the three agents and rooms and the assignment of the agents/rooms to the different odors. Additionally to ratings of valence, arousal, sympathy, and "homelikeness", contingency ratings were performed similarly to the previous study directly after each block. Only the odors, agents, and rooms that had been presented in this block were presented, resulting in two different ratings in each block (one for each odor). For a short description of the balancing strategy and pictures of the contingency ratings, see annex.

4.2.4.2 Physiology Blocks

The physiology blocks consisted of the two attribution blocks. As in the previous study, this session started with three training trials in order to practice inhalation at the right time (see 4.2.3 Procedure). A trial of the physiology blocks lasted about 15 sec (without ITI). It started with participants standing in the corridor in front of the office's door. The door was initially closed and opened as soon as the participants were passively guided (via pre-recorded paths) into the rooms. In front of the participants, approximately in the middle of the office, a virtual agent was standing and looking towards the floor. Participants passively moved inside the room until they reached a distance of approximately 1.20 m to the agent. This passive path lasted about 6 sec. Odor delivery started as soon as the door was opened when participants approached it. Participants were instructed to inhale when entering the room. Notably, the odor took about 1 sec to rise in the breathing mask. Odor delivery started at the beginning of the passive path. It took participants 1 sec to reach the door. Consequently, participants smelled the odor about when they entered the room.

Differently to the previous experiment, the agent looked directly at the participant for the whole duration of the trial and did not perform any facial expression. After the passive path, participants stood in front of the agent for 6.5 sec. The scene then faded out, the olfactometer was closed and a new trial began after an ITI of about 18 sec, during which the screen remained black. Within each block, each agent/room was associated 10 times with one of the odors. The order of trials in the physiology as well as in the withdrawal session (see below) was pseudo-randomized across participants. For an overview of the experimental procedure, see Figure 18.

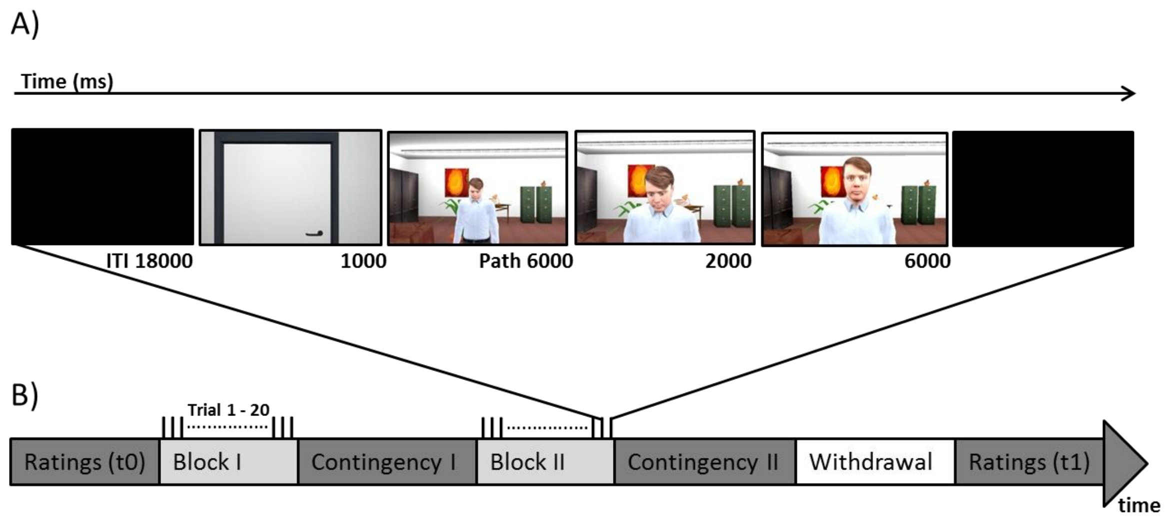

Figure 18: Overview of the experimental procedure in the present experiment. Part B) represents the order of the experimental phases, and part A) depicts one trial of the physiology blocks. ITI = Inter-trial Interval. Contingency I and II represent ratings of contingency at the end of each physiology block. Withdrawal stands for the separate withdrawal part during which participants actively moved in the virtual environment. In the rating parts, ratings of valence, arousal, sympathy, and "homelikeness" were collected.

4.2.4.3 Rating Data

Before (t0) and after the two physiology blocks, as well as after the withdrawal block, i.e., at the end of the experiment (t1), participants were asked to rate the agents and offices. To this purpose, the agents were presented when standing in the room. Notably, this situation matched the one from the physiology blocks. Each combination that was used in the respective version of the experiment was presented pseudo-randomly (in pre-defined orders). Only for the ratings, agents performed a happy, neutral, and angry facial expression similarly to the previous experiment. Each facial expression lasted for about 2.5 seconds and was presented in a pre-defined pseudo-randomized order. The picture then faded out, and a 9-point Likert scale appeared on the screen. Participants told the experimenter their ratings, who noted them. The whole scene was rated on valence and arousal. Agents were additionally rated for sympathy, and the rooms were rated for "homelikeness". The rating scales were the same as in Study 2. The four ratings always appeared in the same order. In this regard, valence and arousal ratings served as general evaluations of the whole situation (as the questions asked how pleasant/aroused participants felt), whereas the ratings of sympathy and "homelikeness" were used to assess a more direct evaluation of the agents and rooms. At t0, participants were also asked to rate the valence, arousal, and intensity (ranging from 1 "*very faint*" to 9 "*very strong*") of the two odors. To this purpose, the odors were presented for 6 sec while the words “please sniff” appeared on the screen. Afterwards, these words were replaced by the rating scales.

4.2.4.4 Withdrawal Session

After the last physiology block, a withdrawal block was conducted. At the beginning of this session, participants were instructed to withdraw from the agent until they reached a position where they felt comfortable. The trials during this block were held as similar as possible to the ones of the physiology blocks. Thus, each trial started with the participant standing in front of the closed door of the office. Then the passive path toward the room/agent was played again and the respective odor was delivered. While moving forwards, participants saw the agent was standing in the middle of the office and kept looking at them. After participants were passively guided towards the agent, they were able to actively move away from the agents by means of the gamepad. They then could indicate their final position by pressing a button on the gamepad. After the button press, the image faded out, the odor delivery was stopped and a new trial began after an ITI of 14 sec. During the withdrawal session, each agent/room-odor combination was presented 3 times resulting in a total of 12 trials.

4.2.4.5 Questionnaires and test batteries

Before the start of the physiology blocks, participants completed the screening version of the Sniffin’ Sticks test battery (Hummel et al., 2001b) and filled in a sociodemographic questionnaire and the PANAS (Krone et al., 1996). Between the two physiology blocks and the withdrawal block, a break of about 10 min was interposed, during which participants filled in the PANAS a second time and also completed the IPQ (Schubert, 2003), the SPAI (Turner et al., 1989), and a post-test questionnaire.

4.2.5 Data Preprocessing and Statistical Analysis

Preprocessing of the physiological data was done using the software Vision Analyzer 2.0 (BrainVision, Munich, Germany). For analysis of the heart rate, the data were filtered applying a high pass filter of 1.59 Hz, a low pass filter of 30 Hz, and a 50 Hz notch filter. Markers were then set on the R-spikes of the heart rate. Markers were corrected manually. Afterwards, the data were transformed into continuous heart rate applying an in-house-made heart rate macro. A baseline correction was performed using the last 3000 ms before trial onset. Heart rate was then averaged over all trials of each participant and exported in time windows of 1000 ms length.

The exclusion of 7 EDA-nonresponders resulted in 25 datasets for the analysis of skin conductance level. A high-pass filter of 0.1 Hz was applied to the data, and the 1000 ms before the start of each trial were taken for baseline-correction. The averaged SCL was calculated only for the *approaching time* (i.e., the time between the opening of the door and the end of the passive path, in total 6 sec) and not for the *social encounter* (i.e., the time when participants stood in front of the agent, in total 6 sec) in order to keep the analysis as comparable as possible to the following study that applied a similar design. Average SCL data were then exported. Raw data were then logarithmized (SCL + 1) and averaged for each condition.

For withdrawal measurements, the resulting distance between participants and agents and the withdrawal time was calculated similarly to the previous experiment. In the present experiment, datasets of 3 participants could not be included into statistical analysis, resulting in 28 subjects for this analysis. Average withdrawal distance and average withdrawal time was calculated for each participant.

Social Anxiety and awareness of contingency were used as moderating factors. The between-subjects factor of social anxiety was constructed by median-split of the SPAI (Turner et al., 1989) data (*Median* = 1.71), resulting in a group of LSA (n = 16) and HSA (n = 15), respectively. The between-subjects factor of awareness was constructed using the contingency ratings. Participants who identified the correct origin for both of the odors were classified as “aware” (n = 19), whereas all other participants (who misidentified one or two odor sources) were classified as “unaware” (n = 12). Both factors were included separately as between-subjects factors into the overall-ANOVAs of the dependent variables. Significant interactions are listed separately at the end of the results section.

Ratings were analyzed by application of a 2 x 3 x 2 x 2 ANOVA with the within-subjects factors of Odor (pleasant vs. unpleasant), Facial Expression (happy vs. neutral vs. angry), Attribution (social vs. contextual), and Phase (t0 vs. t1). Significant interactions were further explored applying post-hoc ANOVAs and paired *t*-tests. For heart rate change, a 2 x 6 x 2 ANOVA with the factor Odor (pleasant vs. unpleasant), Time (6 sections of 1 sec each), and Attribution (social vs. contextual) was applied. For the SCL, two 2 x 2 ANOVAs with the factors Odor (pleasant vs. unpleasant) and Attribution (social vs. contextual) were calculated. The same factors were applied for withdrawal distance and time. Significant effects were further tested calculating post-hoc ANOVAs or *t*-tests.

In case of a violation of the sphericity assumption, Greenhouse-Geisser-corrected degrees of freedom were used. For all statistical tests, the significant level was set at p = .05 (two-tailed). Estimated effect sizes (η_p^2) and Greenhouse-Geisser epsilon (*GG*-ε) are reported. Marginally significant effects (.05 < p < .1) were further examined if they were hypothesis-driven. In all other cases, no post-hoc tests were applied to effects with p > .05. Marginally significant interactions of

Odor x Facial Expression were further analyzed including only data of t1 as at t0, no pairing of odors and agents/rooms had taken place. For moderating variables, only significant results (and no marginal results) were further tested, as the whole analysis was considered exploratory in nature. Significant interactions in this case were explored by calculating separate tests for each group.

4.3 Results

4.3.1 Ratings

4.3.1.1 Sympathy Ratings of Agents in Contexts

For sympathy ratings, the ANOVA revealed a significant main effect of Odor (*F*[1, 30] = 13.46, *p* = .001, η_p^2 = .31; indicating that agents in rooms in the condition of a pleasant odor were rated as more likable than in the condition of an unpleasant odor. In addition, the ANOVA returned a significant main effect of Facial Expression (*F*[2, 60] = 76.78, *p* < .001, η_p^2 = .72), meaning that agents performing the happy facial expression were rated as more likable than when performing the neutral one (*t*[30] = 3.29, *p* = .003), which in turn was rated as more likable than the angry one (*t*[30] = 10.04, *p* < .001). The interactions of Odor x Phase (*F*[1, 30] = 32.16, *p* < .001, η_p^2 = .52) and Facial Expression x Phase (*F*[2, 60] = 3.40, *p* = .040, η_p^2 = .10) were also significant. The interactions of Odor x Attribution x Phase (*F*[1, 30] = 3.73, *p* = .063, η_p^2 = .11), Facial Expression x Attribution x Phase (*F*[2, 60] = 2.95, *p* = .060, η_p^2 = .09), and Odor x Facial Expression (*F*[2, 60] = 2.50, *p* = .090, η_p^2 = .08) were marginally significant. All other effects did not reach significance (Attribution: *F*[1, 30] = 0.57, *p* = .455, η_p^2 = .02; Phase: *F*[1, 30] = 0.26, *p* = .615, η_p^2 = .01; Odor x Attribution: *F*[1, 30] = 2.76, *p* = .107, η_p^2 = .08; Facial Expression x Attribution: *F*[2, 60] = 0.07, *p* = .868, η_p^2 < .01, *GG-ε* = .69; Attribution x Phase: *F*[1, 30] = 1.63, *p* = .212, η_p^2 = .05; Odor x Facial Expression x Attribution: *F*[2, 60] = 0.35, *p* = .704, η_p^2 = .01; four-way interaction: *F*[2, 60] = 1.16, *p* = .319, η_p^2 = .04). As the interaction of Facial Expression x Attribution x Phase was not conform to the a priori hypotheses, it was not further tested.

Post-hoc *t*-tests for the interaction of Odor x Phase showed that the two odor conditions did not differ at t0 (*t*[30] = 1.49, *p* = .148), but at t1, agents in rooms that were shown in combination with a pleasant odor were rated as more likable than those in combination with an unpleasant odor (*t*[30] = 6.30, *p* < .001). Sympathy ratings decreased from t0 to t1 in the unpleasant odor condition (*t*[30] = 4.29, *p* < .001)). Sympathy ratings of the agent increased from t0 to t1 in the pleasant odor condition (*t*[30] = 3.86, *p* = .001). See panel A of Figure 19.

Post-hoc *t*-tests for the interaction of Facial Expression x Phase revealed no changes from t0 to t1 (all *p*s > .123). At t0, the same pattern as in the main effect of facial expression was found (happy > neutral > angry; all *p*s < .001). At t1, however, agents performing both the happy facial expression and the neutral facial expression were rated as more likable than when performing the angry facial expression (happy: *t*[30] = 8.96, *p* < .001; neutral: *t*[30] = 8.97, *p* < .001), whereas the latter two differed only marginally (*t*[30] = 1.92, *p* = .064).

To explore the interaction of Odor x Facial Expression, ratings of t0 were not included in further analysis, as pairing of odors and agents/rooms did take place after ratings at t0, and the interaction of Odor x Facial Expression was therefore not meaningful at t0. At t1, a significant interaction of Odor x Facial Expression was found (*F*[2, 60] = 4.29, *p* = .018, η_p^2 = .13). In the condition of the pleasant odor, the same pattern as in the main effect of Facial Expression was found (happy > neutral > angry, all *p*s < .021), whereas in the condition of the unpleasant odor, the neutral (*t*[30] = 6.45, *p* < .001) and the happy (*t*[30] = 5.81, *p* < .001) facial expression were both rated as more likable than the angry one, while the latter two did not differ from each other (*t*[30] = 0.86, *p* = .398). See panel A of Figure 20.

The interaction of Odor x Attribution x Phase conformed to the a priori hypotheses and therefore, post-hoc tests were conducted for each time point separately. At t0, the ANOVA with the factors Odor and Attribution did not reveal any significant effects (all *p*s > .148). At t1, however, a significant main effect of Odor (*F*[1, 30] = 39.70, *p* < .001, η_p^2 = .57) as well as a significant interaction of Odor x Attribution (*F*[1, 30] = 4.97, *p* = .033, η_p^2 = .14) were found. The main effect of Attribution did not reach significance (*F*[1, 30] = 1.41, *p* = .245, η_p^2 = .05). Post-hoc *t*-tests for the interaction showed that agents in rooms in combination with a pleasant odor were rated as more likable than in combination with an unpleasant odor in both attributional conditions (social: *t*[30] = 4.96, *p* < .001; contextual: *t*[30] = 4.75, *p* < .001). Agents in the unpleasant odor condition were rated as less likable in the social than in the contextual attribution (*t*[30] = 2.87, *p* = .007), whereas agents in the pleasant odor condition did not differ between the two (*t*[30] = 0.38, *p* = .711). To further explore the interaction, differences between the pleasant and the unpleasant odor condition were compared between the attributions. It was found that differences were larger in the social than in the contextual attribution (*t*[30] = 2.23, *p* = .033). See Figure 21.

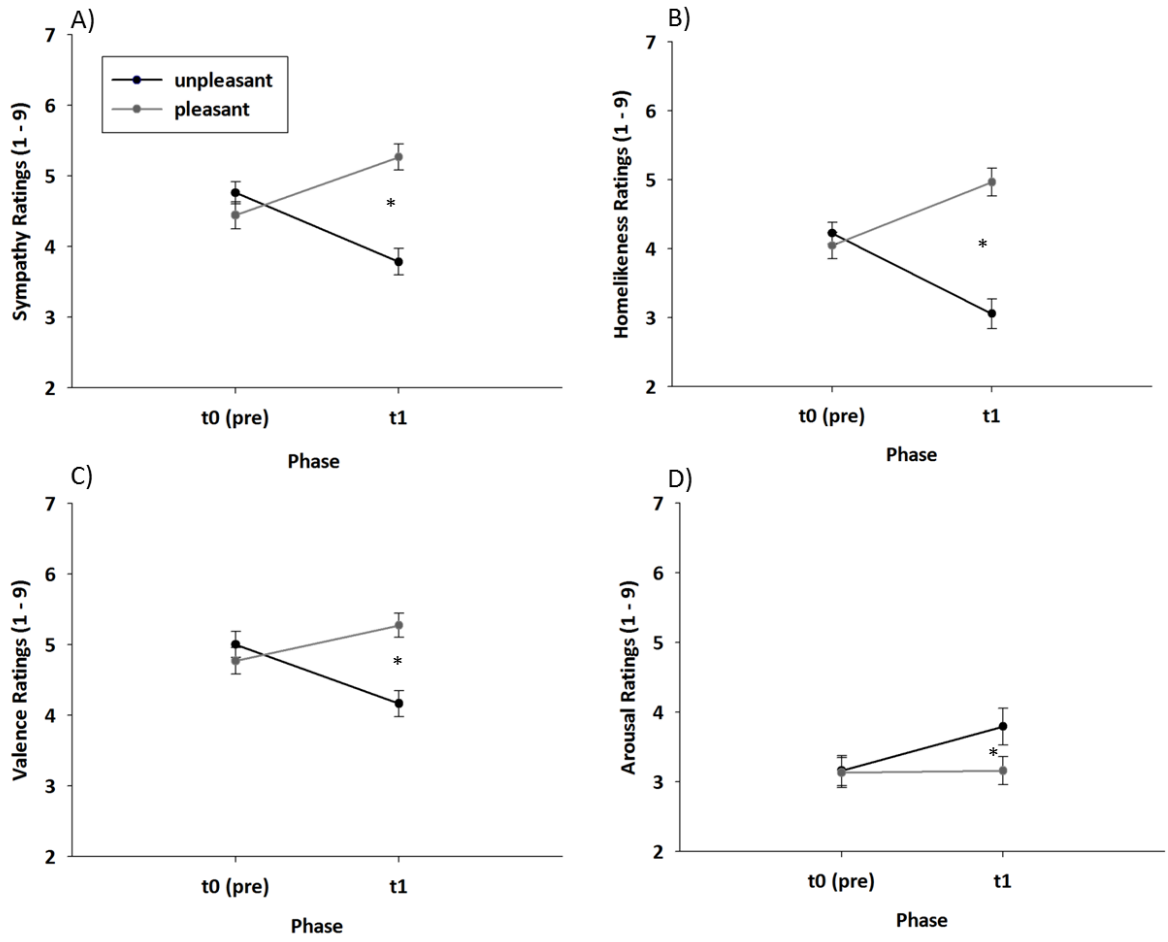

Figure 19: The interaction of Odor x Time is displayed for all four ratings. Panel A = sympathy ratings of agents; Panel B = homelikeness ratings of rooms; Panel C = valence ratings; Panel D = arousal ratings. Black lines represent the unpleasant odor condition, gray lines the pleasant odor condition. Error bars represent standard errors.

4.3.1.2 Homelikeness Ratings of Contexts with Agents

For homelikeness ratings, the ANOVA revealed a significant main effect of Odor (F[1, 30] = 29.97, p < .001, η_p^2 = .49 which indicates that participants enjoyed spending time in a room of the pleasant odor condition more than in one of the unpleasant odor condition. The main effect of Facial Expression (F[2, 60] = 66.26, p < .001, η_p^2 = .69) was also significant. Rooms with an agent performing the happy facial expression received higher preference scores than rooms with an agent performing the neutral facial expression (t[30] = 4.31, p < .001), which in turn received higher preference scores than rooms with an agent performing an angry facial expression (t[30] = 7.64, p < .001).

The interactions of Odor x Phase (F[1, 30] = 54.69, p < .001, η_p^2 = .65), Facial Expression x Phase (F[2, 60] = 8.22, p = .001, η_p^2 = .22, GG-ε = .84), and Odor x Facial Expression (F[2, 60] = 3.14, p = .050, η_p^2 =

.10) were also significant. The latter one was further qualified by a marginally significant interaction of Odor x Facial Expression x Phase (F[2, 60] = 2.49, p = .092, η_p^2 = .08). Since the interaction was in accordance with the a priori hypotheses, it was further analyzed. All other effects did not reach significance (Attribution: F[1, 30] = 1.71, p = .201, η_p^2 = .05; Phase: F[1, 30] = 0.56, p = .459, η_p^2 = .02; Odor x Attribution: F[1, 30] = 1.52, p = .228, η_p^2 = .05; Facial Expression x Attribution: F[2, 60] = 0.25, p = .780, η_p^2 = .01; Attribution x Phase: F[1, 30] = 1.08, p = .308, η_p^2 = .04; Odor x Facial Expression x Attribution: F[2, 60] = 0.74, p = .481, η_p^2 = .02; Odor x Attribution x Phase: F[1, 30] = 1.68, p = .205, η_p^2 = .05; Facial Expression x Attribution x Phase: F[2, 60] = 0.80, p = .456, η_p^2 = .03; four-way interaction: F[2, 60] = 1.34, p = .268, η_p^2 = .04).

The interaction of Odor x Phase could be explained as follows: At t0, homelikeness of the two rooms did not differ (t[30] = 1.08, p = .288). However, at t1, participants reported to enjoy spending time in rooms previously paired with a pleasant odor more than in rooms paired with an unpleasant odor (t[30] = 7.51, p < .001). Homelikeness ratings for rooms paired with a pleasant odor increased from t0 to t1 (t[30] = 4.92, p < .001), while ratings for rooms paired with an unpleasant one decreased (t[30] = 4.80, p < .001). See panel B of Figure 19.

Post-hoc t-tests for the interaction of Facial Expression x Phase showed that the same pattern as in the main effect Facial Expression was also found in both odor conditions (happy > neutral > angry; all ps < .012). Homelikeness ratings of rooms with agents performing a happy facial expression decreased from t0 to t1 (t[30] = 2.34, p = .026). In contrast, homelikeness ratings of rooms with agents performing the neutral (t[30] = 0.41, p = .684) or angry (t[30] = 1.00, p = .326) facial expression did not change over time.

Explorative analysis of the interaction of Odor x Facial Expression x Phase, separately for the two phases, revealed that at t0, only a main effect of Facial Expression (F[2, 60] = 54.24, p < .001, η_p^2 = .64) but no other significant effect (all ps > .288) were found. At t1, significant main effects of Odor (F[1, 30] = 56.42, p < .001, η_p^2 = .65) and Facial Expression (F[2, 60] = 34.23, p < .001, η_p^2 = .53) as well as the interaction of Odor and Facial Expression (F[2, 60] = 8.26, p = .001, η_p^2 = .22) were found. The three-way interaction therefore originated from differences found at t1. Post-hoc t-tests of the interaction of Odor x Facial Expression at t1 revealed that homelikeness ratings were higher for rooms with agents in the pleasant than in the unpleasant odor condition for every facial expression (all ps < .001). The pattern that was found in the main effect of facial expression was also seen in the case of rooms paired with pleasant odors (happy > neutral > angry; all ps < .006). In the unpleasant odor condition, rooms with agents that performed a happy (t[30] = 3.69, p = .001) or a neutral facial expression ($t[30] = 4.33$, $p < .001$) were more preferred than rooms with agents performing an angry facial expression. The latter two did not differ ($t[30] = 0.55$, $p = .587$). See panel B of Figure 20.

