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Odour-evoked memory and influence of olfactory memory on cortical event-related potentials

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1. Introduction

Odours have a unique ability to remind us on different moments from our past. A smell can bring on memories, influence people's moods and even affect work performance (Reid et al. 2015). Due to its special neuroanatomical features smell can call up memories and powerful responses almost instantly. Odour-evoked memories are often described as emotionally strong and specific (Willander and Larsson, 2006) and were therefore chosen as a subject for a current study to investigate the sense of olfaction in terms of autobiographical memory.

1.1 Theoretical background

1.1.1 Odour memory

Odour memory can be understood as two different cognitive processes. One is recognition and identification, if one has smelled an odour before. The second type of odour memory is odour-evoked memory, which evokes autobiographical memories or associations (Herz und Engen 1996). Odour-evoked memory is a unique feature of odours to elicit memories of the past personal events, which are described as intense, emotional and rather old (Jellinek 2004). In the following paragraphs will describe more detailed specific features of odour memory and its relation to neuroanatomical structures, factors influencing odour-evoked memory and its influence on physiological and psychological health.

1.1.2 Unique characteristics of olfactory memory

Odour-evoked memories have numerous characteristics which differentiate them from memories evoked by other sensory cues. Odours are one of the best reminders of the past experience (Larsson and Willander 2009). In numerous studies it has been observed that odour-evoked memories are characterized as being more emotional in comparison to visual, verbal and tactile memories (Herz 1998; Herz und Schooler 2002). Moreover, memories triggered by odours in comparison to visual and verbal stimulus showed that odour memories are stronger and more vivid (Chu und Downes 2002) and participants felt significantly more brought back in time (Herz und Schooler 2002; Willander und Larsson 2006).

The distribution of memories evoked by odours and other sensory modalities differ along the life span (Willander and Larsson, 2006). There were numerous studies about autobiographical memories evoked by verbal cues, which described its three components: childhood amnesia, reminiscence ‘‘bump,’’ and recency (Rubin et al. 1998). Childhood amnesia is described by a small number of memories, a bump is associated with a peak of memories at the age over 50 related to events occurred in young adulthood (between 10 and 30 years), recency means memories related to recent events. However, studies concerning autobiographical odour memories are generally limited. In studies by Willander und Larsson (2006); Chu und Downes (2000) autobiographical memories evoked by words, pictures and odours were compared. The memories triggered by odours elicited autobiographical episodes, dated in the childhood period of 6-10 years and decreased steadily thereafter, whereas memories associated to verbal labels peaked in young adulthood (11-25 years). Odours mostly retrieve episodes from the early childhood due to the fact that odour memory representations are novel (Rubin et al. 1998). Interesting results supported that theory. The 24 newborns from 24 women who consumed anise and from those who did not, were examined upon oral and facial expressions and approach to the anise odourant in the first eight hours after birth and in a follow-up test on the 4th day. This study demonstrated, that neonates born to anise consuming mothers showed positive facial actions, compared to newborns from the non-anise consuming mothers (Schaal 2000). In summary, odour-evoked memories are developed very early in the childhood compared to verbal memory.

Moreover, odours elicit less memories compared to other stimuli and are therefore characterized as being more specific (Willander and Larsson 2006).

To sum up, odour-evoked memories are unique and differ from other modalities in a number of ways. They are described as more emotional, eliciting a stronger feeling of being transported back in time and date to the early childhood.

1.1.3 Factors influencing olfactory memory

There are different factors influencing odour-evoked memory. First of all, odour-evoked memories are influenced by age and gender. It was suggested that fragrances are able to evoke more memories among females than males and were equal at the age over 65 (Zucco et al. 2012). Analysis of autobiographical and referential memory (memory related to a person or subject), found that the number of autobiographical odour memories increased with the age, while the number of referential memories decreased (Zucco et al. 2012).