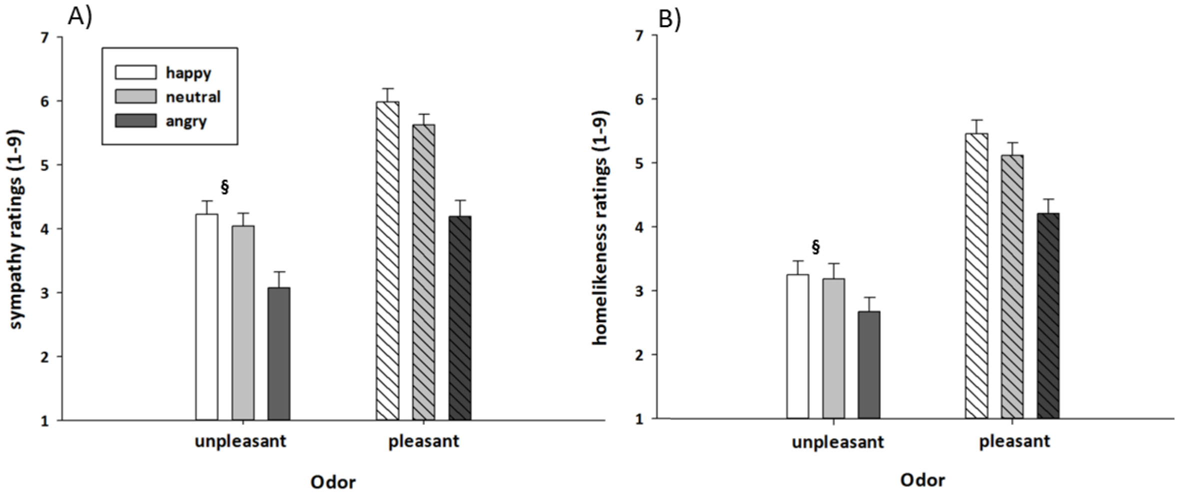

Figure 20: Sympathy ratings of agents and homelikeness ratings of contexts when agents were displaying the different facial expressions within both odor contexts. Panel A = sympathy ratings, panel B = homelikeness ratings. Striped bars represent the agents paired with a pleasant odor and bars without stripes agents paired with an unpleasant odor. White bars represent the happy, light gray bars the neutral, and dark gray bars the angry facial expression. Error bars represent standard errors. Note that for a better overview, only non-significant interactions are marked with a "§".

4.3.1.3 Valence Ratings of combined scenes

The ANOVA revealed a significant main effect of Odor ($F[1, 30] = 16.44$, $p < .001$, $\eta_p^2 = .35$), indicating that in combination with a pleasant odor, the scenes were rated as more pleasant than in combination with an unpleasant odor. The main effect of Facial Expression was also significant ($F[2, 60] = 72.07$, $p < .001$, $\eta_p^2 = .71$), which means that scenes with the agent performing the happy facial expression were rated as more pleasant than with the agent performing the neutral facial expression ($t[30] = 4.30$, $p < .001$) that in turn were rated as more pleasant than the ones with the agent performing the angry facial expression ($t[30] = 8.48$, $p < .001$). The main effect of Phase was marginally significant ($F[1, 30] = 2.99$, $p = .094$, $\eta_p^2 = .09$). Additionally, a significant interaction of Odor x Phase ($F[1, 30] = 41.76$, $p < .001$, $\eta_p^2 = .58$) and a marginally significant interaction of Odor x Attribution x Phase ($F[1, 30] = 3.41$, $p = .075$, $\eta_p^2 = .01$) were found. All other effects did not reach significance (Attribution: $F[1, 30] = .036$, $p = .552$, $\eta_p^2 = .01$; Odor x Facial Expression: $F[2, 60] = 2.08$, $p = .134$, $\eta_p^2 = .07$; Odor x Attribution: $F[1, 30] = 0.96$, $p = .335$, $\eta_p^2 = .03$; Facial Expression x Attribution: $F[2, 60] = 0.68$, $p = .513$, $\eta_p^2 = .02$; Facial Expression x Phase: $F[2, 60] = 1.91$, $p = .158$, $\eta_p^2 = .06$; Attribution x Phase: $F[1, 30] = 0.01$, $p = .934$, $\eta_p^2 < .01$; Odor x Facial Expression x Phase: $F[2, 60] =$

0.13, p = .878, η_p^2 < .01; Odor x Facial Expression x Attribution: F[2, 60] = 0.85, p = .434, η_p^2 = .03; Facial Expression x Attribution x Phase: F[2, 60] = 0.45, p = .640, η_p^2 = .02; four-way interaction: F[2, 60] = 0.40, p = .673, η_p^2 = .01).

Post-hoc *t*-tests of the interaction of Odor x Phase revealed no difference in rated valence at t0 (t[30] = 1.58, p = .125). However, at t1, scenes presenting agents in a room associated with a pleasant odor were rated as more pleasant than scenes presenting agents in combination with an unpleasant one (t[30] = 7.25, p < .001). The pleasant odor condition was rated as more pleasant at t1 than at t0 (t[30] = 4.05, p < .001). The unpleasant condition was rated as more unpleasant at t1 than at t0 (t[30] = 5.26, p < .001). See panel C of Figure 19.

The interaction of Odor x Phase x Attribution was explored by calculating two ANOVAs with the factor Odor x Attribution separately for each phase. At t0, no significant effects were found (all *p*s > .125).

At t1, the main effect of Attribution did not reach significance (F[1, 30] = 0.24, p = .672, η_p^2 = .01). However, a significant main effect of Odor (F[1, 30] = 52.58, p < .001, η_p^2 = .64) and a marginally significant interaction of Odor x Attribution were found (F[1, 30] = 2.94, p = .097, η_p^2 = .09). Explorative post-hoc *t*-tests for the interaction showed that in each Attribution, the pleasant odor condition was rated as more pleasant than the unpleasant odor condition (social: t[30] = 5.98, p < .001; contextual: t[30] = 4.25, p < .001). The two attribution conditions did not differ significantly when directly compared (pleasant: t[30] = 0.68, p = .500; unpleasant: t[30] = 1.37, p = .182). However, the difference between the pleasant and unpleasant condition was marginally higher for the social than for the contextual attribution condition (t[30] = 1.71, p = .097). See Figure 21.

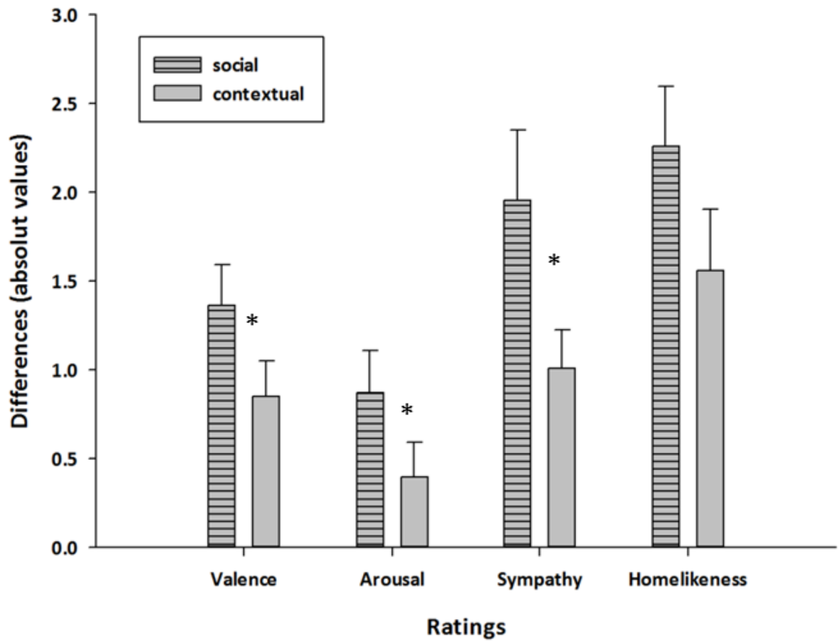

Figure 21: Difference scores between the unpleasant and pleasant odor condition are shown for each rating at t1. Note that the absolute difference between unpleasant and pleasant odor conditions is shown. Striped bars represent the social attribution condition; empty bars the contextual attribution condition. Error bars represent standard errors.

4.3.1.4 Arousal Ratings of combined scenes

The ANOVA for arousal ratings returned a significant main effect of Odor (*F*[1, 30] = 10.16, *p* = .003, η_p^2 = .25), indicating that the scenes were rated as more arousing in the unpleasant odor condition. The main effect of Facial Expression also was significant (*F*[2, 60] = 18.94, *p* < .001, η_p^2 = .39). The scenes including an agent performing an angry facial expression were rated as more arousing than scenes including an agent performing a happy (*t*[30] = 5.42, *p* < .001) or neutral expression (*t*[30] = 4.12, *p* < .001). Scenes with agents performing a happy compared to a neutral facial expression did not differ (*t*[30] = 1.37, *p* = .182). The interactions of Odor x Phase (*F*[1, 30] = 10.98, *p* = .002, η_p^2 = .27) and Odor x Attribution (*F*[1, 30] = 4.18, *p* = .050, η_p^2 = .35) were also significant. In addition, the interaction of Facial Expression x Phase was marginally significant (*F*[2, 60] = 2.70, *p* = .086, η_p^2 = .08, *GG-ε* = .83). All other effects did not reach significance (Attribution: *F*[1, 30] = 0.10, *p* = .758, η_p^2 < .01; Phase: *F*[1, 30] = 2.53, *p* = .122, η_p^2 = .08; Odor x Facial Expression: *F*[2, 60] = 0.15, *p* = .857, η_p^2 = .01; Facial Expression x Attribution: *F*[2, 60] = 0.53, *p* = .591, η_p^2 = .02; Attribution x Phase: *F*[1, 30] = 0.82, *p* = .372, η_p^2 = .03; Odor x Facial Expression x Attribution: *F*[2, 60] = 0.95, *p* = .394, η_p^2 = .03; Odor x Facial Expression x Phase: *F*[2, 60] = 1.06, *p* = .353, η_p^2 = .03; Odor x Attribution x Phase: *F*[1, 30] =

0.76, p = .392, η_p^2 = .03; Facial Expression x Attribution x Phase: $F[2, 60]$ = 1.05, p = .356, η_p^2 = .03; four-way interaction: $F[2, 60]$ = 0.48, p = .619, η_p^2 = .02).

Post-hoc *t*-tests for the interaction of Odor x Phase showed that the two odor conditions did not differ at t0 ($t[30]$ = 0.27, p = .790). However, at t1 the conditions (i.e., room and agent) associated with the unpleasant odor were rated as more arousing ($t[30]$ = 3.77, p = .001). In addition, arousal ratings increased from t0 to t1 in the unpleasant odor condition ($t[30]$ = 2.49, p = .019), yet did not differ in the pleasant odor condition ($t[30]$ = 0.14, p = .892). See panel D of Figure 19.

Post-hoc *t*-tests for the interaction of Odor x Attribution revealed that the unpleasant odor condition was rated as more arousing than the pleasant odor condition only in case of the social attribution condition ($t[30]$ = 3.98, p < .001). The two attributions did not differ when separately tested for each odor (pleasant: $t[30]$ = 0.87, p = .390; unpleasant: $t[30]$ = 1.26, p = .219). See Figure 21.

4.3.2 Heart Rate

The ANOVA revealed a significant main effect Time ($F[5, 150]$ = 14.31, p < .001, η_p^2 = .32, *GG-ε* = .38) and an interaction of Time x Odor ($F[5, 150]$ = 3.88, p = .021, η_p^2 = .12, *GG-ε* = .45). Neither the main effects of Odor ($F[1, 30]$ = 1.26, p = .271, η_p^2 = .04) and Attribution ($F[1, 30]$ = 0.02, p = .900, η_p^2 < .01) nor the interactions (Odor x Attribution: $F[1, 30]$ = 0.96, p = .334, η_p^2 = .03; Time x Attribution: $F[5, 150]$ = 0.96, p = .403, η_p^2 = .03, *GG-ε* = .49; Odor x Attrbution x Time: $F[5, 150]$ = 0.51, p = .605, η_p^2 = .02, *GG-ε* = .40) reached significance.

Post-hoc *t*-tests of the interaction of Time x Odor revealed that the heart rate was higher after 5 sec ($t[30]$ = 2.55, p = .016) and after 6 sec ($t[30]$ = 2.12, p = .043) when participants were exposed to a pleasant as compared to an unpleasant odor. At all other time points, heart rate did not differ between the odors (all *p*s > .332). Within the pleasant and the unpleasant odor, the same pattern of heart rate change was found. Thus, the heart rate did not change from the first to the second time window (pleasant: $t[30]$ = 0.89, p = .383; unpleasant: $t[30]$ = 0.79, p = .434), but accelerated from second 2 to 3 (pleasant: $t[30]$ = 2.47, p = .002; unpleasant: $t[30]$ = 3.97, p < .001), from second 3 to 4 (pleasant: $t[30]$ = 6.67, p < .001; unpleasant: $t[30]$ = 5.47, p = .001), from second 4 to 5 (pleasant: $t[30]$ = 2.98, p = .006; no change within the unpleasant: $t[30]$ = 0.99, p = .329), and decelerated from second 5 to 6 (pleasant: $t[30]$ = 2.86, p = .008; unpleasant: $t[30]$ = 3.23, p = .003). See Figure 22.

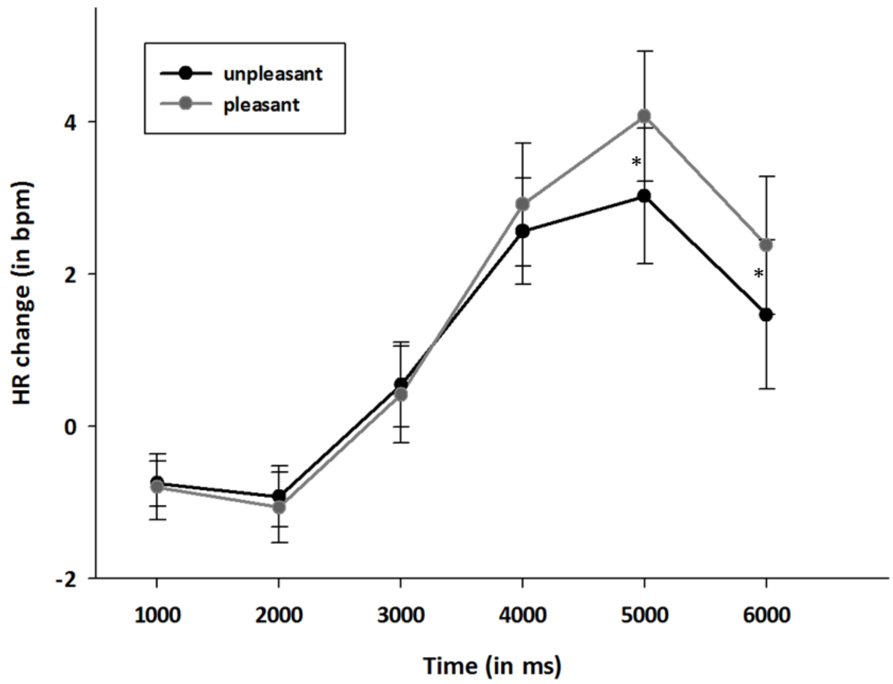

Figure 22: Heart rate change as a function of odor condition and time. The black lines represent the unpleasant odor condition, the gray lines the pleasant odor condition. Error bars represent standard errors.

4.3.3 Skin Conductance Level

The 2 x 2 ANOVA regarding skin conductance level revealed no significant effects (Odor: *F*[1, 24] = 0.24, *p* = .628, η_p^2 = .01; Attribution: *F*[1, 24] = 0.93, *p* = .345, η_p^2 = .04; Odor x Attribution: *F*[1, 24] = 2.01, *p* = .169, η_p^2 = .08).

4.3.4 Behavioral Test

For the distance measurement, the ANOVA with the factors Odor x Attribution did not reveal any significant effects (Odor: *F*[1, 27] = 2.47, *p* = .128, η_p^2 = .08; Attribution: *F*[1, 27] = 1.46, *p* = .238, η_p^2 = .05; Odor x Attribution (*F*[1, 27] = 0.36, *p* = .551, η_p^2 = .01).

In contrast, the ANOVA of the withdrawal time revealed a significant main effect of Odor (F[1, 27] = 14.81, p = .001, η_p^2 = .35), indicating that participants spent more time withdrawing from the agent when an unpleasant odor was presented. The main effect Attribution (F[1, 27] = 0.87, p = .359, η_p^2 = .03) and the interaction Odor x Attribution (F[1, 27] = 0.70, p = .409, η_p^2 = .03*)* did not reach significance. See Figure 23.

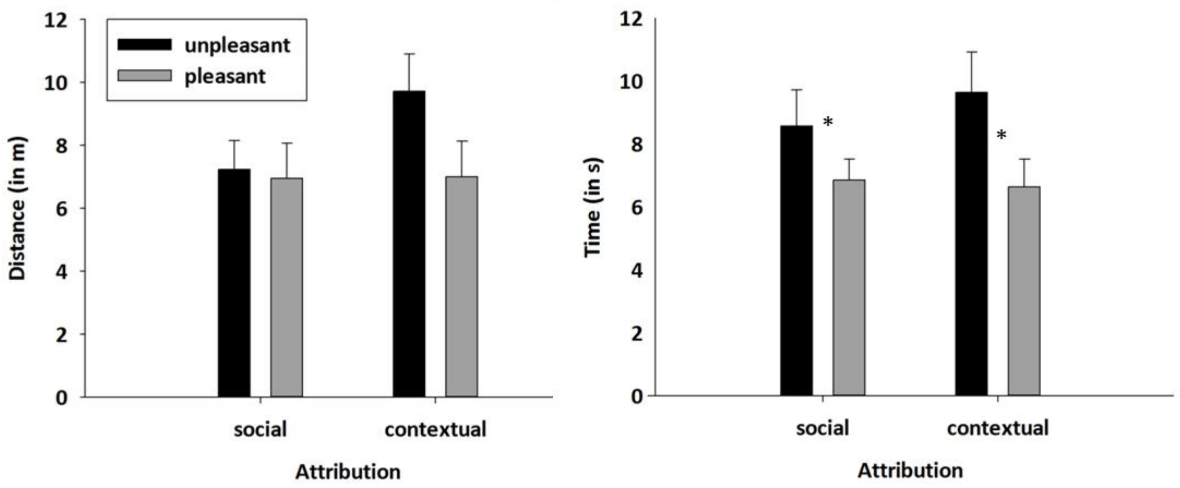

Figure 23: The distance participants kept to the agents (left panel) and the time they spent withdrawing (right panel) as a function of odor and attribution. Black bars represent the unpleasant odor condition; gray bars the pleasant odor condition. Error bars represent standard errors.

4.3.5 Influence of Moderating Variables

No significant correlation between the distribution of HSA and LSA participants and aware and unaware participants could be found (X^2_1 = 1.78, p = .183).

4.3.5.1 Social Anxiety

The factor Social Anxiety (LSA vs. HSA) was included as an additional between-subjects factor into the ANOVA with the within-subjects factors Odor (pleasant vs. unpleasant) x Facial Expression (happy vs. neutral vs. angry) x Attribution (social vs. contextual) x Phase (t0 vs. t1). For sympathy ratings, a significant main effect of Social Anxiety (F[1, 29] = 5.07, p = .023, η_p^2 = .15; indicating that LSA participants rated agents as less likable than HSA participants) and a significant interaction of Facial Expression x Phase x Social Anxiety were found (F[2, 58] = 9.54, p < .001, η_p^2 = .25). All other effects did not reach significance (all ps > .131). At t0, a main effect Social Anxiety was found (F[1, 29] = 10.88, p = .003, η_p^2 = .27), the interaction of Facial Expression x Social Anxiety did not reach significance (F[2, 58] = 1.57, p = .217, η_p^2 = .05). At t1, neither the main effect Social Anxiety (F[1, 29] = 3.46, p = .073, η_p^2 = .11) nor the interaction was significant (F[2, 58] = 2.40, p = .100, η_p^2 = .08).

For homelikeness ratings of the context, a significant interaction of Facial Expression x Phase x Social Anxiety was found (F[2, 58] = 3.88, p = .026, η_p^2 = .12). All other effects did not reach significance (all ps > .051). At t0, a significant main effect of Facial Expression was found (F[2, 58] = 53.04, p < .001, η_p^2 = .65). The main effect Social Anxiety (F[1, 29] = 3.46, p = .073, η_p^2 = .11) and the interaction of Facial Expression x Social Anxiety (F[2, 58] = 0.56, p = .576, η_p^2 = .02) were not significant. The same pattern was found at t1 (Facial Expression: F[2, 58] = 36.51, p < .001, , η_p^2 = .56, GG-ε = .69; Social Anxiety: F[1, 29] = 2.44, p = .129, η_p^2 = .08; Facial Expression x Social Anxiety: F[2, 58] = 2.53, p = .109, η_p^2 = .08, GG-ε = .69).

The analysis of valence ratings revealed a significant interaction of Phase x Social Anxiety (F[1, 29] = 5.07, p = .023, η_p^2 = .15). Additionally, the five-way interaction reached significance (F[2, 58] = 3.33, p = .043, η_p^2 = .10). All other interactions with the factor Social Anxiety did not reach significance (all ps > .135). Post-hoc t-tests of the interaction of Phase x Social Anxiety showed that LSA participants rated the agents in rooms as more pleasant than HSA participants at t0 (t[29] = 2.13, p = .041) but not at t1 (t[29] = 0.82, p = .418). Ratings dropped from t0 to t1 in LSA (t[15] = 3.04, p = .008) but not in HSA participants (t[14] = 0.32, p = .754). To explore the origin of the five-way interaction, two ANOVAs with the factors Odor x Facial Expression x Attribution x Social Anxiety were conducted, one at each phase. Neither at t0 nor at t1 could any significant interaction with the factor Social Anxiety be found (all ps > .130), apart from a main effect of Social Anxiety at t0 that was also reflected in the interaction calculated before. To further explore the interaction, two ANOVAs with the factors Odor x Facial Expression x Attribution x Phase were calculated for both HSA and LSA participants. For LSA participants, the main effects of Time (F[1, 15] = 9.27, p = .008, η_p^2 = .38), Odor (F[1, 15] = 10.15, p = .006, η_p^2 = .40), and Facial Expression (F[1, 15] = 51.28, p < .001, η_p^2 = .77), as well as the interaction of Odor x Phase (F[1, 15] = 30.45, p < .001, η_p^2 = .67) were significant, while all other effects were not (all ps > .082). In the group of HSA participants, the main effects of Odor (F[1, 14] = 6.67, p = .022, η_p^2 = .32) and Facial Expression (F[1, 14] = 25.10, p < .001, η_p^2 = .64) as well as the interaction of Odor x Phase (F[1, 14] = 14.32, p = .002, η_p^2 = .51) were significant, while all other effects were not (all ps > .058). As the pattern for the interaction of Odor x Phase were similar in both groups and did not differ from the pattern found for the whole group, this interaction was not further analyzed.

For arousal ratings, a main effect of Social Anxiety was found (F[1, 29] = 4.35, p = .046, η_p^2 = .13; indicating that HSA participants evaluated the situations as more arousing than LSA participants) as well as a significant interaction of Facial Expression x Attribution x Phase x Social Anxiety (F[2, 58] = 3.52, p = .036, η_p^2 = .11). All other interactions with the factors Social Anxiety did not reach significance (all ps >.057). Post-hoc ANOVAs for the interaction did not reveal any significant interactions with the factor Social Anxiety, neither at t0 (all ps > .136) nor at t1 (all ps > .632). Besides, separate ANOVAS for both LSA and HSA participants separately revealed significant main effects of Facial Expression (low: F[2, 30] = 6.61, p = .004, η_p^2 = .31; high: F[2, 28] = 12.63, p < .001, η_p^2 = .47), while all other effects did not reach significance (all ps > .060). In both groups, the angry facial expression was rated as more arousing than the two other expressions (LSA: all ps < .005; HSA: all ps < .003), which did not differ (all ps > .402).

Including the factor Social Anxiety into the analysis of heart rate change revealed a significant four-way interaction of Time x Odor x Attribution x Social Anxiety (F[5, 145] = 3.81, p = .025, η_p^2 = .12, *GG-ε* = .43). All other interactions with the factor Social Anxiety did not reach significance (all ps > .123). In the LSA group, only the main effect of Time was significant (F[5, 75] = 9.12, p = .001, η_p^2 = .38, *GG-ε* = .38; all other ps > .181). Interestingly, in the HSA group, the main effect Time (F[5, 70] = 5.72, p = .010, η_p^2 = .29, *GG-ε* = .38) and the interactions of Time x Odor (F[5, 70] = 4.28, p = .024, η_p^2 = .23, *GG-ε* = .40), as well as Time x Odor x Attribution (F[5, 145] = 3.90, p = .024, η_p^2 = .22, *GG-ε* = .48) were significant. All other effects did not reach significance (all ps > .174). See Figure 24 for a graphical display of this interaction.

Post-hoc t-tests for the interaction of Time x Odor revealed that in HSA participants, the same pattern as in the whole sample was found (i.e., unpleasant > pleasant at t5, t[14] = 2.77, p = .015, and at t6, t[14] = 2.43, p = .029, but not at all other stages, all ps > .455). In follow-up ANOVAs of Time x Odor for each attribution condition, the interaction of Time x Odor was significant only in the contextual attribution condition (F[5, 70] = 7.01, p = .005, η_p^2 = .33, *GG-ε* = .36), but not in the social attribution condition (F[5, 70] = 0.57, p = .629, η_p^2 = .04, *GG-ε* = .45). In the contextual attribution condition, heart rate was higher when an unpleasant than when a pleasant odor was presented during the first second (t[14] = 2.15, p = .049), while no difference was found at all later stages (all ps > .098).

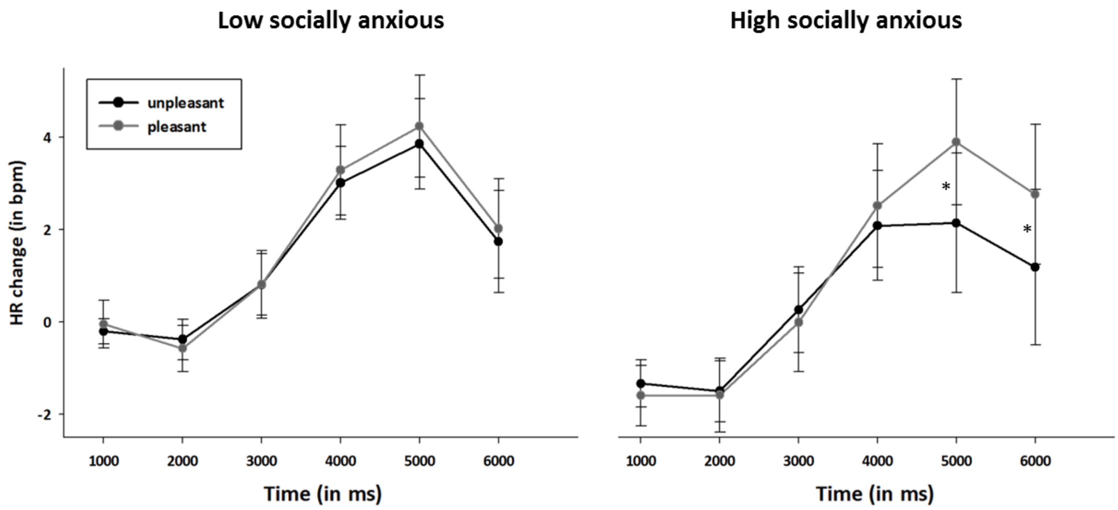

Figure 24: Heart rate change as a function of presented odor in the group of LSA (left) and HSA participants (right). Black lines represent the unpleasant and gray lines the pleasant odor. Error bars represent standard errors.

Including the factor Social Anxiety into the analyses of the skin conductance level (all *p*s > .225), withdrawal distance (all *p*s > .205), and withdrawal time (all *p*s > .237) did not reveal any significant effects.

4.3.5.2 Awareness

The factor Awareness was included as a between-subjects factor into the ANOVAs with the within-subjects factors Odor x Facial Expression x Attribution x Phase. For sympathy ratings, a significant interaction of Attribution x Phase x Awareness was found ($F[1, 29] = 6.76$, $p = .014$, $\eta_p^2 = .19$). Additionally, the main effect of Awareness was significant ($F[1, 29] = 4.33$, $p = .046$, $\eta_p^2 = .13$), indicating that the group of aware participants rated the agents as less likable than the group of unaware participants. All other effects did not reach significance (all *p*s > .051). Post-hoc ANOVAs for the interaction revealed no effects in the unaware group (all *p*s > .187). In the group of aware participants, however, the interaction of Attribution x Phase was significant ($F[1, 18] = 10.59$, $p = .004$, $\eta_p^2 = .37$), which can be explained by the fact that sympathy ratings of aware participants dropped from t0 to t1 only in the social ($t[18] = 2.50$, $p = .023$), but not in the contextual attribution condition ($t[18] = 1.53$, $p = .143$). All other effects were not significant (all *p*s > .095). For homelikeness ratings, no significant interactions with the variable of awareness were found (all *p*s > .185).

For valence ratings, a significant interaction of Odor x Attribution x Phase x Awareness was found ($F[1, 29] = 6.86$, $p = .014$, $\eta_p^2 = .19$). All other interactions with the factor Awareness did not reach significance (all *p*s > .054). Separate ANOVAs at t0 and t1 revealed no significant interactions with the factor Awareness (all *p*s > .155). To explore the origin of the interaction, additional ANOVAs with the factors Odor x Attribution x Phase were calculated for each awareness group. In the group of unaware participants, only a significant interaction of Odor x Phase (F[1, 29] = 5.50, p = .026, η_p^2 = .16) was found. All other effects did not reach significance (all *p*s > .073). In the group of aware participants, however, a significant main effect of Odor (F[1, 18] = 14.19, p = .001, η_p^2 = .44), an interaction of Odor x Phase (F[1, 18] = 29.30, p < .001, η_p^2 = .62), and an interaction of Odor x Attribution x Phase (F[1, 18] = 10.30, p = .005, η_p^2 = .36) were found (all other *p*s > .052). At t0, no significant differences were found (all *p*s > .106). At t1, differences between unpleasant and pleasant odors were greater in the social than in the contextual attribution condition (t[18] = 2.13, p = .047), See Figure 25.

For arousal ratings, the interaction of Odor x Attribution x Phase x Awareness was significant (F[1, 29] = 5.50, p = .026, η_p^2 = .16). All other effects did not reach significance (all *p*s > .054). Post-hoc *t*-tests showed that at t0, no significant effects were found in the ANOVA of Odor x Attribution x Awareness (all *p*s > .293). The interaction of Attribution x Awareness was marginally significant (F[1, 29] = 3.26, p = .081, η_p^2 = .10). At t1, the interaction of Odor x Attribution x Awareness was marginally significant (F[1, 29] = 5.50, p = .026, η_p^2 = .16). No further significant results were found (all *p*s >.287). The interaction was analyzed further. In unaware participants, no significant differences could be found (all *p*s > .101). In aware participants, a similar pattern as in the whole group was found. Agents in rooms of the unpleasant odor condition were rated as more arousing than agents in rooms of the pleasant odor condition, but only in the social (t[18] = 3.26, p = .004) and not in the contextual attribution condition (t[18] = 1.09, p = .292). Within the odor conditions, no significant differences between the odors could be found (all *p*s > .092). See Figure 25.

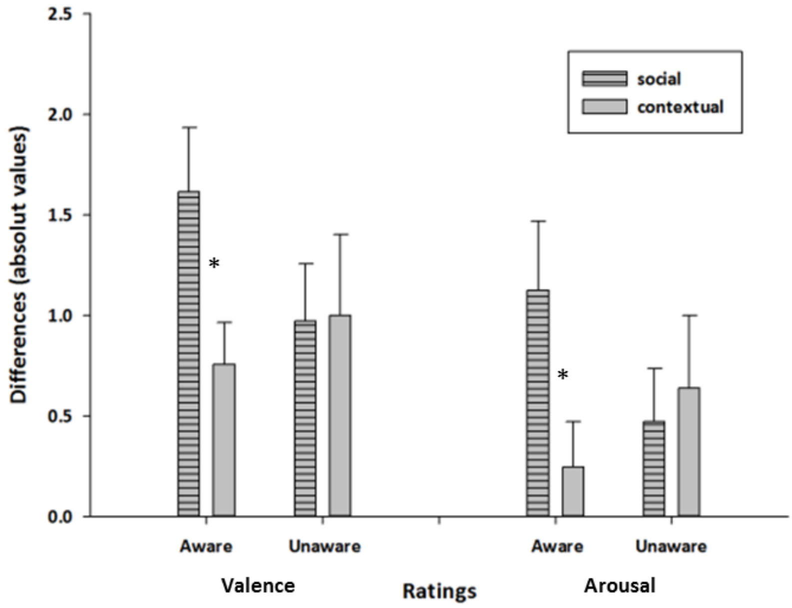

Figure 25: Valence and arousal ratings in the group of aware and unaware participants as a function of attribution condition. Note that the absolute difference between unpleasant and pleasant odor conditions is shown. Striped bars represent the social attribution condition; empty bars the contextual attribution condition. Error bars represent standard errors.

Including the factor Awareness into the analysis of the heart rate change returned a significant interaction of Odor x Attribution x Awareness (*F*[1, 29] = 5.50, *p* = .026, η_p^2 = .16). All other interactions with the factor Awareness were not significant (all *p*s > .126). Post-hoc *t*-tests for the interaction revealed that in the group of fully aware participants, heart rate was higher when a pleasant than when an unpleasant odor was presented only in the social attribution condition (*t*[18] = 2.61, *p* = .018). The difference was not significant in the contextual attribution condition (*t*[18] = 0.50, *p* = .624). The two attribution conditions did not differ within each odor (pleasant: *t*[18] = 0.97, *p* = .347; unpleasant: *t*[18] = 1.38, *p* = .185). In the group of unaware participants, a marginally higher heart rate change in the social than in the contextual attribution condition was found (*t*[14] = 1.97, *p* = .075). Apart from that, no significant differences could be shown (all *p*s > .243).

Including the factor Awareness into the analyses of the skin conductance level (all *p*s > .478), withdrawal distance (all *p*s > .155), or withdrawal time (all *p*s > .484) did not reveal any significant interaction.

4.4 Discussion

The present study aimed at replicating the findings from the previous between-subjects manipulation of the attribution of smells in a within-subjects design. Additionally, drawbacks from the previous study, like the missing comparability of the rating data between the two attributional groups and the confounding between approach distance and odor presentation time were improved. Similar to the previous study, a social and a contextual attribution manipulation were applied. In contrast to the previous study, agents did not perform any emotional facial expression during the physiology blocks. However, in the rating blocks, happy, neutral, and angry facial expressions were performed and subsequently evaluated. During physiology blocks, heart rate and SCL were recorded. After both blocks, a withdrawal session was conducted during which participants had to choose the distance to the agents they felt comfortable with while being presented with pleasant vs. unpleasant odors.

Paralleling the results of Study 2, olfactory conditioning of the agents and rooms was successful as was observed on the rating data. Agents and rooms paired with an unpleasant odor were subsequently evaluated as less likable or homelike compared to those paired with a pleasant odor. Moreover, scenes with agents/rooms paired with a pleasant odor were evaluated as more pleasant and less arousing than those paired with an unpleasant odor. Additionally, it could be shown that the difference between pleasant and unpleasant odors did not only depend on the unpleasant odor (as one would be tempted to suppose from the fact that unpleasant odors are preferentially processed). In fact, on valence, homelikeness, and sympathy, ratings did not only drop for the unpleasant odor but increased for the pleasant one compared to ratings before conditioning. Hence, successful explicit both aversive and appetitive conditioning of agents and rooms may be concluded (Gottfried et al., 2002a), leading to both an increase in pleasantness of the CS_{app} and a decrease of the CS_{av}. Moreover, homelikeness ratings of the rooms gained from odors that were attributed to the agents placed inside them in the social attribution block. Similarly, sympathy ratings of the agents gained from pleasant odors that were attributed to the rooms the agents were presented in.

However, these results are only partly reflected in the physiological and behavioral data. In detail, no significant results were found for skin conductance data. This is apparently contradictory to what was found in the previous study (i.e., higher SCL during presentation of the unpleasant odor). From what can be found in the literature (Glass et al., 2014; He et al., 2014), I would also have expected higher electrodermal activity during presentation of an unpleasant than a pleasant odor. However, it should be considered that reports on the successful manipulation of electrodermal activity are scarce. At least the study by He et al. (2014) used smells of vomit and something burnt that supposedly elicit high autonomic arousal. In contrast to this, the arousal elicited by the smells I used in the present study was rather moderate. In the ratings of the odors at the beginning of the experiment, participants indicated higher subjective arousal for the unpleasant odors on the one hand, but higher intensity for the pleasant odors on the other. This seems somewhat counterintuitive as odor arousal and intensity should refer to the same concept. It could, however, have led to increased SCL in both odor conditions. A neutral odor condition could have helped in order to solve this drawback. Such a neutral condition has not been included in order not to overload the paradigm. Additionally, one has to take into account that the previous study was based on a larger sample size and more repetitions of trials than the present one. Despite that, some results were only marginally significant, indicating that effects on the SCL are rather small. A larger sample could help to resolve this confusion.

Interestingly, heart rate data showed a larger increase after 5 sec during presentation of the pleasant odor. The effect of a larger increase after an initial decrease in heart rate for appetitive than for aversive stimuli has been found before (Löw et al., 2008). The *defensive cascade model* (Fanselow, 1994) predicts a larger initial deceleration in heart rate as a function of threat intensity, which may reflect an orienting response to the threatening stimulus. In the present case, however, no difference in initial drop amplitude was found, indicating that the two odor conditions probably did not differ according to activation of motivational systems. The *defense cascade model* predicts an increase in heart rate after the initial drop, again being higher with increasing threatening value (Fanselow, 1994). During the period that was included in the analysis of heart rate change, participants were passively guided towards the agent. Higher acceleration in heart rate could reflect increased involvement of resources in the preparation for an action. It seems logical that an enhanced approach motivation would be found in combination with a pleasant compared to an unpleasant odor. In line with this, the difference in heart rate occurred after 5 sec. when participants were close to agents. It could be that in combination with being rather close to the virtual agent, the rewarding value of the pleasant odor was as high as or even higher than the penalizing value of the unpleasant odor. Interestingly, heart rate difference was higher in the social than in the contextual attribution. Thus, attributing the pleasant odor to the social agent increased the difference between pleasant and unpleasant odors. Moreover, this difference in heart rate was especially pronounced in the group of HSA participants. As heart rate change was evaluated for the period of time when participants approached the virtual agents, I assume that the group of HSA participants reacted more strongly to the approach towards the virtual agents. The stronger acceleration in heart rate during presentation of the pleasant odor was interpreted as higher involvement of resources for the social encounter. It has been shown before that HSA participants react more strongly to social stimuli than LSA participants (Garner et al., 2006; Mogg & Bradley, 2002; Wieser et al., 2012). I therefore argue that the differential effect for HSA vs. LSA participants was in accordance with the social nature of the approach situation.

Concerning the distance measurement, it could be shown that participants spend more time withdrawing from agents presented together with an unpleasant odor than from agents presented with a pleasant odor. In contrast to a pleasant smell, the agent associated with an unpleasant smell caused facilitated withdrawal behavior. Notably, more withdrawal behavior was associated with longer odor presentation in the present paradigm. This seems somehow counterintuitive, as one might hypothesize that participants would withdraw for a shorter time from an agent presented with an unpleasant odor to get rid of the odor as soon as possible by pressing a button. These results disprove the suspicion that was drawn in the previous study that the main intention of participants was to get rid of the unpleasant smell. On the other hand, it does not explain why there was an effect of odor on withdrawal time only and not on distance. Nonetheless, the withdrawal task is in itself not very ecologically valid, as it represents something that one would seldom encounter in daily life. It was included into the present study in order to disentangle odor presentation time and distance to the virtual agents. Yet, the original reason to include this kind of task was its ecological validity. Application of withdrawal in the present study reached its goal to refute the alternative explanation of the previous study, but apart from that, it was possibly not suitable to collect data about social behavior. Nonetheless, it could be shown that the simultaneous presentation of a virtual agent with an unpleasant odor resulted in increased withdrawal behavior, which is in line with the results of the previous study.

The processing of facial expressions was differentially modulated by odor valence only on ratings of sympathy and homelikeness and not on ratings of arousal and valence. The results from the sympathy ratings replicated the findings of the previous study: the presentation of an unpleasant odor flattened the impact of facial expressions produced by the agents on sympathy and homelikeness ratings in both the social and contextual attribution condition. No differences were found for angry facial expressions. Thus, in the unpleasant odor condition, the sympathy ratings of agents producing a happy or neutral facial expression did not differ. In contrast, in the pleasant odor condition, agents producing a happy facial expression were rated as more likeable than agents producing a neutral facial expression. No differences were found for angry facial expressions. This might mirror the results from previous studies that showed an enhanced impact of accompanying contextual stimuli on the processing of neutral or ambiguous facial expressions compared to clearly threatening facial expressions (Wieser & Brosch, 2012). What is even more surprising is the parallel effect that was found for homelikeness ratings. Evaluations of the room decreased and increased as a function of the facial expression of the agent that was placed inside it. Interestingly, these evaluations were differentially modulated by the odors the agents were paired with, such that pairing with the unpleasant odor led to a flattening of the differences between happy and neutral facial expressions. To account for these results one may suggest that the participants did not differentiate between both rating tasks. The wording of the homelikeness rating might have contributed to the results, as the participants were supposed to indicate how much they would like to spend time in the room. It seems reasonable that one would prefer to spend time in a room with a likable person compared to a room with a person one does not like. This strongly suggests that participants did not rate the room independently from the agent that was standing in the middle of the room. Thus, their response might rather reflect the hedonic value of the complete situation, although the interaction of odor and facial expression failed to reach significance in case of the valence ratings. Therefore, it seems to make a difference whether participants rated the agent/room or their affective state when exposed to the situation.

Regarding the predicted effects of odor attribution it could be shown that the social attribution of odors indeed enhanced the difference between pleasant and unpleasant smells. This effect was evident in the valence, arousal, and sympathy ratings but not in physiological and behavioral measures. However, the predicted three-way interaction of Odor x Attribution x Facial Expression was not found. Thus, the attributional direction did not differentially affect the influence of odors on face processing. The conclusion to be drawn is therefore that attributing a hedonic odor to a social agent leads to stronger aversive and appetitive conditioning effects than attributing it to the surrounding environment. This could be due to the fact that the agents recruit more processing resources than the rooms, on the one hand because they were presented in the foreground and the rooms in the background and on the other hand because social stimuli are of special importance for human beings (Öhman & Dimberg, 1978; Phan & Wagner, 2004). Supportively, on homelikeness ratings, where one would expect the opposite results (i.e., larger differences in the contextual than in the social attribution block), no significant effects were found. This result points towards attention being drawn away from the agents and towards the rooms during homelikeness ratings. This could be the origin of the absent attribution effects for homelikeness ratings. Regarding the valence and arousal ratings, the manipulation of attributional direction had an effect only in participants who were able to consciously report the contingency between odor and agents/rooms. That means on the one hand that they correctly assigned odors to their potential source, but on the other hand that they understood the attribution manipulation correctly. Namely, participants that were classified as "aware" not only assigned the right pairings of agents/rooms and the respective odors but also indicated agents for the social attribution condition and rooms for the contextual attribution condition. Although the experimental design of the present study was rather sophisticated and included four different combinations of odor and agents/rooms, about 60% of the participants were fully aware of the experimental contingencies. However, compared to the previous study, which used only two odors and two combinations of agents and rooms per attribution group, the percentage of aware participants appeared to be less (60% vs. 72%). As it has been shown before

(Dawson et al., 2007), contingency awareness also seems to play its part in the result of the present study, especially in the manipulation of odor attribution. Results from the previous study have shown that awareness of contingency plays a role in the results of subjective ratings. For future research, it would be suitable to either simplify the paradigm or to recruit a larger sample in order to be able to possibly exclude unaware participants.

Some remaining open questions have to be taken into account with respect to the results I found. Heart rate changes should reflect an enhanced motivational value of the pleasant vs. unpleasant odor. In the previous study and in the rating data of the present one, different variables reflected enhanced significance for the unpleasant odor. This is in accordance with assumptions derived from an evolutionary perspective arguing that unpleasant odors are preferentially processed (Weber & Heuberger, 2008) as they are potentially harmful to the organism and require immediate behavioral responses. Heart rate acceleration has been interpreted as recruitment of resources before action in both aversive and appetitive conditioning paradigms (Light & Obrist, 1983). An alternative explanation for these effects could be that the heart rate pattern simply depicted a difference in breathing volumes. It was shown before that the heart rate increases during inhalation and decreases during exhalation (Hirsch & Bishop, 1981). Moreover, heart rate acceleration and respiratory volume are positively correlated (Wood & Obrist, 1964). In line with this argumentation, the previous study of this thesis demonstrated that participants inhaled more deeply when exposed to a pleasant compared to an unpleasant odor. It seems plausible that participants inhaled more deeply when exposed to a pleasant odor and this might have contributed to an increase in heart rate acceleration around 5 sec after stimulus onset. Strikingly, this increase in heart rate was especially pronounced in HSA participants. However, while inhalation could be interpreted as preparation for approach behavior in HSA participants, it also points towards the social nature of the effect of odor valence on heart rate and against a purely physical origin of this effect.

Taken together, the present study replicated results from the previous study on the effects of odor valence and attribution. Thus, unpleasant odors lead to a more negative evaluation of both agents and rooms. Moreover, agents in the contextual attribution condition were influenced by the pairing of the rooms with an odor. In parallel, rooms in the social attribution condition were also influenced by pairings of the agents with an odor. Independently of odor attribution, withdrawal behavior has been shown to be influenced by the presented odor such that participants spent more time withdrawing from agents in combination with an unpleasant odor. Heart rate reflected an enhanced recruitment of action resources in combination with a pleasant odor during the passive approach to the agent. In sum, I demonstrated influences of presented odors on different parameters of social preferences and the processing of social cues. The paradigm seems therefore to be equally suitable for a within-subjects design as for the between-subjects design. Odor source attribution seems to have an influence on some variables, but not on others. The original reason to include the two different odor conditions was to investigate the difference between an odor that is directly attributed to a social counterpart and a contextual odor. Possibly, affective state as evoked by olfactory stimuli functions as a mediator of social behavior. This was supported by a study by Baron and Thomley (1994) demonstrating that pleasant odors increased pro-social behavior but reception of a small gift did too. Although I did not directly control or manipulate for the mediatory role of the odor-elicited affective states, this should be controlled in future experiments. Most likely, the influence of odors on the evaluation and the processing of social stimuli as well as the influence of the affective state evoked by such odors will always be intertwined. Hence, it is quite difficult to investigate the influence of emotionally relevant stimuli without treating the question of their influence on affective state.