Whether olfactory memory and verbal memory are connected is an open issue. Numerous studies observed the correlation between odour memory (olfactory identification and discrimination) and verbal memory showing controversial results. Some studies indicated a reliable relationship between identification and recognition memory performance such that a higher ability to identify odours was associated with better odour memory (Olsson et al. 2009; Croy et al. 2015). It was observed that verbal representations influence olfactory memory, in which easily nameable odours were faster recognized than odours with difficult names (Yeshurun et al., 2008). Furthermore, the study of Hedner et al. (2010) elicited that semantic memory contributed significantly to odour discrimination and identification performance (Hedner et al., 2010). Some studies showed positive influence of cognitive speed and verbal fluency on odour identification (Larsson et al. 2005), while another study established no correlation between verbal fluency and olfactory performance (Croy et al., 2015). Thus, we found it of great interest to investigate the influence of verbal memory and linguistic performance on olfactory memory and its influence on a number of odour-evoked memories.

1.1.4 Neuroanatomical features of olfactory memory

Odours are closely connected with memories and emotion, depending on past experience (Sullivan et al. 2015). These unique features of olfactory memory found its explanation in numerous studies about the anatomy of olfactory system. Compared to other sensory systems, olfactory stimuli are indirectly analysed in the medio-dorsal nucleus of the thalamus and have close neural connections between the olfactory bulb and the hippocampus. Other sensory systems are first analysed in thalamus before being analysed in the cerebral cortex (Sabri et al. 2005). The olfactory nerve is separated only by three synapses from the hippocampus (Herz und Engen 1996). The role of hippocampus is to retrieve episodic information, select it and transform short memory into long-term memory (Ergorul und Eichenbaum 2004).

The olfactory system includes primary and secondary olfactory complex (Canli et al. 2000). The primary olfactory cortex is connected with the amygdala-hippocampal complex of the limbic system, responsible for emotions and associative learning (Canli et al. 2000). An interesting fact is that pleasant odours seem to be associated with bilateral or left amygdala activation and unpleasant odours tend to be more associated with activation of the right amygdala (Patin und Pause 2015). Using fMRI data Herz et al (2004) have shown that odours associated with personal past experience initiate a higher activity of amygdala-hippocampal region and have a high emotional potency.

Additionally, the secondary olfactory cortex is the left lateral prefrontal cortex, the brain region critical for the recollection of autobiographical information (Cabeza und St Jacques 2007).

In summary, olfactory memory in comparison with other sensory systems has a high level of target connections with neural substances, which process emotion, memory and associative learning. This provides evidence for the hypothesis, that odour evoked memories produce stronger awareness.

1.1.5 Psychological effects of odour- evoked memories

There are some psychological and physiological effects of odour memory. One psychological effect includes the ability of odours to evoke a greater proportion of positive than negative emotions (Reid et al. 2015). Fragrances can also trigger negative odour-evoked memories, associated with traumatic events. Studies of post-traumatic stress disorders have shown that odours can evoke intense and long-lasting flashbacks (Vermetten und Bremner 2003). Moreover, one study controlled the odour memory by showing an aversive film to all participants in the form of auditory, olfactory and visual stimuli. One week later participants were exposed to the triggers and asked to think about the film and write down the memories. These findings demonstrate that aversive memories, evoked by odours, are more specific, unpleasant and arousing compared to other sensory cues (Toffolo et al. 2012). In summary, odours can elicit both positive and very negative memories, depending on personal experience.

1.1.6 Physiological effects of odour-evoked memory

Pleasant odours, inducing positive emotions, play a great role by influencing health state. Odour-evoked memories can make a person feel more relaxed and reduce stress (Masaoka et al. 2012). Furthermore, positive odour-evoked memories increased feelings of happiness, decreased heart rate, skin conductance and IL-2 level (Matsunaga et al. 2011). A decrease in peripheral IL-2 is normally associated with inhibition of inflammation. Furthermore, it was observed the reduction in the level of proinflammatory cytokins such as tumor necrosis factor-a (TNF-a) and interferon-a (IFN-a) in participants experiencing positive odour-evoked memories (Matsunaga et al. 2013). These results were also observed in the neuroimaging studies investigating brain-immune interactions. It was revealed that ventromedial prefrontal complex and the orbitofrontal cortex regulate natural killer cells in periphery blood (Ohira et al. 2009). As orbitofrontal cortex is involved in olfactory processing, the research result in the thesis, odours may have positive influence on the immune system.