5 Study 4: On the Influence of Smells on Social Behavior in Economic Context

5.1 Introduction

In previous studies, it could be shown that facial expressions were influenced by threatening odors, such that faces in a threatening olfactory context, compared to a neutral one, were preferentially processed, as was reflected by larger LPP, higher SCL, and subjective ratings of valence, arousal, sympathy, and anxiety. Moreover, unpleasant compared to pleasant odors influenced social agents in a VR paradigm as could be demonstrated on larger LPP amplitudes, higher SCL and lower sympathy ratings and lower valence ratings combined with higher arousal ratings as suggested by Russell (2003) to map the emotional space. Unpleasant odors in combination with social agents also led to larger distances between participants' avatars and the virtual agents in an active approach task.

The two previous studies were designed to answer the question whether attributing odors to a social agent (vs. attributing them to the context) leads to larger effects of odor valence on the processing of social cues. The attributional direction of odors was manipulated, resulting in two attributional conditions. In the social attribution condition, hedonic smells were attributed to the social agents, whereas in the contextual attribution condition, smells were attributed to virtual rooms where the social agents were placed. This was manipulated in the two previous studies in both a between-subjects design and a within-subjects design. The social attribution led to larger effects of hedonic odors on social variables such as subjective ratings, corrugator activity, and SCL. On the other hand, no effects were found on behavioral variables and some physiological variables like the LPP.

The present study extends the results from the previous study by applying the same within-subjects manipulation of the attribution of smells. Still, in contrast to Study 3, technically speaking no olfactory conditioning was applied, as no test blocks were conducted. The present study mainly consisted of the physiology blocks of the previous study, but it added a more elaborated behavioral measure to the two objective variables (i.e., heart rate and SCL).

The ultimatum game was chosen as a measure of economic decision-making in social context (Güth et al., 1982). It consists of a proposing player and a receiving player taking part in a task to divide an amount of money between them. The proposer makes an offer on how to divide the money, while the receiver has the right to accept or decline the offer. If declined, none of the two players receives any money. Given a limited number of trials, it would be economically logical to accept all offers, even unfair ones. However, it can be shown that unfair offers are more often rejected than fair ones and that this behavior is predicted by activation of the insula of the receiver (Sanfey, Rilling, Aronson, Nystrom, & Cohen, 2003). Moreover, rejection of unfair offers seems to be associated with elevated autonomic and subjective arousal in the receiver (van'tWout et al., 2006). There are various parameters influencing offers that are perceived as unfair and therefore rejected, like affective states of sadness (Harlé & Sanfey, 2007), anger (Pillutla & Murnighan, 1996), and disgust (Moretti & Di Pellegrino, 2010) that all lead to higher rejection rates of offers by the receiver. Moreover, an influence of perceived attractiveness of both the proposing and the receiving person could be found (Solnick & Schweitzer, 1999; Zaatari et al., 2009). In the present study, participants played the part of the proposer, while the receivers were symbolized by the virtual agents.

An influence of smells on economic decision-making has so far only been shown in a study by Hirsch (1995). He demonstrated an increase in gambling behavior in a casino where a contextual pleasant odor was presented, while administration of a second odor did not lead to any change in gambling behavior. However, as the author did not report the nature of the two pleasant smells, it is hard to draw conclusions about the source of this behavioral effect. Still, a positive influence of a contextual pleasant smell on pro-social behavior has been observed before (Baron, 1997b; Baron & Thomley, 1994).

I expected offers to be higher in combination with a pleasant smell. There should be an influence of the smell attribution, such that in the social attribution, the effect of odor valence should be even higher than in the contextual attribution. Heart rate and SCL were recorded to replicate the findings of the previous study, thereby leading to stronger heart rate acceleration in later time-windows for the pleasant odor. This was expected to be unaffected by the attributional direction. For HSA participants, more pronounced heart rate changes were expected than for LSA participants. The influence of awareness of the contingency between agents/rooms and odors was additionally taken into account.

5.2 Methods

5.2.1 Participants

Thirty female participants took part in the study. One participant was excluded because she did not follow the instructions of the money distribution task (see below), resulting in 29 participants in the study. The mean age was 25.41 (*SD* = 7.68). All participants reached a minimum of 9 out of 12 right answers in the smell screening (m = 10.57; *SD* = 1.10; (Hummel et al., 2001b)). Participants rated their smell abilities as medium (m = 4.52; SD = 1.30). On the SPAI (Turner et al., 1989), an average score of 1.96 (SD = 0.63) was reached. Prior to the experiment, participants indicated a positive affect score of 29.76 (SD = 7.68) and a negative affect score of 12.72 (SD = 3.66) on the PANAS (Krone et al., 1996). Both scores diminished significantly throughout the experiment (positive: m_{post} = 28.07, SD_{post} = 8.72, $t[28]$ = 2.13, p = .042; negative: m_{post} = 11.90, SD_{post} = 3.03, $t[28]$ = 2.41, p = .023). Nine participants reported to be smokers and 16 were classified as EDA-nonresponders (applying the same strategy as in the previous experiments). Thirteen participants were fully aware of the contingency between the odors and the agents/rooms. Twenty participants reported not having believed to be really playing against another person, seven reported rather not believing it and only 2 participants reported that they believed to be playing against another person.

5.2.2 Stimuli and Apparatus

5.2.2.1 Virtual Reality and Pictures

In contrast to the previous experiment, the VR was presented via videos of the virtual scene, instead of participants really moving in the virtual environment. Videos were recorded with the open-source software Fraps (Beepa Pty Ltd.) and presented using the software Presentation (Neurobehavioral Systems, Inc.). The same three office rooms and three agents as in the previous experiment were used. Videos showed the passive paths towards the agents (around 6 sec.). The only difference was that the office door was already open when the video of the path started. This was due to the incompatibility of the controls of the video program and the virtual environment. Additionally, screenshots of agents in rooms were taken to be used in the money distribution task. To symbolize the amount of money participants could dispose of, pictures of euro coin stacks (1 – 10 €) were taken, luminance and color were adjusted using the software GIMP 2 (Free Software Foundation, Inc.).

VR presentation was not stereoscopic, and no perspective adaption was implemented. The videos were displayed centrally at 15.85 x 22.23 cm on a 17 inch computer screen, subtending a horizontal visual angle of 11.32° and a vertical angle of 15.82°. The distance between the screen and the subjects was approximately 80 cm. Videos and pictures were displayed on a black background.

5.2.2.2 Olfactory Stimulation

Olfactory stimulation did not differ from the previous experiment. Again, the same two pleasant und unpleasant substances were used. One combination of pleasant and unpleasant odors was used for the social and the other one for the contextual attribution block, resulting in 4 possible combinations of odors. Assignment of odors to the different agents/rooms/attributions was balanced across participants similarly to what was done in Study 3.

5.2.3 Physiological Measurements

Two adhesive heart rate electrodes fixed directly under the right clavicule and on the lowest rib on the left side were used to assess an electrocardiogram. Impedances were held under 5 µV to minimize noise on the heart rate signal. For measurement of the SCL, two Ag-AgCl-electrodes (diameter 8 mm) filled with 0.05 molar sodium chloride electrolyte gel were attached at the thenar and hypothenar eminence of the non-dominant hand. Participants were requested to wash their hands in order to maximize the quality of skin conductance data. Before the start of the experiment, EDA-nonresponders were identified. Participants were asked to inhale deeply, and if they did not show a drift of the skin conductance signal (of at least 5 µS), they were classified as nonresponder and not included into the analysis concerning skin conductance level. Data were recorded using the software Vision Recorder 1.20 (BrainVision, Munich, Germany).

5.2.4 Procedure

5.2.4.1 Manipulation of the attribution of smells

The manipulation was held as similar as possible to the previous task. Again, the attributional source of the odors was indicated by the logic of the experiment and also instructed at the beginning of each block. In the social attribution block, participants saw one of two agents that were each paired with pleasant vs. unpleasant odors in always the same office room. In the contextual attribution, participants interacted with always the same agent standing in one of two office rooms that were each paired with either a pleasant or an unpleasant odor. Agents, rooms, and odors were each only used for one combination of attribution and odor for each participant. Assignment of agents, room, and odors to the different conditions was balanced across participants. The same balancing strategy as in the previous experiment was used (see annex).

5.2.4.2 Physiology Blocks and Money Distribution Task

Before the start of the main experiment, participants were instructed that they were going to take part in an interactive economic trade game. They were going to offer money to one out of many exchange partners with whom they were connected via internet. The exchange partner was going to be symbolized by the agent on the screen. They would be given 10 Euros that they could distribute voluntarily between themselves and the partner. They would not be allowed to keep all 10 Euros for themselves or offer all of it to their partner. The exchange partner could then decide whether to accept the offer or not. If he accepted, both trade partners received their amount of money. If not, none of them was given any money. For exact instructions, please see annex. Before the start of the first block, the information that participants were going to be connected to their trade partners was presented on the screen, in order to support the cover story.

A trial of the main part started with participants standing in front of the open door of an office room. They were passively guided towards the agent standing in the middle of the office room, looking at them. The agent showed a neutral facial expression. Odor delivery started about the time when participants passed the doorstep. This approach took about 7 sec. The video was then replaced by a static picture of the same scene, and a stack of 10 coins appeared at the bottom left side of the screen. Above the picture a verbal instruction told participants to use the arrow keys to shift coins from their stack to the stack of their exchange partner (or back). They were told to indicate the final offer by pressing the space bar. Odor delivery stopped when the money transfer was finished. A feedback was presented to inform participants whether the fictive exchange partner accepted the offer or not (4000 ms). Half of the offers were accepted, the order was completely random within each odor condition. In case of accepted offers, participants were informed about how much money they gained. Afterwards, an ITI of 15000 ms consisting of a black screen was presented. In both attribution blocks, each odor condition was presented 10 times. Odor conditions were presented in randomized order within the attribution blocks. Between the two blocks, a break was granted to the participants, and they were told to relax as long as they wanted to. See Figure 26 for an overview of the experimental procedure.

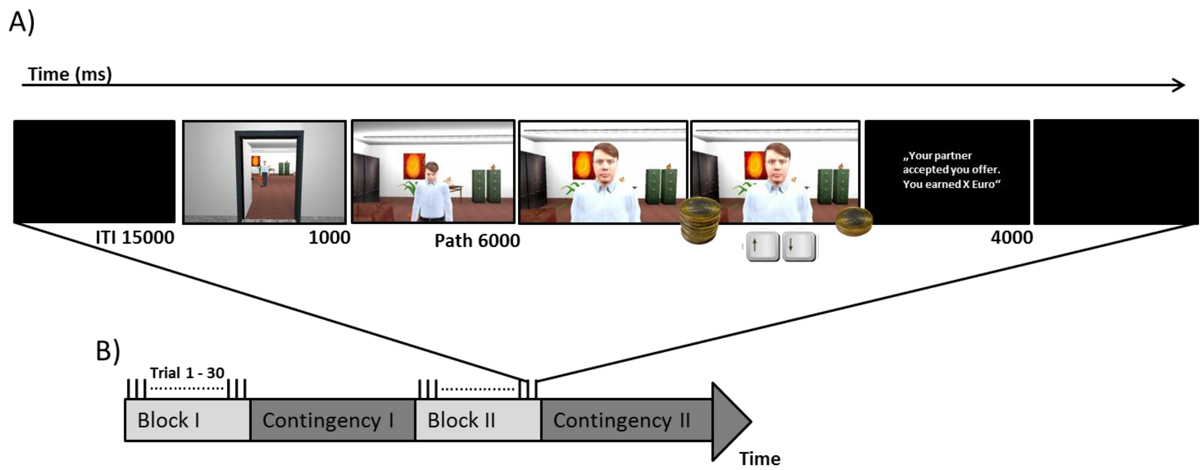

Figure 26: One trial of the physiology and money distribution session (A) and order of experimental procedure (B). ITI = Inter-trial interval.

5.2.4.3 Questionnaires and test batteries

Prior to the experiment, participants filled in a sociodemographic questionnaire and completed the screening version of the Sniffin' Sticks test battery (Hummel et al., 2001b). Additionally, participants filled in the PANAS (Krone et al., 1996) and the SPAI (Turner et al., 1989) before the start of the experiment. After finishing the main part, they again filled in the PANAS and additionally the IPQ (Schubert, 2003) and a post-test questionnaire, where they were asked to indicate whether they believed to be playing against others on a 5-point Likert scale ranging from 1 (not at all) to 5 (definitely yes).

5.2.5 Data Preprocessing and Statistical Analysis

The preprocessing of the physiological data paralleled the strategy that was applied in Study 3. The exclusion of 16 EDA-nonresponders resulted in 14 datasets for the analysis of skin conductance level. Heart rate and SCL were exported only during the passive path (*approaching time,* in total 6 sec) as I suspected the rest of the trial (i.e., the *social encounter*) to be contaminated by moving artifacts of the trade game.

Averaged data of the trade game were calculated for each of the four odor (pleasant vs. unpleasant) x attribution (social vs. contextual) conditions. Trials in which participants kept all 10 euros for themselves only by mistake were not included into further analysis. The average amount of money participants kept for themselves was then analyzed applying a 2 x 2 ANOVA with the factors odor (pleasant vs. unpleasant) and attribution (social vs. contextual), as it was also done for mean skin conductance levels. Heart rate change was analyzed with a 2 x 2 x 7 ANOVA with the factors odor, attribution, and time (7 time-windows of 1 sec. each). In case of significant interactions with the factor time, only the difference between the two odors at each time point and differences between subsequent time points were explored using post-hoc *t*-tests.

Social Anxiety and Awareness were applied as influencing factors to the investigated variables. The between-subjects factor of social anxiety was constructed with the values of the SPAI (Turner et al., 1989; *Median* = 2.03). A median split was calculated over the whole sample, resulting in one group of LSA (n = 15) and one group of HSA participants (n = 14). The between-subjects factor of Awareness was constructed with the help of the contingency ratings. Participants that indicated the right origin for both of the odors were classified as "aware" (n = 13), whereas all other participants were classified as "unaware", whether they misidentified one or more odor origins (n = 16). Both factors were included as between-subjects factors into separate overall-ANOVAs of the different variables. Significant interactions are listed separately at the end of the results section.

Marginally significant effects (.05 < p < .1) were further examined if they were hypothesis-driven. In all other cases, no post-hoc tests were applied to effects with p > .05. For moderating variables, only significant results were further tested, as the whole analysis was considered exploratory in nature. Significant interactions in this case were explored calculating separate tests for each group. In case of a violation of the sphericity assumption, Greenhouse-Geisser-corrected degrees of freedom were used. The significant level for all statistical tests was set at p = .05 (two-tailed). Estimated effect sizes (η_p^2) and Greenhouse-Geisser epsilon (GG-ε) are reported.

5.3 Results

5.3.1 Money Distribution

The ANOVA regarding money distribution revealed a significant main effect of Odor (F[1, 28] = 11.11, p = .002, η_p^2 = .28), indicating that participants kept more money to themselves when exposed to an unpleasant odor than when exposed to a pleasant one. Neither the main effect Attribution (F[1, 28] = 0.28, p = .600, η_p^2 = .01) nor the interaction reached significance (F[1, 28] = 2.06, p = .163, η_p^2 = .07). See panel A of Figure 27.

5.3.2 Heart Rate

The ANOVA revealed a significant interaction of Time x Odor (F[6, 268] = 5.15, p = .003, η_p^2 = .16, GG-ε = .49). The main effects of Time (F[6, 268] = 1.09, p = .339, η_p^2 = .04, GG-ε = .30), Odor (F[1, 28] = 1.20, p = .283, η_p^2 = .04), and Attribution (F[1, 28] = 0.13, p = .726, η_p^2 < .01) did not reveal any significant difference, neither did other two-way interactions (Odor x Attribution: F[1, 28] = 0.07, p = .796, η_p^2 < .01; Time x Attribution: F[6, 268] = 0.60, p = .613, η_p^2 = .02, GG-ε = .47) or the three-way interaction (F[6, 268] = 0.39, p = .753, η_p^2 = .01, GG-ε = .49).

Post-hoc t-tests of the interaction revealed that the heart rate was higher after 6 seconds (t[28] = 2.66, p = .013) and 7 sec (t[28] = 3.39, p = .002) after pleasant odor onset than after unpleasant odor onset. At all other time points, heart rate did not differ between the odors (all ps > .485). Within the pleasant odor, heart rate did not change significantly between consecutive time points (all ps > .089). However, within the unpleasant odor, heart rate decreased from second 1 to second 2 (t[28] = 2.44, p = .021) and from time 6 to time 7 (t[28] = 3.28, p = .003). All the other consecutive time points did not reveal significant changes in heart rate (all ps > .170). See panel B of Figure 27.

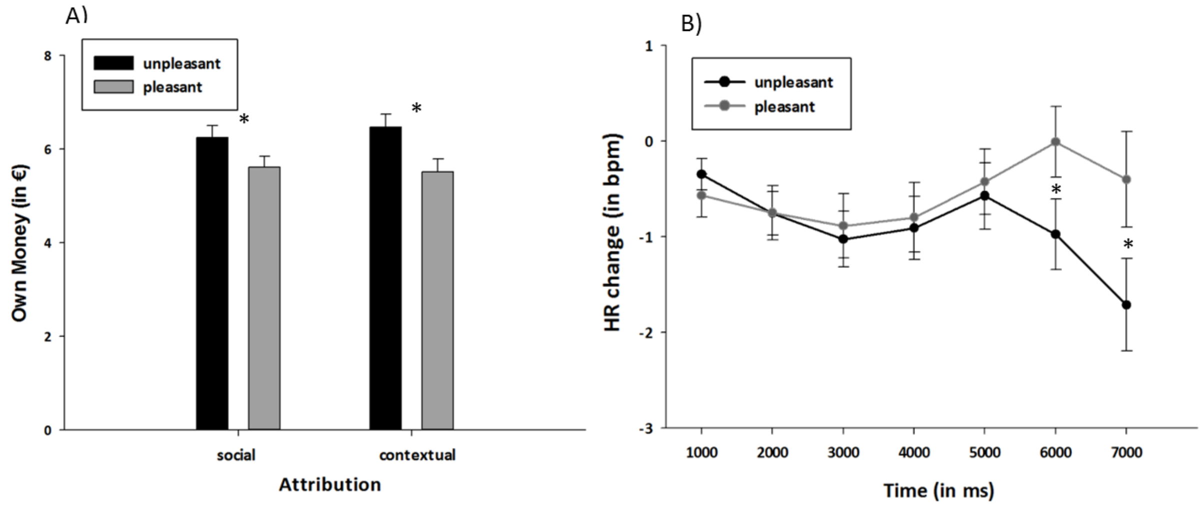

Figure 27: The money participants intended to keep for themselves as a function of odor and attribution (A) and the heart rate as a function of odor (B). Black bars/lines represent the unpleasant odor condition and gray bars/lines the pleasant odor condition. Error bars represent standard errors.

5.3.3 Skin Conductance Level

The ANOVA regarding skin conductance level did neither reveal significant main effects (Odor: *F*[1, 13] = 0.01, *p* = .932, η_p^2 < .01; Attribution: *F*[1, 13] = 0.04, *p* = .517, η_p^2 = .03) nor did the interaction reach significance (*F*[1, 13] = 0.02, *p* = .890, η_p^2 < .01).

5.3.4 Influence of Moderating Variables

No significant correlation between the distribution of HSA and LSA participants and aware and unaware participants could be found (X^2_1 = 0.62, *p* = .431).

5.3.4.1 Social Anxiety

Including the factor Social Anxiety into the analysis of money distribution did not reveal any significant effects (Social Anxiety: *F*[1, 27] = 1.35, *p* = .256, η_p^2 = .05; Odor x Social Anxiety: *F*[1, 27] = 1.61, *p* = .216, η_p^2 = .06; Attribution x Social Anxiety: *F*[1, 27] = 0.60, *p* = .447, η_p^2 = .02; three-way interaction: *F*[1, 28] = 1.06, *p* = .311, η_p^2 = .04).

Including the factor Social Anxiety into the analysis of heart rate change revealed a marginally significant interaction of Odor x Attribution x Time x Social Anxiety (*F*[6, 162] = 2.61, *p* = .062, η_p^2 = .09, *GG-ε* = .46). All other interactions with the factor Social Anxiety did not reach significance (all *p*s > .230). Explorative post-hoc *t*-tests revealed that in the group of LSA participants, no significant differences were found through time points for the LSA group (all *p*s > .120). The group of HSA participants, however, showed a significant interaction of Odor x Time (F[6, 78] = 3.58, p = .035, η_p^2 = .22, GG-ε = .38). Post-hoc t-tests showed that the heart rate did not differ between odor conditions at t1 to t6 (all ps > .164), but showed a trend towards significance at t7 (t[13] = 1.99, p = .068). Heart rate tended to be higher when a pleasant odor was presented. All other effects did not reach significance (all ps > .139). See Figure 28.

Inclusion of the factor Social Anxiety into the analysis of skin conductance level did not reveal any additional interactions with this factor (Social Anxiety: F[1, 12] = 0.01, p = .932, η_p^2 < .01; Odor x Social Anxiety: F[1, 12] = 0.01, p = .925, η_p^2 < .01; Attribution x Social Anxiety: F[1, 12] = 0.52, p = .484, η_p^2 = .04; three-way interaction: F[1, 12] = 0.39, p = .544, η_p^2 = .03).

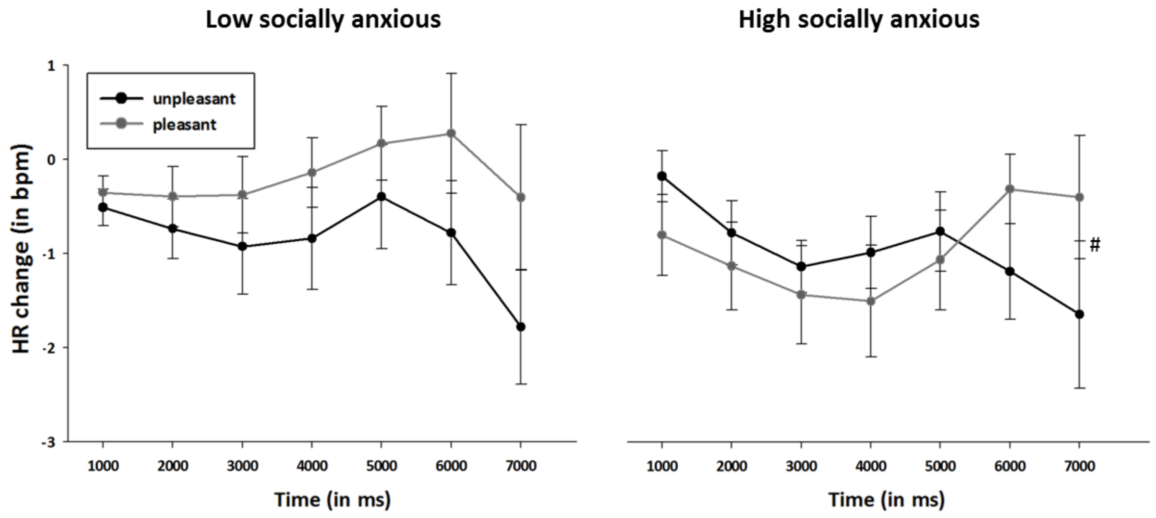

Figure 28: Heart rate change as a function of presented odor in the group of LSA (left) and HSA participants (right). Black lines represent the unpleasant and gray lines the pleasant odor. The hash sign stands for marginally significant differences. Error bars represent standard errors.