Odour-evoked memories are not only effective in reducing stress but could also be implemented in treatment of alcohol abuse and excessive food intake. Sniffing either unpleasant or pleasant odour reduced an urge to smoke among chronic smokers (Sayette and Parrott 1999). As it was shown in a study, smelling a neutral unfamiliar odour could reduce cravings for desired food (Kemps and Tiggemann 2013). To sum up the results written above, we can state that odours could be implemented as a new source in therapy of psychological, psychiatric, immune problems to improve health status. Besides, some ambient scents are used in marketing and are capable to influence people`s mind without them being aware of this fact (Chebat and Michon 2003). It was observed, that the effect of ambient scent can change consumers` mood and influence their decisions while shopping (Chebat and Michon 2003). The reduced odour identification abilities not only impair the life but are used in diagnostics of neurological disorders such as Alzheimer`s and Parkinson`s diseases (Muller et al. 2002).

In summary, odour-evoked memories play a significant role in everyone`s life affecting psychological and physiological health. Odour memories are able to reduce stress, help people with alcohol and drug abuse and moreover even strengthen the immune system, reducing the level of proinflammatory cytokines.

1.2 Methods and techniques in studies of olfactory memory

Numerous techniques are available for the investigation of chemosensory functions in humans, including psychophysical measures of chemosensory function, neurophysiological and electrophysiological (Hummel and Welge-Luessen 2006).

1.2.1 Psychophysical methods

Among psychophysical methods to detect olfactory function are odour threshold test, odour identification, odour discrimination, odour recognition and retronasal perception of odours (Hummel and Welge-Luessen 2006). The odour threshold test is used to measure the lowest concentration of the odour being identified by the subject. In odour identification a participant has to identify the odour from the named list and in odour discrimination tests to differentiate between odourants (Eibenstein et al., 2005). Furthermore, there are tests to evaluate the subjective significance of olfactory function like questionnaire “Importance of olfaction” (Croy et al., 2015). The study of Croy et al. (2010) suggested that there is only a weak to moderate correlation between rated olfactory function and measured function for anosmic and hyposmic patients, while patients with normal olfactory function underestimate their sense of smelling (Welge-Luessen et al. 2005).

1.2.2 Neuropsychological methods

Additionally, objective techniques can be used to assess olfactory function and effects of odour stimulation, like for example positron emission tomography (PET), functional magnetic resonance imaging (fMRI), and magnetic source imaging based on magnetoencephalography, all differing in their spatial and temporal resolutions (Kettenmann et al. 2002). While biomagnetic fields reflect cerebral activity, fMRI measures changes in blood oxygen level to assess the functional status of different brain regions and PET measures changes in neural metabolism. All three techniques have been used extensively to perform research on olfactory-induced emotions, odour memory (Herz 2004) and mechanisms of sniffing (Zald and Pardo 2000).

1.2.3 Electrophysiological methods

A great extension to functional neuroimaging of olfaction remains electrophysiological measures. Olfactory event-related potentials (OERPs) are neural potentials evoked by chemical cues and demonstrate temporal processing of the information (Luck 2005). The measured components of OERPs include P1, N1, P2, and N2 waves, which indicate changes in voltage in positive (P) and negative (N) directions. The importance of those techniques should not be underestimated, being of a great addition to neuroimaging techniques having a high temporal resolution (Luck 2005).

Figure 1 ERP Waveform

Source: University of Waterloo (2017). Online in internet: URL: https://uwaterloo.ca/event-related-potential-lab/about-event-related-potential-lab/our-research), Retrieve date: 29. April 2017.

Olfactory ERPs are derived from the electroencephalogram (EEG) after intranasal chemical stimulation and are implemented in many clinics as a part of the diagnostics of olfactory loss (Lotsch und Hummel 2006).