5.3.4.2 Awareness

Including the factor Awareness into the analysis of money distribution did not reveal any significant interactions with it (Awareness: F[1, 27] = 0.50, p = .486, η_p^2 = .02; Odor x Awareness: F[1, 27] = 1.18, p = .286, η_p^2 = .04; Attribution x Awareness: F[1, 28] = 0.16, p = .693, η_p^2 = .01; three-way interaction: F[1, 28] = 0.15, p = .698, η_p^2 = .01).

The analysis of the heart rate indicated a significant interaction of Odor x Attribution x Awareness (F[1, 27] = 7.30, p = .012, η_p^2 = .21). All other interactions with the factor Awareness did not reach significance (all ps > .472). Separate testing for the two groups did not return any significant results in the group of unaware participants (all ps > .155). In contrast to this, in the group of aware participants, a significant interaction of Odor x Awareness was found (F[1, 12] = 5.81, p = .033, η_p^2 = .33). Post-hoc t-tests for this interaction revealed that the heart rate was higher for pleasant than for unpleasant odors in the social (t[12] = 2.78, p = .017) but not in the contextual attribution (t[12] = 0.73, p = .473). The heart rate did not differ between the attributions for each of the odors (pleasant: t[12] = 1.72, p = .111; unpleasant: t[12] = 1.53, p = .152). Nicely, these findings parallel those of Study 3.

Inclusion of the factor Awareness into the analysis of skin conductance level did not reveal any additional interactions with it (Awareness: F[1, 12] = 0.37, p = .554, η_p^2 = .03; Odor x Awareness: F[1, 12] = 2.16, p = .167, η_p^2 = .15; Attribution x Awareness: F[1, 12] = 1.04, p = .328, η_p^2 = .08; three-way interaction: F[1, 12] = 0.02, p = .900, η_p^2 < .01).

5.4 Discussion

The present study aimed at extending and partially replicating the results from the previous study. In this regard, a similar paradigm was applied, resulting in a social attribution block where a pleasant and an unpleasant odor were to be interpreted as exuding from two virtual agents; and a contextual attribution where the two odors were to be attributed to the rooms the agents were placed in. It was thus possible to elaborate the influence of pleasant vs. unpleasant odors on variables of social interaction on the one hand and to explore the influence of the attributional direction on this effect on the other hand. Despite my investigation of the influence of odor on behavior in the previous studies, I could not make any statement about the underlying decision-making processes. Therefore, in this study I tried to overcome this limitation by measuring behavioral responses of the participants in an ultimatum game in the presence of pleasant vs. unpleasant odors. Importantly, by means of this task I could depict the influence of the odor on decision-making. Additionally, while participants were approaching agents in virtual rooms, heart rate and SCL were recorded. It is of importance to take into account that in the present study, no learning part was implemented. Odors and agents/rooms were present simultaneously throughout the whole experiment. Still, the results parallel the results from the previous study in most regards.

It could be shown that the amount of money participants kept for themselves indeed differed accordingly to the presented odor. When an unpleasant odor was presented, participants offered a lower amount of money to their partner than when a pleasant one was presented. Up to my best knowledge, only one study so far investigated the influence of odors on decision-making in economic context (Hirsch, 1995), and its results are in line with the present study. Thus, pleasant odors were found to increase gambling behavior in a casino where it had been administered into the surrounding air. The attributional direction did not play an influencing role in the present results, and neither did possible moderating variables like social anxiety and contingency awareness. This is in line with other behavioral measures from the previous studies of this thesis. In fact, approach and withdrawal behavior was also influenced by odor pleasantness but not by the attribution of the odors. This suggests that behavioral measures might be either not sensitive enough to reflect changes resulting from attributional directions or that the presence of the odor was too predominant, irrespectively from its exuding source. The latter could point towards a mediating effect of the affective state evoked by the pleasant or unpleasant odors.

It is important to state that the effect which was found on the Ultimatum Game task does not have to be necessarily directly social in nature. As has been shown before, there is a strong link between affective state and divergent vs. convergent thinking (Akbari Chermahini & Hommel, 2012). Negative affective state leads to more convergent thinking, while positive affective state has the opposite effect (Rowe, Hirsh, & Anderson, 2007). It could be shown that induction of divergent thinking, as had been achieved with a creativity test, leads participants to trust others with a larger amount of money (Sellaro et al., 2014). It seems possible that again, the influence of hedonic odors is mainly mediated by the participants' affective state (Baron & Thomley, 1994). When presented with an unpleasant odor, affective state would decrease, and that in turn would lead to more convergent thinking. This would then lead to participants wanting to keep more money for themselves, instead of showing gratitude towards others.

Results of peripheral physiology resembled the results of the previous study. The SCL was influenced neither by presented smells nor by the attributional direction. Heart rate again reflected the pattern that corresponded to the *defense cascade model*, i.e., immediate decrease followed by an increase while approaching a possible opponent (Fanselow, 1994), even though the pattern was not as clear as in the previous study. However, the same influence of hedonic smells was observed, resulting in a higher increase in heart rate after six seconds of approach and smell presentation. A similar pattern was shown in a study by Löw et al. (2008), who used pictures of guns or money as threatening vs. rewarding stimuli. Interestingly, at a later stage of heart rate (i.e., 6 sec after stimulus onset) they also found a larger increase for rewarding than for threatening stimuli. Notably, the *defense cascade model* predicts a larger increase the more threatening a stimulus (Fanselow, 1994), but one has to take into account that the model does not make any predictions for non-threatening stimuli. So far, the study by Löw et al. (2008) is the only one applying the *defense cascade model* to rewarding stimuli. On the other hand, as I already mentioned in the discussion of the previous study, the effects I found could also be mediated by breathing volume, as heart rate has been shown to be very sensitive to inhalation vs. exhalation (Hirsch & Bishop, 1981). As was demonstrated in Study 2 and also corresponds to the literature (Ferdenzi et al., 2015; Pichon et al., 2015), pleasant odors lead to enhanced inhalations in contrast to unpleasant odors that impede it. The observed effect could thus be due to mainly physical reasons that derivate from odor hedonics. Nonetheless, the increased heart rate occurred while participants were approaching the social agents, and the effect has been shown to be mediated by social anxiety, such that increased heart rate was only present in HSA but not in LSA participants. Moreover, heart rate was found to be higher in the social than in the contextual attribution. I therefore argue that the effect on the heart rate is, if not social in nature, at least socially mediated. The question whether the same effect would occur with participants approaching a non-social object could be the subject of further research.

Another notion that has to be discussed is the question whether participants really believed that they were playing against other persons, and results from the post-test questionnaire indicate that the majority of them did not. They were instructed at the beginning of the experiment that their bargaining partner would change after every trial, but the agent representing their partner was the same in every condition. This could have seemed somewhat contradictory to participants and have decreased the effects. This confusion is partly due to the different nature of the Ultimatum Game and the developed paradigm. While the paradigm of the two previous studies aimed at establishing a contingency between a specific agent (or room) and an odor and thereby used mechanisms from classical (Pavlov, 1927) and instructed (Phelps et al., 2001; Rachman, 1977) conditioning, an important characteristic of the Ultimatum Game task is that participants do not believe that they play against the same person more than once, in order to prevent teaching or penalizing mechanisms (Hewig et al., 2011; Rand, Tarnita, Ohtsuki, & Nowak, 2013). It would have been within the logic of the previous paradigm to instruct participants that they would play against one of two persons, each represented by a virtual agent. However, this would contradict the logic of the Ultimatum Game that participants should not believe to be playing against the same person more than once. Nonetheless, the effects I found were in line with a priori hypotheses. Moreover, the average offer, lying around 40% of the total amount of money, corresponds to the “typical” offer found in Ultimatum Game tasks (Camerer, 2003), indicating that the task reflects what I intended.

In summary, it could be shown that hedonic odors have an influence on decision making, such that in combination with pleasant odors, participants make higher offers to virtual agents than in combination with unpleasant odors. Additionally, findings from the previous study concerning heart rate could be replicated. Thus, pleasant odors elicited higher heart rate than unpleasant ones during the last seconds of passive approach towards virtual agents. Moreover, this effect was especially pronounced in HSA individuals, highlighting its social nature. Whether hedonic odors were attributed to the agents or to the rooms did not play any particular role. This is in line with results from my previous studies that also did not show any influence of odor attribution on heart rate or behavioral measures (i.e., distance measurements). Possibly, effects of hedonic odors are mainly mediated by affective state provoked by them rather than their attribution. The influence of pleasant odors on pro-social behavior has been demonstrated before (Baron, 1997b; Baron & Thomley, 1994), but to my knowledge, the present study is the first to show olfactory influences on economic decision-making in a controlled laboratory setting.

6 General Discussion

Olfactory molecules are practically omnipresent in daily life. They frequently enter the nose and bind to receptors on the olfactory epithelium during inhalation and are not always consciously perceived. The influence of olfactory stimuli on daily life matters, for example, in social situations, despite the fact that this influence is often underestimated, possibly because the sensitivity of the nose is outperformed by the sensitivity of the eyes or the ears in humans. However, the influence of olfactory stimuli on social variables can be observed on many occasions. Human body odors caused emotional contagion from a sending person to a perceiving person as transmitted via receptors located in the nasal cavity (Adolph et al., 2013; Lübke et al., 2012; Rubin et al., 2012). Moreover, an influence of purely olfactory stimulants, as processed via the olfactory epithelium and olfactory central nervous pathways, can be observed. Thus, unpleasant and pleasant odors unfold their influence on face processing (Bensafi et al., 2002; Gottfried et al., 2002a; Hermann et al., 2002), on ratings of social preferences (Dematte et al., 2007; Li et al., 2007; Todrank et al., 1995), and behavioral measures of pro-social attitudes (Baron, 1997b; Baron & Thomley, 1994). They have been applied in both conditioning studies where the reinforcing vs. penalizing effects of the odors were tested in a test phase while no odor was presented (Gottfried et al., 2002a; Hermann et al., 2000, 2002) and in studies where odors were presented simultaneously to social stimuli (Baron, 1983; Dematte et al., 2007; Li et al., 2007). Furthermore, while pleasant odors have been shown to enhance pro-social behavior, a small gift had the same effect, possibly mediated via positive affective state (Baron & Thomley, 1994).

Based on this evidence, the present thesis aimed at exploring the influence of odors having emotional value on verbal reports as well as on physiological and behavioral measures of the processing of social cues (Lang, 1995b). The first challenge was to overcome the fact that odor hedonics strongly depend on personal learning history (Ayabe-Kanamura et al., 1998; Poncelet et al., 2010; Rouby et al., 2009; Schaal et al., 2000). Therefore, I first conducted a study in which I investigated the learning processes underlying odors. To this purpose, I paired one initially neutral odor with an unpleasant unconditioned stimulus (i.e., a desperate female scream), thus producing a threatening and unpleasant context. Meanwhile, a second odor was never paired with the aversive scream and thus represented a safety and pleasant olfactory context. In a second step, I tested the influence of those odors on the processing of facial stimuli displaying varying emotional expressions. As a second step for this thesis, I conducted a pilot study in order to identify smells which held positive or negative valence (see annex). These smells were afterwards used in three further studies which explored the influence of hedonic smells on the processing of social stimuli in a VR setting. These studies additionally aimed at disentangling the influence of a contextual smell from the smell that was attributed to a social agent. Moreover, the processing and the evaluations of social cues were scrutinized on many different variables in order to draw an overarching picture of different aspects of social interaction.

6.1 Hedonic Odors and Their Influence on the Processing of Social Stimuli

In all studies, I investigated associative learning processes underlying olfaction over three levels of responses (Lang, 1995b), namely the verbal (i.e., ratings), physiological (i.e., ERPs, SCL, EMG, and HR), and behavioral level (i.e., approach, withdrawal, and decision making). A first hypothesis concerning the influence of hedonic odors on the processing of social cues was related to the effects on the verbal level of responses. In other words, I expected ratings of pictures (Study 1) and of virtual agents/rooms (Study 2 and 3) to gain emotional importance from the odors they were associated with. An important distinction among the considered studies has to be made. In Study 1, pictures were rated when presented together with the contextual olfactory stimulus, whereas in Study 2 and Study 3, agents were rated without the odor they had been paired with during the experiment. Although the ratings of the three studies do not match exactly, results are quite in line with each other. Thus, faces presented within the threat-associated olfactory context in Study 1 were consequently evaluated as less pleasant, less likable, more arousing, and more anxiogenic than those presented within the safety-associated olfactory context. Accordingly, virtual agents in Study 2 and 3 paired with an unpleasant odor were evaluated as less likable, less pleasant, and more arousing than agents that were paired with a pleasant odor. This was also true if the agents were placed in a room paired with an unpleasant odor. Hedonic smells thus seem to exert an influence on the evaluation of other persons who are encountered within such smells. These evaluations are in turn shifted according to affective odor properties. The investigation of the effect of pleasant vs. unpleasant odors on the evaluation of others has a long history in research (Cook et al., 2015; Dematte et al., 2007; Hermann et al., 2000, 2002; Li et al., 2007; Todrank et al., 1995).

It has thereby not only been shown that evaluations suffer from being paired with unpleasant and gain from being paired with pleasant odors, but some other influencing factors have also been established. Thus, the study by Todrank et al. (1995) found effects of odors on the evaluation of facial pictures only if the odors were semantically congruent to social stimuli. However, such differences could not be confirmed by later studies (Dematte et al., 2007). The question arises whether the applied odors in the present studies were semantically different in their attribution to human bodies, namely whether some of them were more easily attributable to humans than others. In Study 1, smells of rose and chemical and in Studies 2 - 4, smells of lemon, eucalyptus, animal dung, and other chemicals were used. None of these odors may be directly semantically related to human bodies. Nonetheless, one can of course argue that the likelihood of smelling of animal dung is higher than that of smelling of chemicals. However, this assumption remains speculative, and it could be shown that influence on the evaluation of social stimuli did indeed work throughout all studies of the present thesis and with different odors as well as different designs (between-subjects and within-subjects).

Another study that makes an important statement about the nature of olfactory influence on social evaluation has been conducted by Li et al. (2007). They used very low concentrations of hedonic odors, meaning that the odors were presented subliminally. They found an effect of odor valence (i.e., lower preference ratings for persons who had been paired with an unpleasant compared to a pleasant odor) only if participants were not able to consciously detect the odor. However, physiological changes (i.e., stronger heart rate increase after administration of the unpleasant odor) were independent of the conscious perception of the odor. They argue that top-down processes that only play a role in conscious processing may have exerted a compensatory influence on social evaluation. This might, however, only be true for concentrations that vary around the perception threshold. To my best knowledge, in no other published study, olfactory influence on evaluative processing had been impaired by the fact that odors were consciously perceived. Considering that, in my studies, odors were presented at a much higher concentration than in the study by Li et al. What has been reflected by their results is probably substantially different to what I found in mine. In fact, odors in my studies were presented in a way that all participants were able to perceive them (not least because the olfactometer that was used did not allow odor presentation of high accuracy). It could nonetheless be very interesting to repeat a similar paradigm with odors varying around the perception threshold in order to explore more bottom-up driven influence of odors on social evaluations.

A second hypothesis concerned psychophysiological variables that were recorded during the test session in Study 1 and during the social encounter in VR in the Studies 2 - 4. I expected physiological variables to display the difference between pleasant and unpleasant odors, the latter being associated with enhanced electrodermal activity (Bensafi et al., 2002a), higher amplitudes of the late positive potential (Bensafi et al., 2002; Cook et al., 2015), higher activity of the corrugator muscle (Delplanque et al., 2009), flattening of inhalation volume (Ferdenzi et al., 2015; Pichon et al., 2015), and lower heart rate changes in late time-windows (Löw et al., 2008). Changes in EDA could be shown in Study 1 and Study 2, thereby displaying higher SCL during presentation of an unpleasant (or threatening) odor than during presentation of a pleasant (or safety) odor. In Study 3 and Study 4, no such effects could be found, most probably due to the lack of statistical power in these analyses. As a measure of autonomic arousal, the increased SCL was interpreted as higher arousal during exposure to unpleasant odor in both cases when participants encountered a bad smelling agent (Study 2) and when they learned the odor's adversity through a context conditioning protocol (Study 1). Even though these two studies did not follow the same experimental protocol and the nature of the applied odors was different, they resulted in a similar pattern of results on SCL and interestingly also on the late positive potential.

Thus, the LPP was modulated by the valence of the presented odor such that larger LPP amplitudes were found in both studies when an unpleasant as compared to a pleasant odor was presented. The LPP is normally interpreted as a measure of valence but highly influenced by attentional processes (Schupp et al., 2000). It seems logical that unpleasant odors recruit more attentional resources than pleasant ones, the former being potentially harmful for the organism. In line with this, general influences of potentially threatening contexts on face processing as reflected in the EEG have been demonstrated before (Dunning et al., 2013; Righart & de Gelder, 2005; Rubin et al., 2012). Hence, in the series of studies of this thesis, unpleasant odors seem to require more attentional resources and importantly lead to a boost in attentional processing of social stimuli presented within these odors. To sum it up, it seems logical to pay more attention to persons who exude an unpleasant smell or who have been presented within an environment exuding an unpleasant smell because of their potentially harmful nature.

Besides these quite clear arousal- and attention-related results, the valence-related results appear less clear. Thus, it was expected that the presentation of an unpleasant (compared to a pleasant) odor during a social encounter should lead to a more pronounced corrugator activation, as a reflection of perceived negative valence of the odor (Delplanque et al., 2009; Hermann et al., 2002). Nonetheless, I found no effects of the odors on corrugator activity, indicating that if there had been any effects, they were too weak to be found given the sample size of Study 1. It should be also considered that it is not possible to conclude from the literature whether the valence or the mimicry effect would modulate muscle activity more strongly, as so far, no study has treated facial mimicry under conditions of hedonic odors. Therefore, missing general effects of odor valence on the corrugator muscle activity might be due to specific effects of the odor on face processing (see below).

Heart rate partly followed the pattern found by Löw et al. (2008). In fact, they demonstrated that rewarding pictures (i.e., images of money) elicited a stronger heart rate acceleration than neutral and threatening ones, especially during late processing stages (after 6 sec). This stronger acceleration followed a reduced attenuation in early processing stages. Similarly, I found a stronger acceleration of heart rate during the participants' approach to the agents for the pleasant than for the unpleasant odor exactly after 6 sec of odor presentation and approach. Nicely, this effect was found for both passive approaches to the agents (Study 3), independently of the following active money distribution task after the approach (Study 4). It should be taken into account that when participants are exposed to a pleasant odor, they inhale more deeply. Heart rate and breathing volume have been shown to influence each other (Hirsch & Bishop, 1981). It could therefore be that the effect I observed was not a psychological one, but mainly physically driven. However, this effect was larger for HSA than for LSA participants. Therefore I am confident in claiming that, despite this effect not being purely social, it is at least socially mediated. Heart rate has been argued to reflect the valence rather than the arousal axis of the hedonic space of odors (He et al., 2014; Li et al., 2007). According to the *defense cascade model* (Fanselow, 1994), during the approach of potentially threatening opponents, heart rate should first display a deceleration followed by an acceleration (Lang, 1995b). This effect should be larger the more threatening a cue. However, the model does not make any predictions about rewarding encounters. It seems possible that after a first orienting response (i.e., an initial decrease in heart rate), a good-smelling social encounter might become more attractive, and consequently the autonomic nervous system is boosted for eliciting approach behavior. More research is needed in order to evaluate the role of heart rate in the processing of odors during social encounters.

A third hypothesis concerned behavioral effects that were obtained in combination with pleasant and unpleasant odors. Study 2 demonstrated that under conditions of an unpleasant odor, participants did not approach virtual agents as much as they did when a pleasant odor was presented. They also did not spend as much time approaching the agents as when the pleasant odor was presented. Pleasant compared to unpleasant odors thus seem to facilitate approach behavior towards a social agent. This effect is independent of the attribution of the odors (i.e., social vs. contextual attribution). A confounding factor has nonetheless to be taken into account. As the trial (and thereby the odor presentation) stopped after participants indicated their final position by pressing a joystick button, participants could press earlier to avoid the odor. From a daily life perspective, this makes perfect sense, because if somebody smells badly, one might feel the urge to avoid him or her and also to leave the situation to get rid of the unpleasant smell. It was shown before that when exposed to a member of a positive social group, approach behavior is facilitated (Castelli et al., 2004), and liked pictures were looked at longer than disliked ones (Lang et al., 1993). This can be generalized to the results of Study 2. In fact, participants evaluated agents in combination with a pleasant smell as more likable and in turn showed pronounced approach behavior towards them. Moreover, they spent more time approaching when a pleasant smell was presented. However, it is not possible to conclude whether the effect was due to a social factor, i.e., participants wanting to avoid a badly smelling agent, or to them rather wanting to get rid of the unpleasant smell. Study 3 tried to overcome this interpretation problem by applying a withdrawal instead of an approach task. It could be shown that participants spent more time withdrawing from agents when an unpleasant smell was presented even though the distance between agents and participants' avatars did not differ between the odors. This seems somewhat counterintuitive; however, it suggests that the effect is not only driven by physical properties of the odors. Participants withdrew from agents for a longer time-period when an unpleasant odor was presented (independently from the odor attribution, i.e., to the room or to the agent). Therefore it can be argued that withdrawal behavior is facilitated in the condition of the unpleasant odor.

Interestingly, Study 4 displayed a similar effect although I applied a different measure of social behavior. Virtual agents in combination with an unpleasant smell were offered less money in an Ultimatum Game task than agents in combination with a pleasant smell. Behavior in the Ultimatum Game would, from a game theoretical point of view, be predicted by a maximization of the own amount of money. That means it would be economically logical to offer the least possible amount to the game partner. However, participants have been shown to offer more, this being interpreted as generous behavior (Güth et al., 1982). Proposer and receiver behavior are influenced by mood (Moretti & Di Pellegrino, 2010; Pillutla & Murnighan, 1996) and perceived attractiveness (Solnick & Schweitzer, 1999; Zaatari et al., 2009). Interactions with more attractive persons lead to higher offers and less rejections. Moreover, pleasant smells augment attractiveness, whereas unpleasant ones diminish it (Dematte et al., 2007). The results of Study 4 seem to reflect this relationship. Lastly, affective states of disgust (Moretti & Di Pellegrino, 2010) and anger (Pillutla & Murnighan, 1996) lead to lower offers and more rejections. As odors serve as potent triggers of mood, it is conceivable that the effects of Study 4 reflect the relationship between affective state and social interaction. Apart from this, it was demonstrated that negative affective state leads to more convergent thinking, while positive affective state has the opposite effect (Rowe et al., 2007). It could be shown that induction of divergent thinking leads participants to trust others with a larger amount of money (Sellaro et al., 2014). The present results could alternatively be explained this way.

Additional light was shed on a differential effect of odor valence on the different facial expressions. Strikingly, the specific influence of odors differs between Study 1 and Study 2 and 3. This is most probably due to the fact that odors in Study 1 were conditioned using a context conditioning paradigm and most probably elicited emotions of anxiety vs. safety. This is also supported by subjective ratings of these odors. In contrast to this approach, odors in Study 2 and Study 3 were chosen from a pilot study where participants rated them as being unpleasant vs. pleasant in nature. They therefore perhaps elicited disgust vs. happiness rather than anxiety. Apart from that, in Study 1, angry, neutral, and fearful facial expressions were used, whereas in Study 2 and 3, the fearful one was replaced by a happy facial expression. Results from these two approaches can therefore not be directly compared.