Although nowadays such techniques as PET and fMRI exist, ERP technique is often chosen because of its several advantages. First of all, the ERPs compared to other methods have high temporal resolution, around 1ms, allowing a very accurate study of neural activity (Friedman und Johnson 2000). ERPs determine connections between a stimulus and a response constantly (Luck 2005). One of the greatest advantages of the chosen technique is that ERPs allow an online measure of the processing of stimuli without even a presence of behavioral response (Luck 2005). These features of ERP were considered as an important function to analyse the cerebral responses of participants, who were not aware of which odour they smell during the experiment. A high temporal and spatial information available in the ERP waveform would allow us to detect more precise the onset and duration of the neural activation evoked by olfactory stimuli. Moreover, ERPs is a non-invasive recording technique and is less expensive than other techniques. At the other side ERPs have a few disadvantages. ERP components are virtually never as clear and accurate as the functional imaging and require a large number of trials to measure them accurately (Luck 2005).

Due to the growing use of this technique, guidelines have been published for both recording and analyzing of chemosensory ERPs (Hummel et al. 2000).

ERP waveforms consist of three components: amplitude, latency, and scalp distribution. Amplitudes demonstrate intensity of neural activation or latency shows the time of the activation and component's scalp distribution gives an overview on the brain areas being involved in the process (Luck 2005).

1.3 Influence of psychophysics of odours, aging and memory on oERP

oERP components are affected by the following factors: interstimulus interval (ISI) , stimulus intensity concentration, and odour type (Covington et al., 1999)**.** In the study of Tateyama et al. (1998) oERPs were recorded according to different concentrations of vanillin. The results showed that odour intensity elicits an overall increase in oERP amplitudes and shortened latency with increased stimulus concentration (Tateyama et al., 1998). These observations were supported in later studies, demonstrating that the latency of the N1 component becomes shorter with increasing concentrations and rated intensity of odours (Covington et al., 1999, Hiruma et al., 2005; Frasnelli et al., 2003).

The perception of chemosensory cues differs along the lifespan (Murphy, 1993) as increased age affects olfactory system and impairs odour sensitivity, odour identification, odour recall and odour recognition memory (Murphy et al., 2002; Schubert et al., 2011). Olfactory loss is accompanied by structural changes in the olfactory epithelium, the olfactory tract, bulb and the central olfactory cortices such as hippocampus and amygdala (Paik et al., 1992; Yamagishi et al., 1996; for a review Morgan and Murphy, 2002). Especially, olfactory loss can be noticed among patients with Alzheimer's and Parkinson`s disease, being strongly correlated with the degree of dementia (Fullard et al., 2016; Boesveldt et al., 2008; Peters et al., 2003). Those changes in olfactory performance were noticed in oERP, showing decreased oERP related to lower memory scores (Hummel et al. 1998; Stuck et al. 2006). A decrease in amplitudes of P2 and increase of latencies of N1 has been observed with age (Stuck et al. 2006). One study demonstrated that individuals with partial loss of smell especially in elderly populations may compensate odour loss with odour memory (Pellegrino et al. 2016).

1.4 The goal of the study

Playing an important role in every-day life odour-evoked memories were chosen as a subject of the research. Thus, a typical memory task requires stimulus encoding, retention, and recall, all of which can be influenced by factors such as gender, age, and a basic sense of smell, different factors could influence the odour evoked memory. Numerous studies have researched the influence of cognitive function on olfaction (Olsson et al. 2009; Croy et al. 2015), but no studies have investigated the connection between cognitive abilities and ability to recall odour-evoked memories. Furthermore, odour-evoked memories were investigated only upon PET and fMRI data to find the correct localization of cerebral structures being involved. No analyses were made to find out the temporal correlations between brain activity and odour-evoked memories, using EEG to obtain oERPs. The choice of ERP technique was based on its unique temporal resolution to determine the onset and duration of the brain activity to stimulus. Based on the previous studies showing a higher activation in amygdala-hippocampal region to odour-evoked memories (Willander and Larsson, 2006; Arshamian et al., 2013), we assume that memory and non-memory odours might lead to different results in oERP, in its latencies and amplitudes. Furthermore, the previous studies compared mostly memories evoked by odours with memories evoked by other cues. As far as we are aware, there were no investigations examining the difference in reaction to the odours evoking memories compared to the non-memory odours.

The aims of the study were set to investigate the odour memory by using oERP technique among female volunteers at the Smell and Taste Clinic of the Department of Otorhinolaryngology of the TU Dresden. The main focus was to compare oERP to memory and non-memory odours and to establish influence of verbal and olfactory performance on odour-evoked memory.

1.4.1 Stages of the study

1. to investigate what fragrances evoke more memories among participants and to establish correlations between odour hedonic features and evoked memories, age distribution of memories

2. to find connections between verbal and olfactory memory and its influence on odour-evoked memory

3. to establish coherence between odour-evoked memories and electro-physiological

responses

4. to investigate differences in oERP to autobiographical memories and non-memory odours

5. to assess correlations between the results of ERPs to odour-evoked memories and results of verbal and olfactory tests

2. Methods

2.1 Ethical consideration

This study was performed in accordance to the Helsinki Declaration on Biomedical Studies. The study was approved by the Ethics Committee of the TU Dresden (number of ethics application EK110032016). All participants provided written informed consent prior to their inclusion in the study.

2.2 Phases of the study

The experiment was carried in three sessions preceded by a pilot study.

1) Phase I: Odour evoked autobiographical memories (46 subjects). The subjects were screened for odour memories upon odours assessment test and were asked to answer health history questionnaire (see Index).
2) Phase II: Additional examinations of memory (35 subjects from the Phase I): Test of Individual significance of olfaction (Croy et al. 2010), Auditory verbal learning test adapted from (Kalbe et al. 2004), Test for odour memory (Croy et al. 2015).
3) Phase III: ERP study (24 subjects from the Phase II)

The general inclusion criteria for the experiment were: female gender in the age of 18-50, who reported being healthy. Subjects with severe diseases such as Parkinson disease, diabetes, renal insufficiency, chronic rhinitis, nasal polyps, which could affect olfactory function, were excluded based on the questionnaire received in the first part of the study.

Only women were included into analysis to avoid confounding sex effect. Based on numerous studies it was shown, that olfactory sensitivity, discrimination, and perception abilities of women are superior compared with men, which is partly mediated on female advantage of verbal processing (Brand and Millot 2001; Larsson et al. 2003). Besides, olfaction seems to be more important for women comparing to men (Oberg et al. 2002). Furthermore, there were shown differences in oERP components (P1, N1) recorded from women and men (Olofsson and Nordin 2004) as well as gender differences noted in fMR studies (Yousem et al. 1999).

2.3 Pilot study

There were 16 odours ordered from company Takasago Inc. (Paris, France) to be included in our study. In the pilot study participants were asked to say if they have a memory or not smelling each of 16 odours. Based on a pretest with 9 subjects, we first eliminated some odourants: Le male, Nivea, Aqua di gio, Green tea, Pantene, Cinnamon and apple. Based on the questionnaire the answers related with some odourants were too diverse for the odours to be included in the study. The smells provoking strong memories or on contrary aroused no associations, were included into the first phase of study. Besides, the number of odours was reduced with the goal to decrease the subjects' fatigue during the first part of the study. Pretest results were as following: excluded odours (Le male, Aqua di gio, Green tea, Pantene, Cinnamon and apple), Memory- related odours (Chocolate, After sun, Brut, Apple strudel, Cotton candy, Nivea) and non-memory related (Vanilla, Be delicious, Angel, Vernel).

2.4 Phase I: Memory study

Participants: 46 female healthy subjects participated in the first phase; age range 18-33, mean age 22.96+- 3.21 (SD). All subjects had responded to the online advertisements for participation and reported being healthy. Participants received a moderate amount of money for the participation. The study took place at the Smell and Taste Clinic of the Department of Otorhinolaryngology of the TU Dresden.