In Study 1, a specific influence of the odor on face processing was found on ratings of valence and sympathy as well as on the electrodermal activity. Presentations of facial expressions within the threatening odor led to a more fine-tuned processing of facial expressions, which is in line with previous studies (Wieser & Brosch, 2012). Thus, angry faces were rated as less pleasant and likable than fearful ones that were in turn rated as less likable than neutral ones. Notably, this effect was not observed when faces were presented within the safety odor. Moreover, the angry facial expression was the only one to be rated as less pleasant within the threatening than within the safety odor. The latter effect was also reflected on electrodermal activity. It was thereby shown that the presentation of a potentially threatening odor led to a potentiation of the differences between facial expressions.

In the studies on the influence of initially pleasant vs. unpleasant smells (Study 2 and 3), however, the unpleasant odor was found to rather flatten the differences between facial expressions. This was demonstrated for ratings of sympathy and homelikeness in Study 3 as well as sympathy ratings of the social attribution group in Study 2. I additionally demonstrated differences between facial expressions only when a pleasant and not when an unpleasant odor was presented on both the SCL and corrugator muscle activity. What can be concluded from Study 2 and 3 is that unpleasant odors seem to draw more processing resources than emotional facial expressions. When agents were presented together with the unpleasant odor, the difference between emotional facial expressions seemed to diminish. Physiological effects are highly correlated with subjective arousal (Lang et al., 1993). Moreover, emotional scenes like the International Affective Picture System (Lang, Bradley, & Cuthbert, 1997) usually evoke higher arousal than emotional facial stimuli (Langner et al., 2010). I therefore assume that emotional facial stimuli are weaker in eliciting emotional reactions than high arousing emotional scenes. The unpleasant odor therefore seems to outperform emotional facial expressions. In other words, when meeting someone while smelling something unpleasant, human beings might not pay that much attention to his/her facial expression, as they might be preoccupied with searching for the source of the threat. The fact that in Study 1, an opposite effect was found, i.e., the threatening and thus unpleasant odor provoked a higher differentiation between facial expressions than the safety odor, can be due to different reasons. First of all, the olfactory context conditioning procedure leading to odors being evaluated as threatening was precisely constructed to evoke a state of sustained anxiety, while in Study 2 to Study 4, odors were evaluated as unpleasant per se. Whether this referred to a state of anxiety as unpleasant odors represent potentially harmful stimuli for the organism or rather a state of disgust or even something totally different cannot be answered from the present data. Secondly, in Study 1, only a neutral and two unpleasant facial expressions were used (i.e., angry and fearful), while in Study 2 and 3, happy, neutral, and angry facial expressions were performed by the virtual agents. It is therefore hard to argue that hedonic odors would influence these two different ranges of emotional displays in the same way. Thirdly, Study 1 comprised static photographs that participants were passively watching, while Study 2 and 3 consisted of participants moving in a virtual environment with virtual agents performing dynamic facial expressions. However, dynamic facial expressions do not differ from static ones with respect to their capacity to evoke facial mimicry (Weyers et al., 2006) or electrocortical signals (Mühlberger et al., 2009). Last but not least, the first experiment presented odors as contexts within which faces were presented without any special information on odor attribution, while in all following studies, specific instructions on smell attribution were given. It is therefore difficult to compare results from these two studies directly. In sum, I demonstrated that hedonic odors do not only unfold a general influence on face perception but also a specific one. This underlines the social nature of the effects found in the first three studies. Whether or not the effect I demonstrated would also be present in interactions with non-social objects and thus whether the effects were social in nature is hard to answer due to the lack of a non-social control condition. However, the differential influence of odors on face processing and the results from the Ultimatum Game task are interpreted as social tasks and thus support the partly social nature of the results.

Throughout all of the experiments, learning factors played an important role. Study 1 consisted of two parts, a conditioning part and a test part, where facial stimuli were presented within context odors that were conditioned before. Context conditioning effects in this study were only partly consistent over time. Some effects showed up in both conditioning and test phase, whereas others were only present in one of the two phases. However, systematic results with respect to phases are lacking in this study.

Study 2 (and also Study 3) applied baseline ratings of agents and rooms before they were paired with the odors and post-conditioning ratings after each physiology block. Olfactory conditioning of agents was successful as has been underlined by the rating data. Conditioning effects established themselves throughout the first block, as the effects were observable after the first of three blocks and were rather stable throughout the experiment or at least did not increase after the first block. For physiological variables, however, it is difficult to examine the influence of learning, as physiological variables were not recorded while agents were presented without the reinforcing odor. However, for some variables (SCL, corrugator, breathing volume), the factor block was considered in the analysis. Significant increases of the effects throughout the experiment could not be demonstrated on these variables. If any effect was present, it tended to be stronger in the first block than in the following ones. This supports the results from the rating data, indicating that the association between agents/rooms and odors established itself throughout the first block. Changes over time would therefore rather be due to habituation than to learning effects. Habituation or stabilization effects are reflected by the rating data of Study 2. Associations between the odors and agents/rooms seem to establish themselves rather quickly. Nonetheless, the VR paradigm has proven to be suitable to conduct olfactory conditioning in an ecologically valid virtual environment.

Taken together, the results indicate an influence of odors on the evaluation and processing of social cues. Results from the first study demonstrate that olfactory contextual stimuli can be used to transmit anxiety and thereby lead to a reinforced processing of facial stimuli, as was displayed on verbal reports and physiological measures. The following paradigm was designed to flexibly present odors within a virtual environment and to explore both contextual and social attribution of smells. The presentation of unpleasant vs. pleasant odors has an impact on the processing of social agents. Agents that were paired with an unpleasant odor (or were standing in a room that was paired with it) were evaluated as less likable and more arousing than when paired with a pleasant odor. This was reflected on the physiological level by higher electrocortical signals and measures of the autonomic nervous system. Behavior variables showed a facilitation of social interaction when presented in combination with a pleasant compared to an unpleasant odor. In total, the established VR paradigm has thus proven to be suitable in enacting social scenes in combination with odor presentation via an olfactometer. Strengths of the paradigm lie in its variety of applicable measures that make it possible to display social situations and emotional reactions on different levels as proposed by Lang et al. (1993). Nonetheless, the question remains whether there is a direct effect of odors on social interaction that would result in stronger effects in the social than in the contextual attribution.

6.2 Social vs. Contextual Odor Attribution

Study 1 demonstrated an influence of a previously neutral odor on the processing of facial cues. The odor was emotionally stained by application of a context conditioning paradigm and subsequently administered contextually. A context was thereby defined as a long-lasting stimulus (Bouton, 2010), which is normally presented in the background rather than in the foreground. Within this background stimulus, other stimuli can be presented, and thereby, the influence of the context on their processing can be explored. This is what has been realized in Study 1. Still, one aim of the present thesis was to disentangle the influence of odors that exude directly from a social agent from the influence of a contextual olfactory stimulus. As in this regard no conclusions can be drawn from the results of the first study, a different paradigm was used in Study 2 to Study 4. Social attribution of smells was achieved by placing one out of two agents in the same virtual rooms, while each was associated with the pleasant or the unpleasant smell. In contrast to this, contextual attribution was achieved by placing the same agent in one out of two virtual offices, each of them associated with one of the smells. This attribution manipulation was conducted between-subjects in Study 2 and within-subjects in Study 3 and 4. This procedure implicates that pairing blocks of agents/rooms with odors comprised fewer trials per condition in Study 3 and 4 than in Study 2.

To start with the rating data, I demonstrated that a specific influence of odors on the processing of facial expressions is only found in the social attribution group and not in the contextual attribution group of Study 2. However, a drawback of this study is that rating data of the two groups are not directly comparable, and differences between the groups are therefore not statistically verified. Nonetheless, the specific influence of odors on facial expressions, i.e., the fact that pairing of agents with unpleasant odors flattens the difference between facial expressions, is only observed if odors are attributed to the agents and not if agents are standing in a room that is paired with an unpleasant odor. This specific influence is interpreted as social in nature, and this social effect seems to be dependent on odors being attributed to the agents.

In Study 3, ratings were constructed to be comparable between the two attributional conditions. It could be shown that the difference between pleasant and unpleasant odors was greater in the social attribution than in the contextual one on all ratings but the homelikeness ratings. This makes sense when taking into account that the latter were centered on the evaluation of the rooms and not the agents. If any effect at all, I would have expected the difference in homelikeness ratings to be larger in the contextual attribution. Results from this study thus demonstrate that odors have a greater potential to influence the subjective evaluation of agents if they are attributed to the agents than to the context. Even ratings of valence and arousal that are not centered on the evaluation of the agents but the affective state of participants are more strongly influenced by odors which are attributed on the social agent itself than on the context. However, a specific influence of odors on ratings of different facial expressions could be found for both conditions and not only for the social one. This effect could thus not be replicated from Study 2.

Results from psychophysiological measures demonstrated that the influence of odors on the processing of facial expression was larger in the social than in the contextual condition as reflected on electrodermal activity and corrugator muscle activity in Study 2. This demonstrates again that the attribution of hedonic odors to virtual agents led to larger effects of these odors on the processing of facial expressions. However, these results are not consistent on all variables. On electrocortical signals, no effects of attribution were found. The same was true for the breathing volume in Study 2 and heart rate in Study 3 and 4. Attribution did not, in any way, influence the effect of odors on social behavior, neither regarding approach/withdrawal behavior in Study 2 and Study 3 nor economic decision making in Study 4.

To conclude, I demonstrated that attributing an odor to a social source strengthens the influence of odors on the processing of social stimuli and their evaluation. However, this effect of odor attribution was not consistently found on all variables. This is probably due to some of the variables not being sensitive to the attribution manipulation, which was realized in a cognitive manner. It could thus be possible that the effect of odor attribution mainly shows on variables that are manipulated top-down rather than bottom-up (like the ratings).
Whether the influence of odors on social interaction is additionally mediated by the affective state evoked by the odors, cannot be answered by the present data. In order to disentangle the influence of odor from the affective state, it would have been interesting to conduct a study with two additional conditions where the positive or negative emotional state are differently induced (e.g., by means of video clips). This would have enabled me to quantify the influence of affective state on social behavior and preferences per se and to contrast it with the influence of smells. However, the question remains whether this would make sense with respect to ecologic validity and the nature of olfactory stimuli. It is totally natural that the direct influence of emotional stimuli and the influence that is mediated via the affective state are hard to disentangle. In fact, when confronted with a bad smelling person, one would want to keep distance to this person for different reasons. First of all, unpleasant smells may suggest potential damage to the organism (like poisoning) and consequently tend to be avoided (Auffarth, 2013). Second, unpleasant smells indicate bad hygienic habits, low socioeconomic state, etc. and could therefore be avoided. Third, the negative state evoked by unpleasant smells (Croy et al., 2011; Ekman et al., 1969) may also be preferentially avoided. The two ways of influence (i.e., direct and affectively mediated) are therefore interdependent and together constitute the nature of olfactory experiences in social context.

6.3 Influencing Factors

The present thesis additionally examined some potential mediating factors on the influence of odors on social preferences and behavior, among them social anxiety. Social anxiety has been found to evoke higher arousal ratings in all studies throughout the thesis. This seems logical as social anxiety is characterized as a personality trait associated with fear to be exposed to other persons (American Psychiatric Association, 2000). Exposure to social stimuli is a common feature in all studies.

Moreover, this effect can be used as manipulation check of the social anxiety manipulation and supports its internal validity. I performed a median split of a non-social phobic sample. Even though HSA participants of the present studies were not socially phobic, they were socially anxious enough to show enhanced subjective arousal when exposed to social stimuli. However, these effects were not reflected on physiological measures of autonomic arousal like electrodermal activity. On heart rate change, the effect that was found in the whole group, i.e., stronger heart rate acceleration in late processing stages for pleasant than for unpleasant odors during approach to the agents, was especially pronounced in the group of HSA participants. This effect extends what has already been found in a large body of literature, i.e., enhanced responsiveness of HSA participants in response to social stimuli (Mogg & Bradley, 2002). This has been shown on the behavioral (Garner et al., 2006; Wieser, Pauli, Grosseibl et al., 2010) as well as the physiological level (Adolph & Pause, 2012; Wieser et al., 2012). Besides these two results, effects concerning social anxiety lack consistency throughout the different studies of the thesis. Apart from heart rate, no physiological or behavioral measures were influenced by social anxiety. Concerning verbal reports, only some of them showed an interaction with social anxiety, but all of the effects reflected higher responsiveness of HSA participants compared to LSA ones. Surprisingly, no effect of enhanced conditionability could be shown as has been demonstrated by Lissek et al. (2008), for example. However, there are other studies that did not find such an effect of enhanced conditionability with odors as USs (Hermann et al., 2002). In sum, it can be argued that social anxiety has an influence at least on some variables, but not all of the measures seem to be sensitive enough to display it.

A second variable that was taken into account with respect to the present data was the awareness of the contingency. It was measured between agents/rooms and odors in Study 2 to 4 or between odor and US in Study 1 respectively. Awareness was meant to reflect the participants' capacity to learn and has been shown to effect learning in previous conditioning studies (Hamm & Weike, 2005; Lovibond & Shanks, 2002; Wardle et al., 2007). In Study 1, ratings of anxiety and contingency mainly confirmed the manipulation. As the aware vs. unaware group were divided with respect to contingency ratings, it is not surprising that they showed a significant difference concerning these ratings with respect to the groups. Moreover, it was demonstrated that aware participants displayed a difference in anxiety ratings between the two odors, whereas unaware participants did not.

In the following, effects of awareness were mainly found on rating data in Study 2 and 3. However, the effects that were found consistently displayed greater responsiveness in aware than in unaware participants. This was found for valence ratings in both studies. Aware participants rated agents in combination with the pleasant odor as more pleasant than in combination with the unpleasant odor, whereas for unaware participants, no difference was found. The same pattern was found on homelikenes ratings, while on sympathy and arousal, it was not. Heart rate changes on the contrary were consistently modulated by contingency awareness. Heart rate acceleration in response to the pleasant odor compared to the unpleasant one was only found in aware participants and only in the social attribution block. This result underlines both the importance of the attribution of the smell to the social agent and the influence of contingency awareness on the physiological results. Apart from heart rate, none of the physiological or behavioral measures reflected any influence of contingency awareness. This is similar to the results found for social anxiety. As social anxiety and awareness were not correlated, I would rather assume the variables not being sensitive for effects of mediating variables than both reflecting the same null-effect. It could thus be shown that the awareness of contingency has an effect at least on some of the evaluated variables and above all on rating data. This makes sense as rating data are highly subjective. Participants were most probably aware of what they were rating when they gave their evaluations. It seems therefore logical that the awareness of the odor which the agent/room had been paired with has an influence on this rating. This somehow contradicts the results that were obtained by Li et al. (2007). They demonstrated a larger influence of hedonic odors on face evaluation if participants did not consciously perceive the odor. The effect even vanished with participants detecting the odor. This has been interpreted as a compensatory top-down mechanism (Li et al., 2007). However, as in the present data, odor concentration lay high above the detection threshold, all of the subjective ratings were most likely influenced by a top-down rather than bottom-up mechanism, and an effect of unconscious perception could not be found. A second hypothesis on why results were strongest on rating data is that during the ratings, no odors were presented. The hedonic tone of the ratings therefore highly depended on whether participants learned the relationship or not. On the other hand, during physiology recording, odors and agents/rooms were always presented together. As odors are found to unfold their influence at least partly without the perceiver being conscious of it (Badia et al., 1990; Schredl et al., 2009), it probably did not have great importance for the physiological variables whether participants consciously learned the relationship or not.

6.4 Limitations

While the influence of odor on the processing and the evaluation of social stimuli was successfully investigated on different variables and in two different paradigms and the impact of the attributional direction was taken into account, there are some limitations that need to be discussed.

The inclusion of only female participants constitutes a potential lack of generalizability. Gender constitutes an influencing factor with respect to both face processing and olfactory perception.

Women outperform men in all kinds of smell tasks (Brand & Millot, 2001; Seubert et al., 2009), and this difference is even reflected in central nervous activity (Royet et al., 2003). However, I decided for a completely female sample in order to keep the paradigm as simple as possible and to obtain results which are as clear as possible. Moreover, this was due to practical reasons as samples were collected among psychology students, the majority of whom are female. Apart from that, gender (of both, participants and stimuli) would have constituted an interesting additional influencing factor but it would most likely have overloaded the already quite complex statistical calculation. With respect to face processing, it was shown before that the largest effects for angry facial expressions were found if stimulus material displayed male persons and participants were female (Hess, Adams, Grammer, & Kleck, 2009; Hess, Adams, Kleck, & Philippot, 2007). In Study 1, I decided to use pictures of female participants in order to avoid effects that were due to a potentially threatening character of the stimulus material, as the study aimed at depicting the threatening character of the smells and not the facial stimuli. However, results on both physiological and rating data, as long as they were comparable, were similar in both paradigms. At least gender of the stimulus material seems therefore not to have that much of an influence on the results. Nonetheless, the present results are not totally generalizable to all humans, as they concentrate on a specific sample of participants and a specific choice of stimuli. It should be the subject of future research to replicate the present findings with both male participants and female virtual agents. The inclusion of female participants poses another problem. The menstrual cycle of female participants can influence both emotional processing (Merz et al., 2012) and olfactory sensitivity (Pause et al., 1996; Renfro & Hoffmann, 2013), and the intake of oral contraceptives also unfolds its influence (Merz et al., 2012). It would have been fortunate to collect information about participants' menstrual cycle in order to either include it as a potential mediating variable or to at least make sure that participants in different luteal phases are distributed equally throughout the groups. Nonetheless the same argument as for the gender problem also holds true for this approach. An additional factor would most likely have overloaded the statistical paradigm. Moreover, as results from the between-subjects approach resemble the results from the within-subjects approach where no effects of the mediating variable should be visible, the influence of different luteal phases is most likely balanced across participants of different groups.

The question of conscious processing has been the subject of many studies in the history of smell research. Odors have been demonstrated to unfold a large part of their influence without the recipients' awareness. Li et al. (2007) even claimed the influence of odors on social preferences to vanish if they are consciously perceived. Other studies demonstrated the importance of awareness of odor pleasantness in olfactory hedonic influence (Bensafi et al., 2002b). Knasko (1995) even stated that only the possibility that a pleasant odor could be present already approved affective state. Top-down processing of odor hedonicity therefore seems to have a strong impact on affective odor properties. In the present studies, odors were rated before the start of the experiments (apart from Study 4). This could have influenced olfactory processing and provoked effects that are not due to hedonic properties of the smells but to semantically or affectively related activations in the brain. However, wanting to control that participants really perceived the pleasant vs. unpleasant odors as such, there is no real alternative for this approach. If I had had participants rate the odor at the end of the experiment, habituation effects could have biased hedonic evaluation. Habituation throughout repeated administration of odors has been demonstrated before (Boesveldt, Haehner, Berendse, & Hummel, 2007; Flohr et al., 2015). Moreover, results from Study 4 replicate the results from Study 3 with respect to odor valence, even though odors were rated before the experiment in Study 3 but not in Study 4. Nonetheless, this drawback should be controlled for in future studies.

Results on the psychophysiology did not show consistent results with respect to every measure and each of the hypotheses. This is most probably due to the high amount of noise that is naturally found in physiological measures on the one hand. On the other hand, a closer look has to be taken on the results of facial EMG. Facial mimicry could only partly be shown on activation of the corrugator muscle. Activity potentiation in response to an angry facial expression was not found. This was true for static pictures and dynamic virtual agents all the same. However, in response to virtual agents, at least relaxation of the corrugator muscle in response to happy facial expressions was observed. The lack of effects in response to angry faces could be due to different reasons. First of all, it would be possible that the facial stimuli were just not strong enough to evoke muscle activity potentiation. Still, this does not seem very likely as effects as expected were found on other variables (i.e., the LPP, ratings, SCL), and corrugator activity effects were lacking for both facial pictures and dynamic scenes. What seems more plausible is a confusion of two different effects that could have shown on the corrugator muscle. It is used as both a measure of negative affective state (Cacioppo et al., 1992) and a measure of facial mimicry (Dimberg & Thunberg, 1998). With respect to the present paradigms, I expected the corrugator to reflect both enhanced general activity and decreased mimicry in response to the presentation of an unpleasant odor, while for the presentation of the pleasant odor, I expected the opposite pattern. These two effects could easily influence each other while both effects would be averaged out. Additionally, odor presentation would most likely provoke a sniffing response in participants, especially as they were instructed to inhale through the nose. Sniffing provokes activation of both the *musculus levator lavii* and the *musculus corrugator supercilii*. And finally, one has to take into account that at least in the second study, the head-mounted display was fixed on participants' foreheads. All of these factors could have decreased flexible contraction of the

corrugator muscle and could be the source for the somewhat inconsistent results I found. This issue should be taken care of in future studies on the same topic.
Another confusing result that was found in Study 2 was the consistently higher general activation in the contextual group. Still, this is most probably a physical effect, as it was found on all physiological variables and not reflected on either subjective ratings or behavioral variables. Moreover, it was not found in Study 3 and 4 where the two attribution conditions were manipulated within-subjects. In Study 2, the two groups were investigated one after another. The main effect of group that was found could therefore easily be due to hardware changes or seasonal effects. However, this should be monitored in future research.

It would have been desirable to be able to disentangle the results that I found on the heart rate from the pattern of breathing volumes. As both variables display the same characteristic of smells, namely the valence dimension, this shortcoming is hard to avoid. Nonetheless, as the heart rate data were recorded while participants were approaching virtual agents and as it is mediated by social anxiety, I argue that it is at least socially mediated and not exclusively caused by physiological variations. Unfortunately, I collected heart rate data in Study 3 and Study 4, while the breathing volume was investigated in Study 2. In future studies, it would be appropriate to collect both in the same sample in order to be able to calculate covariation analyses.

Finally, some shortcomings in the virtual reality are observable. The VR I used was not stereoscopic and perspective adaptation was not performed. This was done to make sure that participants kept their head fixed on the virtual agents. Nonetheless, immersion in the VR suffered from these deficiencies. It was demonstrated before that VR experiments gained from perspective adaptation and 3D presentation of the virtual environment (Peperkorn, Diemer, & Mühlberger, 2015). Experiments in VR have been found to evoke higher presence in the virtual environment when being conducted with stereoscopic vision (Peperkorn et al., 2015). Ratings of presence in the studies I performed were rather low. Higher immersion could have led to more pronounced effects of the social encounter and would be a suitable upgrade for the use of this ecologically valid and highly controllable experimental setup.

6.5 Summary and Outlook

The present thesis aimed at investigating the influence of unpleasant in contrast to pleasant odors on the processing of social stimuli as measured with different subjective, physiological, and behavioral variables. Additionally, it was explored whether the attribution of a smell as exuding directly from a social agent in contrast to its attribution to the environment made a difference for results of social behavior and preferences. This was achieved by creating two different paradigms. In a first study, I successfully demonstrated olfactory context conditioning by pairing a previously neutral odor with an anxiogenic unconditioned stimulus. This in turn led to evaluation of this odor as more anxiogenic, arousing, and less pleasant than an additional odor which remained unpaired. In a second step, pictures of angry, neutral, and fearful faces were presented within these conditioned odors. The anxiogenic contextual odor led to a more pronounced processing of facial stimuli as reflected on electrophysiological measurements and ratings than the safety odor. Aside from this general effect of learned hedonic odors, a differential influence on different facial expressions was observed. Angry facial expressions as compared to neutral and fearful ones are additionally boosted when presented within the threatening olfactory context.