Procedure: Memory Study consisted of health history questionnaire including such questions as age, health status, smell disorders, chronic diseases and operations, medicaments and self-assessed smell scale from 1 to 7 varying from very bad to very good.

During the 1st phase of the study the subjects were presented with the odourants twice. Among tested fragrances were: Chocolate, After sun, Brut, Apple strudel, Cotton candy, Nivea, Vanilla, Be delicious, Angel, Vernel. Participants were told to describe their autobiographical memories evoked by the given odours. Subjects were allowed to sniff the odours, either until they could produce an autobiographical event or until they were sure that no memory was forthcoming. The odourants were presented in non-translucent glass jars, and the subjects were allowed to hold the jars themselves. In case of having a memory to an odour, participants were asked to write down a description of memory and rate the odour-memory. The evoked memories were rated across two different experiential dimensions. The following questions were asked: (1) How pleasant is the memory at this moment? (2) How old is the memory? For these questions the scale from 1 (very unpleasant/very old) to 7 (very pleasant/ recent) was used. If no memory was retrieved, the next cue was presented.

After the first odour presentation the subjects were presented with the odours a second time and asked to write down a description of an arousing picture (moment from the past) the subject associated with the presented odourant. Then they were asked to rate the odours according to following questions: (1) How pleasant is the odour? (2) How intense is the odour? (3) How irritating is the odour? (4) How familiar is the odour? For the questions the rating from 1 (definitely not) to 7 (definitely yes) was used. In case participant found an odour familiar, he was asked to guess the odour and write down the answer.

2.5 Phase II. Additional examinations

Participants: 35 female subjects, who were recruited in the first phase, proceeded in the second phase of the study aged 19-25 years (Mean age 22.65 +- 3.34 (SD)). After the first phase two participants were excluded out of the study being current smokers and 3 quit the study due to personal reasons. Participants received reimbursement for the participation. The study took place at the Smell and Taste Clinic of the Department of Otorhinolaryngology of the Technical University of Dresden.

Procedure: Second phase included a test of Individual Importance of Olfaction Scale (Croy et al. 2010). The questionnaire was used to have an overview about subjective importance of the sense of smell. The ‘Importance of Olfaction Questionnaire’ consists of 18 personal statements. The subjects indicate how much they agree with the statement (‘‘I totally agree’’ to ‘‘I totally disagree’’). Questions were organized into three subscales: Association-scale (association with olfactory sensations), Application scale (application of the sense of smell) and Consequence-scale (the ability to draw consequences from everyday odour perception). The Association-scale reflects the emotions, memories, and evaluations that are triggered by the sense of smell. These processes are mostly unconscious and very rapid due to the close connection between the olfactory and the limbic system (Willander und Larsson 2007). The Application-scale was used to determine how a person uses his or her sense of smell in everyday life. The Consequence-scale showed how subjects make conclusions from their olfactory impressions (Croy et al. 2010).

Importance of Olfaction

This questionnaire refers to the role your sense of smell plays in your daily life. Please answer all of the questions spontaneously, there are no right or wrong answers.

Scale		I totally agree	I mostly agree	I mostly disagree	I totally disagree
Ass	The smell of a person plays a role in the decision whether I like him/her.				
App	I smell foods to find out whether it is spoiled or not.				
App	I sniff on food before eating.				
Con	Please imagine you visit a museum. There is an offer to get additionally smell-presentations to underline the overall impression for the price of 2 €. Would you take this offer?				
Con	When I don´t like the smell of a shampoo, I don´t buy it.				
Ass	When I smell delicious food, I´m getting hungry.				
Agg	Without my sense of smell, life would be worthless.				
Con	I try to locate the odor, when I smell something.				
Ass	I feel rather quickly disturbed by odours in my environment.				
Ass	Certain smells immediately activate numerous memories.				
App	Before drinking coffee/tee, I intentionally smell it.				
App	When I buy tomatoes, I pay attention to their odour.				
Con	If my partner has a nasty smell, I avoid kissing him.				
Ass	Certain smells immediately activate strong feelings.				
App	I smell my clothes to judge whether I have to wash them or not.				
Con	When there is a nasty smell in the office/apartment of a colleague, I leave the room as soon as possible.				
Ass	Certain odors can stimulate my fantasy.				
Agg	To me it is more important to be able to smell than to be able to see or hear.				
App	Sometimes I smell a person (e.g. my partner or my child) to judge, if he/she has drunken alcohol or smoked.				
Con	I cannot pass good smelling candles in a store without buying one.				