A second paradigm was established in VR in order to disentangle the influence of odor deriving from a virtual social partner from that deriving from the virtual room (i.e., context) where the interpersonal exchange took place. This approach was mainly chosen because of the odors influencing social interaction parameters but also being potential inducers of affective states. It was therefore proposed that the influence of odors on social interaction could be mediated by affective state. The second paradigm was chosen in order to enlighten this matter and was tested on three consecutive studies applying different variables. In contrast to the first paradigm, this second paradigm applied initially pleasant vs. unpleasant odors as was ensured by a pilot study on odor hedonics (see Annex). I demonstrated preferential processing of social agents when an unpleasant compared to a pleasant odor was presented. This effect was reflected on electrocortical potentials, electrodermal activity, heart rate, subjective ratings, and approach as well as money distribution behavior. Next to this general effect of unpleasant odor, a specific influence of the odors on emotional facial expressions performed by virtual agents was observed on sympathy ratings, electrodermal activity, and facial mimicry. Notably, the general effect of the unpleasant vs. pleasant odor was comparable between the two paradigms, with enhanced processing of social stimuli when an unpleasant odor was presented. However, the two different procedures led to opposite effects regarding the influences of odors on emotional facial expressions. While the threatening odor in Study 1 resulted in more pronounced differences between facial expressions, the unpleasant odor of Study 2 and 3 led to a flattening of the differences between facial expressions compared to the pleasant one. This was probably due to the different olfactory paradigms or to odors evoking especially anxiety in Study 1 and a more generally unpleasant affective state in Study 2 to Study 4. With respect to the different attributions of odor origins, I showed that the social attribution of an odor resulted in larger effects of the pleasant vs. unpleasant odor presentation. This was, however, only shown on some variables (electrodermal activity, facial mimicry, ratings of sympathy, and homelikeness). Effects in this regard thus seem to be small and not very consistent. It can be argued that part of the influence of smells on social preferences and behavior might be mediated by affective state, while part of it is directly transferred from odors to social variables.

To put it in a nutshell, I demonstrated a more pronounced influence of hedonic odors on the processing of social cues when odors were attributed to the social counterpart than when contextually present. Whether this is due to the influence of odors on social interaction being a direct one or rather transmitted via affective state of smell perceivers cannot be answered by the present paradigms. It is most probably an interplay of both factors operating in this regard. This seems logical as odors have been shown to be both potent generators of affective states and influencing factors in social interactions. Nonetheless, the two paradigms both constituted new procedures in smell research. The context conditioning procedure has been successfully applied to the domain of olfactory contexts. The VR paradigm constitutes a successful advancement of studies on olfaction and social interactions and combines olfactory environmental influences and social chemosignals. The potential of these paradigms should be further developed and adapted to future research projects.

The present thesis demonstrated a – weak but nonetheless observable – influence of social anxiety on the results of odor presentation. So far, no studies have explored the influence of social anxiety on olfactory perception, let alone the influence of odors on social interaction parameters. The influence of some mental disorders is documented more extensively. An impact of major depression has long been the subject of different research projects (Croy et al., 2014; Pause et al., 2003; Pause et al., 2001). In the present thesis, the influence of social anxiety has been explored by performing median splits in a non-phobic population. The groups differed with respect to social anxiety as measured by a questionnaire, but nonetheless, most test values grouped around the median. The use of extreme groups or even a patient sample with social phobia could lead to more pronounced results with respect to this personality trait. Moreover, both depression and social phobia are disorders that are accompanied by interpersonal problems. The application of the present paradigm a patient samples could lead to a more profound understanding of the interplay of olfaction and social factors. Above all, including a patient group with social phobia in the paradigm of the first study could show interesting results, as there might be interactions between both the context conditioning procedure with the use of female screams as USs and the olfactory impact on face processing.

Another variable that would be worth taking a closer look at is the notion of subliminally presented odors. Li et al. (2007) found a larger effect of hedonic odors on social preferences when participants were not able to consciously detect the odors. The effect even disappeared when they detected a smell. This is interpreted as a compensatory top-down mechanism. I assume that in the present experiment, I did not find such a compensatory mechanism as most of the effects seem to be mediated top-down rather than bottom-up. This is supported by the fact that effects are stronger in participants that were aware of the contingency between odors and virtual agents. The question whether contingency awareness is a necessary requirement for successful learning has received a lot of attention in the past years. Even though results are still discussed controversially, there is support for the notion of mediation of affective learning by contingency awareness (Hamm & Vaitl, 1996; Hamm & Weike, 2005). However, it would be interesting to pursue this research question by conducting studies in the same paradigm presenting odors in concentrations that vary around the detection threshold. This approach would be able to shed light on the role of conscious odor perception in the olfactory influence on social interaction. Possibly, similar effects to the present ones would be found with subliminal odor presentation on physiological variables, as they are by any means processed unconsciously. However, results from the subjective ratings and behavioral data would most probably vary with manipulation of odor consciousness.

Besides the concept of odor consciousness, the question of odor associability also deserves a closer look. There are contradictory results with regard to this variable. Todrank et al. (1995) only performed successful olfactory conditioning when odors were easily associable with social agents. Nonetheless, Dematte et al. (2007) did not find any effect in the same regard. The theory refers to the concept of *preparedness* as suggested by Seligman (1971) in phobia acquisition. He proposes that phobias are more easily achieved by some stimuli than others, depending on their potentially harmful character. Similarly, in olfactory conditioning studies of social stimuli, some odors should be more easily associated with human beings than others. This has also been referred to as *belongingness* in fear conditioning studies (Hamm et al., 1989). However, the semantic matching between social agents and the used odors could easily be manipulated as an additional factor in the present paradigm and could lead to a more profound understanding of olfactory learning in social context.

Finally, it seems very tempting to apply both paradigms with the presentation of stress vs. sport sweat. These body odors have been demonstrated to evoke affective states in a very distinct way (Adolph & Pause, 2012; Adolph et al., 2010; Prehn-Kristensen et al., 2009; Rubin et al., 2012). This approach would constitute an interesting extension of the second paradigm by evoking a distinct affective state of anxiety instead of the rather vague unpleasant feeling evoked by unpleasant odors. It would also fit very well in the first paradigm as an external validation of the olfactory context conditioning procedure in order to compare results of both approaches. In terms of preparedness learning, it would also be promising to apply an olfactory context conditioning procedure to already affect-loaded stress chemosignals.

In sum, the potential of the paradigms I developed has not been fully exploited. They could be further extended with regard to other dependent and independent variables to extensively investigate the impact of this underinvestigated sense on daily life matters. Moreover, it would be interesting to compare the impact of olfactory stimuli with stimuli from other sensory domains in order to shed additional light on the broad field of emotional experiences. Apart from this, the impact of pleasant odors on social interaction could be of use in the therapeutic progress of mental disorders. As the relationship between patient and therapist is one of the most important parameters of therapeutic success (Rudolf, Grande, & Porsch, 1988), ambient odors in therapeutic context could be used to improve this relationship or the bonding between patient and therapist. This thesis approached this topic from a perspective that has not been taken very frequently. By following one's nose, insights into the domain of human emotional processing can be achieved.

7 References

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8 Annex

A Pilot Study

B Pictures of Agents, Rooms, and Emotional Expressions

C Contingency Ratings

D Overview Over Balancing Strategies

E Instructions

F Sociodemographic Questionnaire

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A Pilot Study: On the Challenge to Find Pleasant and Unpleasant Smells

Introduction

Preferences for smells are highly individually different. Although some of them might be innate, they depend on personal learning history (Ayabe-Kanamura et al., 1998; Rouby et al., 2009; Schaal et al., 2000). Babies do not differ in their preferences as much as adults do, even though they are able to discriminate between smells (Engen, 1973), indicating the importance of experience-based preferences. Apart from hedonic evaluation, odors can differ with regard to the proportion of trigeminal vs. olfactory processing of the odor (Boyle et al., 2007). While some substances are processed almost exclusively via the olfactory system, the tactile stimulation that is processed via the trigeminal nerve (like cold or itching sensations accompanying some odorous substances) adds substantially to the olfactory percept and the related processing.

The present pilot study was conducted in order to find odors which are evaluated as pleasant or unpleasant respectively for a majority of participants. The following paradigm was planned to have four conditions (two odors: pleasant vs. unpleasant, and two attributions: social vs. contextual).

Valence and arousal ratings were collected in order to span the emotional space as proposed by Russell (2003). Intensity ratings were additionally collected, even though arousal ratings and intensity ratings of odors are highly correlated (Engen, 1973). Intensity and valence are often used in order to describe the hedonic characteristics of odors (Smeets & Dijksterhuis, 2014). Skin conductance level was collected as it constitutes an objective measure of the arousal/intensity domain (and is easy to record).

Methods

Participants

Fifteen undergraduate students (6 males and 9 females) from the University of Würzburg participated in the pilot study. Their age ranged from 19 to 29 years (*M* = 24.27; *SD* = 3.58). Two participants reported occasional smoking habits. They rated their smelling abilities on average (on a scale from 0 "*no smelling abilities*" to 7 "*very good smelling abilities*" with 4 being anchored with "*normal*"; *M* = 4.07; *SD* = 0.46).

In the Screening Version of the Sniffin' Sticks test battery (Hummel, Konnerth, Rosenheim, & Kobal, 2001b), all participants reached a minimum score of 9 right answers (out of 12). On average, they reached a score of *M* = 10.21 (*SD* = 1.05).

Odors

Seven odors were chosen from former studies on hedonic values of smells (Adolph & Pause, 2012; Bensafi, M. et al., 2002a; Gottfried et al., 2002a) or personal recommendations (Hummel, personal communication, 2013; Pause, personal communication, 2013): Isobutyraldehyde (IBU), Isocaproic Acid (ICP), "Animalis" (ANI; a mixture mixed by Fragrance Resource, Hamburg, Germany; Civette Base 847), Menthol (MEN), Isoamylacetate (IAM), Eucalyptol (EUC), and CItral (CIT). All substances were diluted in propane-1,2-diol at the solution ratio proposed in the above mentioned literature or communications. For used solution ratios, literature references and verbal labels of the used substances see Table 6.

Two different concentrations were used in the present study: 20% of odorous air vs. 90% of odorous air (and 80% vs. 10% clean room air respectively). The use of 7 substances in 2 concentrations added up to 14 conditions.

Table 6: Used substances with reference of origination, applied solution, and supposed hednonics ("unpl". meaning unpleasant and "pl." meaning pleasant)

Substance	Solution ratio	Source	Smell	Hedonics
IBU	1/30	(Adolph & Pause, 2012)	"Chemical"	Unpl.
ICP	5%	(Gottfried et al., 2002a)	"Sewer"	Unpl.
ANI	1.65%	(Hummel, personal communication, 2013)	"Dung"	Unpl.
MEN	150mg/5ml	(Bensafi, M. et al., 2002a)	"Menthol"	Pl.
IAM	1/100	(Bensafi, M. et al., 2002a)	"Gummy bears"	Pl.
EUC	1/100	(Bensafi, M. et al., 2002a)	"Eucalyptus"	Pl.
CIT	5%	(Pause, personal communication, 2013)	"Lemon"	Pl.

Procedure

When participants arrived in the laboratory, they were required to wash their hands in lukewarm water and without soap. They then filled in the informed consent form and underwent olfactory testing (Hummel et al., 2001a). An inclusion criterion of 9 out of 12 correct answers was set for the latter in order to ensure at least average smell abilities in all of the participants. After having filled in a sociodemographic questionnaire, they entered the cabin where the olfactometer and the experimental screen were placed and electrodes for electrodermal measurement were fixed to their non-dominant hand. They were placed comfortably in front of a screen (distance approximately 80 cm), and the breathing mask was fixed over their mouth and nose. For presentation of inhalation commands and the odors, the software Presentation (Neurobehavioral Systems, Inc.) was used.

The experiment consisted of 14 trials (7 substances x 2 concentrations) that appeared in a pseudo-randomized order, meaning that the same odor was never presented twice in a row. One trial comprised an exhalation and an inhalation phase (Figure 29). The exhalation phase was announced by the appearance of the word "exhale" written in white (font size 100) in the middle of the black screen. It lasted for 3000ms. After 1500 ms, the olfactometer was opened and odorous air was released into the breathing mask, as the rising time of the odorous air in the mask is about 1500 ms. The inhalation phase was signaled by a picture of a nose (6.10 x 8.53 cm, subtending a horizontal visual angle of 4.37° and a vertical angle of 6.10°) and lasted for 6000 ms. Afterwards, the odor presentation stopped.

This was followed by the presentation of three Likert scales ranging from 1 to 9 that assessed valence (from "*unpleasant*" to "*pleasant*"), arousal (from "*calm*" to "*aroused*"), and intensity (from "*not intense at all*" to "*very intense*"). These scales were always presented in the same order. Participants indicated their ratings by pressing the buttons from 1 to 9. The scale vanished afterwards. This part was followed by an ITI of 20000 ms indicated by a black screen, and a new trial began. For a schematic overview of one trial of the pilot study, see Figure 29.

After the last trial, participants had the breathing mask and the electrodes removed and were released from the experiment. The whole procedure lasted about half an hour. Participants received credits for their study program as reimbursement for their participation.

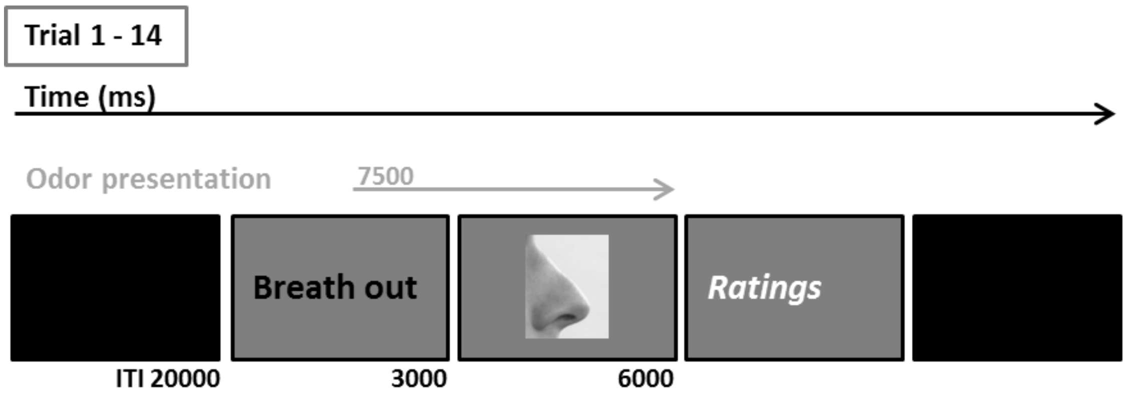


Figure 29: One trial of the pilot study. After the odor presentation, ratings of valence, arousal, and intensity were collected. ITI = Inter-trial Interval.

Physiological Measurements

Electrodermal activity was measured with two Ag-AgCl-electrodes (diameter 8 mm) filled with 0.05 molar sodium chloride electrolyte gel that were fixed on the thenar and hypothenar eminences of the non-dominant hand. The signal was recorded using the software Vision Recorder 1.20 (BrainVision, Munich Germany).

Data Preprocessing and Statistical Analysis

The skin conductance level was preprocessed using the software Vision Analyzer 2.0 (BrainVision, Munich, Germany). A low cutoff filter of 0.1 Hz, a high cutoff of 35 Hz, and a notch filter of 50 Hz were applied to the data. A baseline correction of 1000 ms before stimulus onset was applied. Mean skin conductance level was then exported for each concentration (20% vs. 90%) and each stimulant separately. Raw data were added 1 and logarithmized afterwards.

Malfunctioning of the olfactometer led to single missing data (in total 4 odors over all participants were not delivered, so 12 ratings were not filled in, and additionaly 2 cells were missing for SCL data). These single misses were replaced by the means of the respective odor and concentrations by all participants.

The software SPSS (Version 21, IBM Corp., Armonk, NY, US) was used for statistical analysis. Skin conductance level and ratings of valence, arousal, and intensity were analyzed applying repeated-measures ANOVAs with the within-subjects factors substance (7 levels) x concentration (2 levels). Significant main effects of substance or interactions were further analyzed using post-hoc *t*-tests. Main effects of substance were explored by averaging values across both concentrations and then comparing mean values of every substance with each other. However, this was only performed if the interaction did not reach significance, as the goal of the study was to explore the effect of substance in specific concentrations. Alpha level was set to .05. In case of violation of the sphericity assumption, Greenhouse-Geisser (*GG-ε*)-corrected degrees of freedom were used. Partial η^2 (η_p^2) is reported.

Results

Rating Data

For an overview, mean ratings of valence, arousal, and intensity of all the substances (averaged over both concentrations) are displayed in Table 7.

For the valence ratings, the ANOVA revealed a significant main effect of Substance ($F[6,78] = 18.98$, $p < .001$, $\eta_p^2 = .59$) and a significant interaction of Substance x Concentration ($F[6,78] = 4.54$, $p = .001$, $\eta_p^2 = .26$). The main effect Concentration did not reach significance ($F[1,13] = 1.14$, $p = .305$, $\eta_p^2 = .08$). Post-hoc *t*-tests to compare different substances in the 20% condition revealed that Isobutyraldehyde was rated as less pleasant than all other substances (ICP: $t[14] = 2.17$, $p = .048$; ANI: $t[14] = 2.66$, $p = .019$; IAM: $t[14] = 3.67$, $p = .003$, EUC: $t[14] = 4.25$, $p = .001$; CIT: $t[14] = 3.93$, $p = .001$) but Menthol ($t[14] = 1.90$, $p = .079$). Eucalyptol (ICP: $t[14] = 3.81$, $p = .002$; ANI: $t[14] = 3.69$, $p = .002$; MEN: $t[14] = 4,82$, $p < .001$; IAM: $t[14] = 3.51$, $p = .003$) and Citral (ICP: $t[14] = 2.75$, $p = .016$; ANI: $t[14] = 2.21$, $p = .044$; MEN: $t[14] = 3.40$, $p = .004$; IAM: $t[14] = 2.36$, $p = .033$) were rated as more pleasant than all the other substances, while they did not differ from each other ($t[14] = 1.74$, $p = .104$). All the other substances did not show any significant difference in valence ratings (all *p*s > .111).

Additionally, in the 90% condition, Isobutyraldehyde was rated as less pleasant than all other substances (ICP: $t[14] = 3.35$, $p = .005$; MEN: $t[14] = 4.63$, $p < .001$; IAM: $t[14] = 3.96$, $p = .001$, EUC: $t[14] = 9.27$, $p < .001$; CIT: $t[14] = 8.13$, $p < .001$) but Animalis ($t[14] = 1.77$, $p = .098$). Animalis was rated less pleasant than Menthol ($t[14] = 3.01$, $p = .009$). Eucalyptol (ICP: $t[14] = 7.34$, $p < .001$; ANI: $t[14] = 7.06$, $p < .001$; MEN: $t[14] = 5.39$, $p < .001$; IAM: $t[14] = 3.92$, $p = .002$) and Citral (ICP: $t[14] = 5.62$, $p < .001$; ANI: $t[14] = 4.54$, $p < .001$; MEN: $t[14] = 2.82$, $p = .014$; IAM: $t[14] = 3.86$, $p = .002$) were rated as more pleasant than all the other substances, while they did not differ from each other ($t[14] = 1.33$, $p = .208$). All the other substances did not show any difference in valence ratings (all *p*s > .257).

On the level of substances, the 20% concentration was rated as more pleasant than the 90%

concentration only for Animalis (t[14] = 4.58, p < .001). For all the other substances, the two concentrations did not differ from each other (all ps > .119).

For arousal ratings, the ANOVA returned a significant main effect Substance (F[6,78] = 4.86, p < .001, η_p^2 = .27). The main effect Concentration (F[1,13] = 3.28, p = .093, η_p^2 = .20) and the interaction (F[6,78] = 1.13, p = .350, η_p^2 = .08) did not turn out significant. The main effect of Substance returned that Isobutyraldehyde was rated as more arousing than all the other substances (ICP: t[14] = 4.08, p = .001; ANI: t[14] = 2.71, p = .017; MEN: t[14] = 3.89, p = .002; IAM: t[14] = 2.88, p = .012; EUC: t[14] = 4.39, p = .001; CIT: t[14] = 2.64, p = .020). Moreover, Eucalyptol was rated as less arousing than Isoamylacetat (t[14] = 2.53, p = .024) and Citral (t[14] = 2.31, p = .036). All the other substances did not differ significantly from each other according to perceived arousal (all ps > .089).

Intensity ratings revealed significant main effects for Substance (F[6,78] = 53.42, p < .001, η_p^2 = .80) and Concentration (F[1,13] = 10.55, p = .006, η_p^2 = .45) and a significant interaction (F[6,78] = 5.23, p < .001, η_p^2 = .29). Post-hoc t-tests of the interaction revealed that in the 20% concentration, Isobutyraldehyde was rated as more intense than all the other substances (ICP: t[14] = 9.11, p < .001; ANI: t[14] = 6.79, p < .001; MEN: t[14] = 11.12, p < .001; EUC: t[14] = 3.44, p = .004; CIT: t[14] = 4.23, p = .001) but Isoamylacetat (t[14] = 1.73, p = .105), followed in intensity by Isoamylacetat that was rated more intense than all remaining substances (ICP: t[14] = 6.55, p < .001; ANI: t[14] = 6.17, p < .001; MEN: t[14] = 10-08, p < .001; CIT: t[14] = 3.17, p = .007) but Eucalyptol (t[14] = 1.50, p = .156). Eucalyptol was rated as more intense than all remaining substances (ICP: t[14] = 7.26, p < .001; ANI: t[14] = 5.20, p < .001; MEN: t[14] = 7.46, p < .001) but Citral (t[14] = 1.94, p = .073). Additionally, Menthol was rated less intense than Animalis (t[14] = 2.46, p = .027) and Citral (t[14] = 5.02, p < .001) that was itself rated as more intense than Isocaproic acid (t[14] = 3.13, p = .007). All other substances did not differ from each other in perceived intensity (all ps > .109).

In the 90% concentration, Animalis was rated as more intense than Isocaproic acid (t[14] = 7.47, p < .001), which was rated as more intense than Menthol (t[14] = 2.69, p = .018). Moreover, Isobutyraldehyde (ICP: t[14] = 12.35, p < .001; ANI: t[14] = 6.00, p < .001; MEN: t[14] = 16.91, p < .001), Isoamylacetat (ICP: t[14] = 8.20, p < .001; ANI: t[14] = 3.51, p = .003; MEN: t[14] = 13.22, p < .001), Eucalyptol (ICP: t[14] = 8.26, p < .001; ANI: t[14] = 3.64, p = .003; MEN: t[14] = 11.22, p < .001), and Citral (ICP: t[14] = 8.06, p < .001; ANI: t[14] = 3.75, p = .002; MEN: t[14] = 11.15, p < .001) were all rated as more intense than the three other substances, but they did not differ from each other (all ps > .127).

The 90% concentration was rated as more intense than the 20% concentration when being stimulated with Animalis (t[14] = 3.28, p = .005), Citral (t[14] = 3.73, p = .003), and Eucalyptol (t[14] = 5.44, p < .001). For all other substances, concentrations did not differ from each other (all ps > .181).

Table 7: Mean ratings (SD) of valence, arousal, and intensity for the different odors, averaged across both concentrations. The abbreviation "Unpl." stands for unpleasant odors and "pl." for pleasant odors.