Table 1 Questionnaire "Importance of Olfaction"

(Source: Croy et al. 2010 p. 68)

A memory test adapted from (Kalbe et al. 2004) was used in the second part. First, subjects underwent Auditory Verbal Learning Test. The test consists of three trials of free recall of 10 items list. The list included following words: Teller, Hund, Lampe, Brief, Apfel, Hose, Stuhl, Wiese, Glas, Baum. The subjects were instructed to listen carefully the word list and attempt to memorize the words. The subject`s first recall was recorded, after which the procedure was repeated again. Second, a B-test was used to evaluate participants` verbal fluency. Participants were asked to name as many words as possible starting with B during one minute. After a B-test was completed, subjects were asked to recall the list of words, named in the beginning, to assess the delayed recall of the word list.

The third part was focused on assessment of odour memory. To asses odour memory was used a set of everyday familiar odours. Those odours were included in the “Sniffin Sticks” (Hummel et al. 1997). Sniffin` Sticks are pens with a length 14cm and inner diameter of 1.3cm. The pen`s tampon is filled with 4ml liquid odourant (Hummel et al. 2007). The Test of Odour Memory (TOM) (Croy et al. 2015), was chosen to detect normal olfactory function. This test included identification and discrimination tests, which are believed to reflect central olfactory processing (Hummel und Welge-Luessen 2006). Participants were presented with 8 odours which were incorporated in Sniffin` Sticks. The presentation followed two different randomized schemes (see Table 2). The presentation interval was around 10-15 seconds between each odourant. During the odour presentation the cap was removed and the pen`s tip was placed during three seconds in around 2cm in front of both nostrils. To prevent visual identification subjects were blindfolded with a mask. Participants were instructed to memorize all the 8 presented odours carefully. After that, 16 odours were presented, including 8 distractor odours. For each of the 16 odours the subject was asked to indicate whether they recognize (yes-response) or didn’t recognize (no response) the odours being presented in the beginning. For the analysis hits, correct rejections, false alarms and not recognized odours were calculated. The second part of odour memory test included odour identification. Each participant was asked to identify each of 16 odours by giving it a name. The correct answers were calculated as free identification. The odours, which were not identified, were shown again together with 4 alternative responses, one of which included the correct odour. The correct answers were calculated as cued identification. Furthermore, reaction time, the time from the moment of starting to smell the Sniffin` stick till the answer of the participant, was calculated for each odour for both free and cued identification. Additionally, TOM score was calculated by subtracting the z-score of false alarms (incorrect Yes answers) by the z-score of hits (correct Yes answers). To obtain the identification score, the number of correct answers was divided by the total number of presented odours (16).

	Encoding version 1	2	Odour identification test
Anise	x		Anise, rum, honey, pine tree
Pineapple		x	Pear, plum, peach, pineapple
Turpentine		x	Mustard, pear, cheese, turpentine
Banana	x		Cherry, banana, walnut, coconut
Rose		x	Chamomile, raspberry, rose, cherry
Apple	x		Melon, peach, orange, apple
Cinnamon	x		Honey, vanilla, chocolate, cinnamon
Mushroom		x	Garlic, wood, ham, mushroom
Fish		x	Bread, fish, cheese, ham
Coffee		x	Cigarette, coffee, wine, candles
Leather	x		Smolder, leather, glue, grass
Cloves	x		Cloves, pepper, cinnamon, mustard
Peppermint		x	Chive, peppermint, pine tree, onion
Lemon		x	Peach, apple, lemon, grapefruit
Garlic	x		Pickled cabbage, onions, garlic, carrots
Orange	x		Orange, blackberry, strawberry, pineapple