Substance	Supposed hedonics	Valence	Arousal	Intensity
IBU	Unpl.	3.23 (1.43)	4.59 (1.72)	7.70 (0.92)
ICP	Unpl.	4.77 (1.02)	3.46 (1.26)	2.97 (2.17)
ANI	Unpl.	4.70 (1.28)	3.50 (1.43)	4.37 (1.45)
MEN	Pl.	5.10 (0.69)	3.12 (1.47)	1.83 (0.92)
IAM	Pl.	5.20 (1.45)	3.87 (1.32)	7.03 (1.29)
EUC	Pl.	7.10 (1.27)	2.97 (1.29)	6.77 (1.43)
CIT	Pl.	6.83 (1.41)	3.60 (1.54)	6.03 (1.75)

SCL Data

The ANOVA regarding SCL revealed neither significant main (substance: F[6,84] = 1.58, p = .214, η_p^2 = .10, *GG-ε* = .46; concentration: F[1,14] = 0.02, p = .885, η_p^2 = .00) nor interaction (F[6,84] = 0.22, p = .969, η_p^2 = .02) effects.

Discussion

The aim of the pilot study was to identify two pleasant and two unpleasant olfactory substances. Two pleasant odors (i.e., Citral and Eucalyptol) and two unpleasant ones (i.e., Isobutyraldehyde and Animalis) were found. While the pleasant odors were evaluated more positively than the unpleasant ones, no differences in valence ratings were observed when comparing the two odors of the same valence category.

It could be shown that the *mere exposure effect* (i.e., stimuli getting evaluated more positively with repeated presentation) is smallest for very intense unpleasant and very intense pleasant odors (Delplanque, Coppin, Bloesch, Cayeux, & Sander, 2015). Considering that in the main paradigm, odors were to be presented multiple times, extreme concentrations (i.e., 90%) were chosen in order to have participants change as little as possible in their reaction to the odors and also because they displayed clearer differences between the two hedonic contents.

Another advantage of the chosen substances was that two are transmitted rather olfactorily (Citral and Animalis) and two have high trigeminal components (Isobutyraldehyde and Eucalyptol), as Eucalyptol provokes a cold sensation in the nose whereas Isobutyraldehyde provokes a pungent sensation. As one olfactory and one trigeminal substance was evaluated as pleasant and one olfactory and one trigeminal as unpleasant, and as odors were to be balanced over participants and conditions, a hypothetical influence of trigeminal vs. olfactory processing should be controlled.

A drawback of the identified odors is constituted by the difference in intensity ratings between the two unpleasant odors. However, this is not surprising as one is trigeminally processed and provokes a pungent sensation (i.e., Isobutanal) and the other one is not (i.e., Animalis). Trigeminal odors are found to be preferentially processed and rated as more intense (Flohr et al., 2015). As the two odors are meant to be counterbalanced over conditions in the main studies, this potential drawback should be overcome.

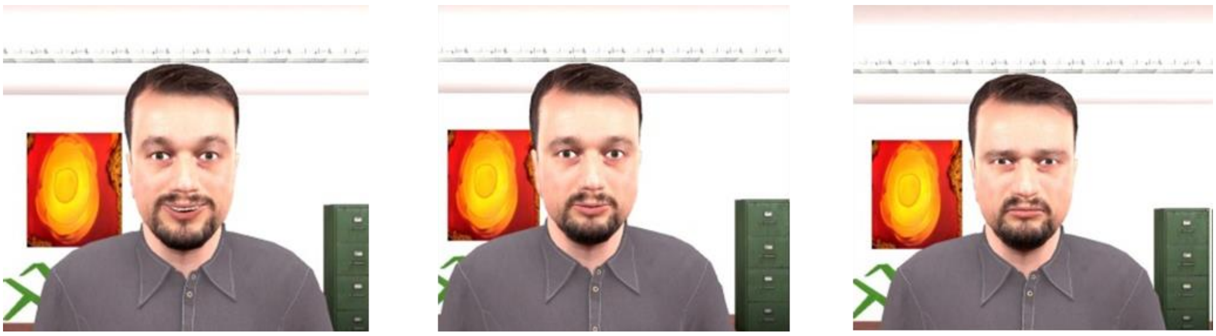
The fact that for SCL data, no results were found is most probably due to the small sample size. The effect size, at least of the main effect of substance, displayed a strong effect. This suggests that given a larger sample size, the difference in skin conductance level could become significant. Moreover, substances were only presented once per odor and condition. Error variance could be minimized by applying more repetitions per condition.

It can be concluded that the pilot study fulfilled its purpose by identifying two odors of each valence category to be applied in the main studies. To control for potential individual differences in preferences for odors, it will have to be made sure that participants perceived odors respectively by collecting subjective ratings when using the hereby chosen smell substances.

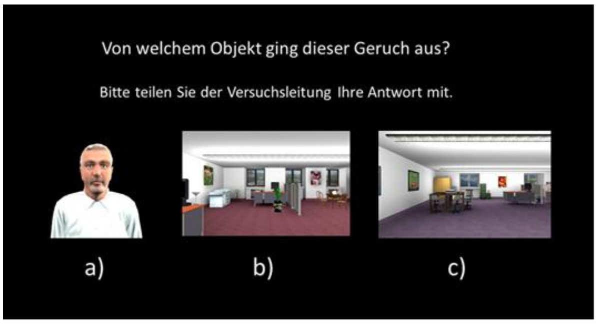
B Pictures of Agents, Rooms, and Emotional Expressions

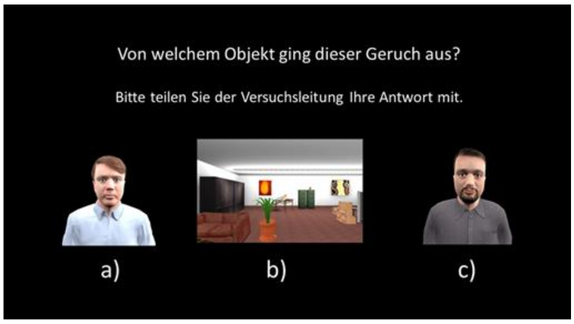
From top to bottom: Agent A, Agent B, Agent C in Room 1, Room 2, and Room 3 (from left to right)

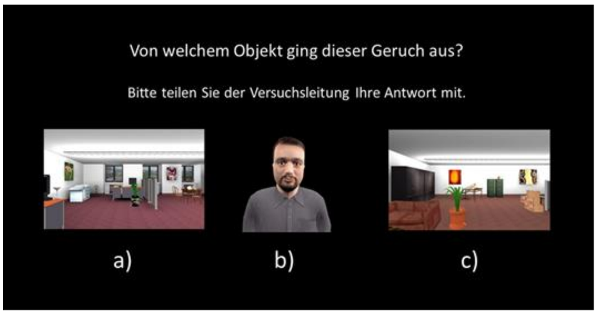
From left to right: happy, neutral, and angry facial expression

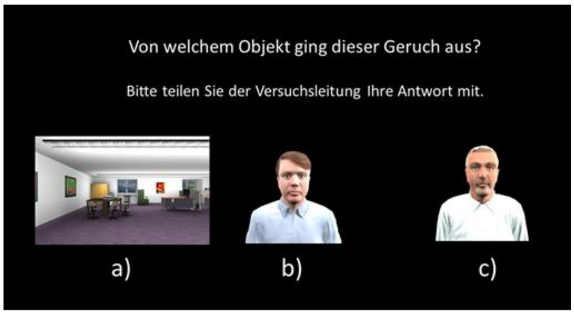


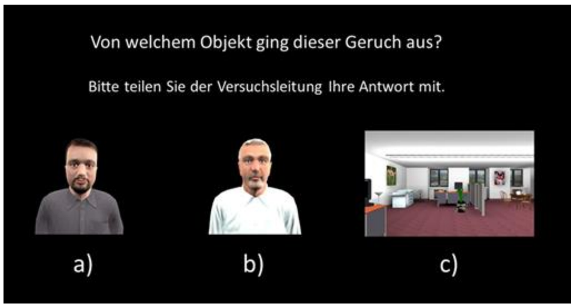
C Contingency Ratings











D Overview over Balancing Strategies

Pilot Study

Seven trial orders were generated randomly. It was made sure that the same odor did not appear twice in a row. See the following arrays for the exact order of appearance, taken out of the presentation file. The numbers 1 and 2, 3 and 4, 5 and 6, 7 and 8, 9 and 10, 11 and 12, 13 and 14 represent the seven odors respectively, while odd numbers represent one concentration and even numbers the other.

array <int> abfolge_1 [14] = {2,5,9,13,3,6,4,14,12,7,11,1,10,8};

array <int> abfolge_2 [14] = {4,13,5,12,2,8,1,10,7,9,6,14,3,11};

array <int> abfolge_3 [14] = {6,14,10,4,7,1,9,11,2,8,12,3,5,13};

array <int> abfolge_4 [14] = {8,12,4,2,10,3,14,11,1,7,9,5,13,6};

array <int> abfolge_5 [14] = {10,3,5,13,4,6,11,7,9,2,8,14,12,1};

array <int> abfolge_6 [14] = {12,2,7,13,1,11,14,6,9,4,8,5,10,3};

array <int> abfolge_7 [14] = {14,7,12,2,4,1,8,11,5,3,9,6,13,10};

Between-Subject Manipulation

Order of trials within the three physiology blocks

1 = unpleasant odor; 2 = pleasant odor; a = happy; b = angry; c = neutral

Trial	A	B	C
1	"1c"	"2b"	"1a"
2	"1b"	"1b"	"1c"
3	"2a"	"2a"	"2b"
4	"2b"	"1b"	"2c"
5	"1b"	"2c"	"1a"
6	"2c"	"1a"	"2b"
7	"2b"	"2b"	"1c"
8	"1a"	"2c"	"1a"
9	"2c"	"1a"	"2c"
10	"2c"	"1b"	"1a"
11	"1a"	"2a"	"2c"
12	"2b"	"1b"	"2b"
13	"2a"	"2b"	"1b"
14	"1c"	"1c"	"2c"
15	"1b"	"2c"	"1a"
16	"2a"	"1a"	"2b"
17	"1b"	"2b"	"2a"
18	"2c"	"1c"	"1c"
19	"1c"	"2b"	"1c"
20	"2a"	"2c"	"2a"
21	"1a"	"1a"	"1b"
22	"2b"	"2a"	"1c"
23	"1c"	"1c"	"2b"
24	"2c"	"1c"	"1b"
25	"1b"	"2a"	"2c"
26	"1a"	"1b"	"1b"
27	"2b"	"2a"	"2a"

28	"1a"	"1c"	"1b"
29	"2a"	"2c"	"2a"
30	"1c"	"1a"	"2a"

Order of trials in the approach session

1 = unpleasant odor; 2 = pleasant odor

X) "1" "1" "2" "1" "2" "2"

Y) "2" "2" "1" "2" "1" "1"

Z) "2" "1" "2" "1" "2" "1"

Description of different versions

Version	**Triallist-order**	**Unpl. odor**	**Pl. odor**	**Agent/room paired with unpl. odor**	**Room in social attribution/ agent in CTX-attribution**	**Trials in approach session**
1a	A-B-C	ANI	CIT	A/1	1/A	X
1b	B-C-A	ANI	CIT	A/1	1/B	Y
1c	C-A-B	ANI	CIT	A/1	1/A	Z
2a	B-A-C	IBU	EUC	A/1	1/B	X
2b	A-C-B	IBU	EUC	A/1	1/A	Y
2c	C-B-A	IBU	EUC	A/1	1/B	Z
3a	A-B-C	IBU	CIT	B/2	1/A	X
3b	B-C-A	IBU	CIT	B/2	1/B	Y
3c	C-A-B	IBU	CIT	B/2	1/A	Z
4a	B-A-C	ANI	EUC	B/2	1/B	X
4b	A-C-B	ANI	EUC	B/2	1/A	Y
4c	C-B-A	ANI	EUC	B/2	1/B	Z

Within-Subject Manipulation

Combinations of odors, agents, and rooms

Odors:

1: ANI – CIT

2: IBU – EUC

3: IBU – CIT

4: ANI – EUC

Rooms-Agents:

	Social	CTX
X)	1, A, B	2, 3, C
Y)	2, B, C	3, 1, A
Z)	3, C, A	1, 2, B

Order of trials within physiology blocks

1 = unpleasant odor; 2 = pleasant odor

Trial	A	B	C	D
1	1	2	1	2
2	2	1	2	2
3	1	2	2	1
4	2	1	1	2
5	1	2	1	2
6	1	2	2	1
7	2	1	1	1
8	1	2	2	2
9	2	1	2	1
10	1	2	1	2
11	2	1	1	1
12	2	2	2	2
13	1	1	2	1
14	2	1	1	2
15	1	2	1	1
16	1	1	2	1
17	2	2	2	2
18	2	1	1	2
19	1	1	1	1
20	2	2	2	1

Order of trials in withdrawal session

1 = a of first block, 2 = b of first block, 3 = a of second block, 4 = b of second block

Trial	**[1]**	**[2]**	**[3]**
1	3	4	3
2	3	3	1
3	2	1	4
4	3	2	1
5	1	3	4
6	4	3	2
7	2	4	4
8	4	4	3
9	1	2	3
10	1	1	1
11	2	2	2
12	4	1	2

Order of facial expressions in ratings

Xa) t0.1	ang - hap - neu;	t0.2 neu - ang – hap;	t1.1 hap - neu – ang;	t1.2 ang - hap - neu
Xb) t0.1	neu - ang - hap;	t0.2 hap - neu – ang;	t1.1 ang - hap – neu;	t1.2 neu - ang - hap
Xc) t0.1	hap - neu – ang;	t0.2 ang - hap - neu;	t1.1 neu - ang – hap;	t1.2 hap - neu – ang

Order of odors in ratings

Xa) ANI – CIT – IBU - EUC

Xb) CIT - IBU - EUC - ANI

Xc) EUC – ANI – CIT – IBU

Description of different versions

Version	Triallist-orders	Odor combi	Agent-room combi	First block	Agent/room paired with unpl. odor	Trials in approach/ratings session
1a	A - B	1-2	X	Social	A/2	Xa
1b	C - D	1-2	Y	CTX	B/3	Xb
1c	B - A	1-2	Z	Social	C/1	Xc
2a	D - C	2-1	X	CTX	A/2	Xa
2b	A - C	2-1	Y	Social	B/3	Xb
2c	B - D	2-1	Z	CTX	C/1	Xc
3a	C - A	3-4	X	Social	B/3	Xa
3b	D - B	3-4	Y	CTX	C/1	Xb
3c	A - D	3-4	Z	Social	A/2	Xc
4a	B - C	4-3	X	CTX	B/3	Xa
4b	D - A	4-3	Y	Social	C/1	Xb
4c	C - B	4-3	Z	CTX	A/2	Xc

E Instructions

Study 2 – 4

To get an idea of the instructions of the attribution manipulation, the exact instructions of Study 4 are presented here. Additionally, the instructions of the rules of the ultimatum game in Study 4 are given.

The following instructions were presented before the start of the experiment in Study 4.

„In diesem Experiment nehmen Sie an einer wirtschaftlichen Verhandlung einige Male teil. Dabei werden sie einem Partner zugewiesen, mit dem Sie interagieren müssen. Ihr Gegenspieler ist in jeder Verhandlung eine andere Person, mit der Sie über das Internet verbunden sind.

Ihre Aufgabe besteht darin, in zwei Phasen mit Ihrem Gegenspieler zu verhandeln, wie 10 Euro zwischen Ihnen beiden aufgeteilt werden sollen. Zuerst schlagen Sie vor, wie die 10 Euro zwischen Ihnen und Ihrem Gegenspieler aufgeteilt werden. Sie können ein Angebot nur einmal machen.

In Ihrem Angebot ist jede mögliche Aufteilung der 10 Euro erlaubt. Wenn Sie sich beispielsweise 4 Euro zuteilen, werden die restlichen 6 Euro Ihrem Gegenspieler zugeteilt. Wenn Sie sich selbst 6 Euro zuteilen, werden die restlichen 4 Euro Ihrem Gegenspieler zugeteilt.

Wenn Sie Ihr Angebot abgegeben haben, bekommt ihr Gegenspieler das Angebot vorgelegt und muss entscheiden, ob er das Angebot annimmt oder ablehnt. Wenn er das Angebot annimmt, werden die 10 Euro entsprechend aufgeteilt. Wenn ihr Gegenspieler das Angebot ablehnt, erhalten Sie und ihr Gegenspieler nichts. Die Verhandlung ist abgeschlossen und ein neuer Durchgang beginnt. Die Durchgänge sind auf eine bestimmte Anzahl begrenzt, so dass der Gewinn jedes einzelnen Durchgangs wichtig für Ihr Endergebnis ist.

In diesem Experiment ist Anonymität gewährleistet. Sie wissen nicht, wer Ihre Gegenspieler sind, und ihre Gegenspieler wissen nicht, wer Sie sind.

Um ein Angebot zu machen, verwenden Sie die Pfeiltasten an der Tastatur. Zu Beginn der Verhandlung liegen 10 Euro auf Ihrem Stapel. Mit einem Druck der Pfeiltaste nach oben legen Sie je einen Euro zu Ihrem Gegenspieler. Mit einem Druck der Pfeiltasten nach unten legen Sie je einen Euro zu Ihnen zurück. Durch einen Druck der Leertaste bestätigen Sie Ihr Angebot. Ihr Angebot muss mindestens einen und kann höchstens 9 Euro betragen. Am Ende der Verhandlung erfahren Sie, ob ihr Gegenspieler ihr Angebot angenommen oder abgelehnt hat.

In diesem Versuch möchten wir den Einfluss von Gerüchen in einem interaktiven PC-Spiel testen. In jedem Teil werden Sie virtuelle Büroräume betreten und mit virtuellen Agenten interagieren. Dort wird auch die Verhandlung über die 10 Euro stattfinden. Das Experiment ist in zwei Teile gegliedert. Für jeden Teil erhalten Sie nochmal eine separate Anleitung.“

The following instructions were presented before the start of each block in Study 3 and Study 4 and before the start of the experiment for one of the two groups in Study 2.

Social attribution:

„In diesem Teil des Experiments betreten Sie einen Büroraum, in dem Sie einen von zwei Agenten antreffen, von denen jeweils ein bestimmter Geruch ausgeht. Die Agenten symbolisieren Ihre jeweiligen Interaktionspartner. Anschließend findet die Verhandlung statt.

Bitte lassen Sie die Gerüche und den Agenten auf sich wirken. Atmen Sie bitte die ganze Zeit tief durch die Nase ein."

Contextual attribution:

„In diesem Teil des Experiments betreten Sie einen von zwei Büroräumen, von denen jeweils ein bestimmter Geruch ausgeht. In den Räumen treffen Sie auf immer denselben Agenten. Er symbolisiert Ihren jeweiligen Interaktionspartner. Anschließend findet die Verhandlung statt.

Bitte lassen Sie die Gerüche und den Agenten auf sich wirken. Atmen Sie bitte die ganze Zeit tief durch die Nase ein."

F Sociodemographic Questionnaire

(Note that the last item, „II PC-Spiele“ was only collected in Study 3 and Study 4)

Bitte kreuzen Sie das entsprechende Kästchen an.

I Allgemeine Angaben

Körpergröße (in cm)________ Körpergewicht (in kg)________ Alter ________Jahre

Geschlecht .... ☐ männlich ☐ weiblich

Händigkeit ....☐rechts ☐links ☐beidhändig

Höchster Berufsabschluss . ... ☐ kein ☐ Hauptschulabschluss ☐ Mittlere Reife ☐ Abitur ☐ Berufsausbildung ☐ Hochschulabschluss

Trinken Sie **Alkohol**?
☐ nein
☐ ja ☐ gelegentlich ☐ regelmäßig ca. ……….Gläser/Woche

Rauchen Sie?
☐ nein, noch nie
☐ nein, nicht mehr seit .... Jahren
☐ ja seit .... Jahren ca. ……….Zigaretten/Tag

Trinken Sie **Kaffee**?
☐ nein
☐ ja ca. ……… Tassen/Tag

Nehmen Sie **Medikamente**?
☐ nein
☐ ja und zwar ____

Nehmen Sie die **Pille**?
☐ ja
☐ nein
Wenn nein: Wann war Ihr letzter **Zyklus**?
____

II Riechen

Wie beurteilen Sie Ihr **Riechvermögen** im Vergleich zu anderen?

sehr gut---------------------------- ☐
deutlich besser------------------- ☐
etwas besser --------------------- ☐
normal ---------------------------- ☐
etwas schlechter ---------------- ☐
deutlich schlechter ------------- ☐
sehr schlecht --------------------- ☐
keine Riechwahrnehmung ---- ☐

II PC-Spiele

Wie häufig spielen Sie PC-Spiele?

sehr häufig ------------------------ ☐
häufig ------------------------------ ☐
gelegentlich----------------------- ☐
selten------------------------------- ☐
sehr selten ------------------------ ☐
nie----------------------------------- ☐

Welche? ____

Wie viele Stunden/Woche?____________________________________ h

G Table of Figures

H Table of Tables

Publication List

Research Articles in Peer-Reviewed Journals

Flohr, E. L. R., Erwin, E., Croy, I., Hummel, T. (accepted). Sad Man's Nose: Emotion Induction and Olfactory Perception. *Emotion*. (EMO-2015-1248R3).

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Flohr, E.L.R., Andreatta, A., Mühlberger, A., Pauli, P. (2016). On the Influence of Social vs. Contextual Attribution of an Odor on Social Preferences and Behavior. *Psychologie und Gehirn,* Berlin, Germany.

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Curriculum Vitae

Personal Information

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Working experience

Since 2014	**Outpatient clinic for sexual and violent offenders, Caritasverband, Würzburg** Psychotherapist
Since 2012	**Department of Psychology I, University of Würzburg** Doctoral researcher at the department of biological psychology, clinical psychology and psychotherapy, work group Prof. P. Pauli
2007 – 2011	**Department of Psychology I, University of Würzburg** Student research assistant
2009 – 2011	**Department of Psychology III, University of Würzburg** Student tutor for statistics

Education

Since 2012	**Graduate School of Life Science, University of Würzburg** Doctoral researcher, associated member of the Research Training Group 1253/1 „Processing of affective stimuli: from the molecular basis to the emotional experience”
2007 – 2012	**University of Würzburg** Studies of Psychology Diploma Thesis „Smelling with the Mind’s Nose - Odor Imagery in Anosmia - an fMRT-study“
September 2009 – February 2010	**University of Granada** Studies of Psychology
2006	**German-French High School Freiburg i. Breisgau** High school diploma

Practical experience

November 2011 – January 2011	**Interdisciplinary Center of Smell and Taste Research, Technical University of Dresden** Research Internship, Diploma Thesis
March 2011 – April 2011	Internship at the **Ward of Social Therapy** at the **JVA Würzburg,** Germany
March 2010 – April 2010	Clinical Internship in **BKH, Lohr am Main**, Germany

Awards

2014	Research Award of the Section Neuroscience of the Graduate School of Life Sciences, University of Würzburg
2013	Travel Award of the Association for Chemoreception Sciences

Affidavit

I hereby confirm that my thesis entitled "The Scents of Interpersonality - On the Influence of Smells on Social Behavior and Preferences" is the result of my own work.

I did not receive any help or support from commercial consultants. All sources and /or materials applied are listed and specified in the thesis.

Furthermore, I confirm that this thesis has not yet been submitted as part of another examination process neither in identical nor in similar form.

_____________________ _____________________

Place, Date Signature