Table 2 Stimuli used in the Sniffin` TOM and odour identification

2.6 Phase III. ERP Study

Participants: Based on the results of the first phase of study 24 subjects were enrolled into the third part. There were 24 people associating very strong memories with particular odour and without any memories associated to the second odour, 19 subjects associating memories with chocolate and 5 with apple strudel. All subjects were female aged 19-25 years with a mean age of 21.8 ± 2.0 years (SD). The study took place at the Smell and Taste Clinic of the Department of Otorhinolaryngology of the TU Dresden.

Procedure: In the third phase of the study event related potential (ERP) techniques was used to analyse the participants` responses to the odours memory related and non-related. Two odourants were chosen for the ERP study: apple strudel and chocolate. Both odours were food related to exclude the difference in food related and nonfood related smell memories. Chocolate and apple strudel odours were chosen as stimuli for EEG recordings since individuals reported memory-association to one but not the other odour. Odourants matched in pleasantness 5.45, intensity 5.43 and irritability 1.95.

Third phase called ERP study was conducted in the laboratory “Smell and Taste” with 24 subjects. ERP study took place one month later after psychophysical study to avoid the “fresh” exposition effect and recover the change in sensitivity to the odours. Research suggests that repeating stimulus could lead to decrease in olfactory sensitivity and can last up to 2 weeks after the last exposure to recover from adaptation (Dalton und Wysocki 1996).

During the ERP the goal was to record olfactory event-related potentials (oERP). A computer-controlled olfactometer was used to present stimulus. The olfactometer allows rapid presentation of odours to evoke olfactory related potentials, based on the principle of air-dilution olfactometry. In our study olfactory stimulus were applied using a dynamic air-dilution olfactometer (olfactometer OM6b; Burghart, Wedel, Germany) (Kobal und Hummel 1988). This instrument directs olfactory stimuli with a constant, humidified airstream (37C, 7L/Min, 80% relative humidity) and does not cause mechanical or thermal sensations.

The experiment took place in a room with adequate air conditioning system. Special conditions were settled to minimize the influence of external factors such as mechanical, thermal, acoustical, which could lead to appearance of event-related potentials. Every participant was provided with headphones and mp3 player and was supposed to listen to white noise to prevent distraction by solenoid closure and opening. To minimalize the eye movement a participant had to perform a tracking task, shown on a computer screen, using the joystick and was asked to locate a white ball in a gray square slowly moving on the screen. 10 electrodes were applied to the scalp of the participant cleaned with “Skin Pure” (electrode cream; Nihon Kohden, Tokyo, Japan) and attached with a self-adherent electrode cream (“EC2 Grass Electrode Cream”; Grass, Warwick, RI, USA). Data were obtained with golden electrodes (electrode diameter 5 mm; Grass Instruments Division, Astro Med Inc.,Warwick, RI, USA). Reference electrodes were attached to both earlobes (A1+A2) and ground electrodes to mastoids (M1+M2), Fp1 was used to record vertical eye movement. EEG electrodes were additionally placed on the following positions: Fz, Cz, Pz, C3, C4. A soft nasal catheter was placed into a right nostril of a subject to conduct two odours (chocolate and apple strudel), being selected in a first phase of the study. Olfactory stimulus were applied with the help of olfactometer. During inter-stimulus intervals participants received into a nasal cavity warm humid clean airflow. The EEG was amplified by a 16 channel amplifier (Brain Star AC-2000; Schabert instruments, Röttenbach, Germany) digitalized and saved on a hard disk. While a subject was performing a task on the computer, odours were applied through the right nostril. The odour application was randomized and programmed into 3 sequences; each sequence included 100 impulses differing in a number of odour presentations. Odour presentation was divided into blocks of 5 of one stimulus. The interstimulus interval (ISIs) of clean air between stimuli was between 18 – 22 s while odour pulse duration was 250 ms. Sampling frequency was 250Hz. Recording time was 2048 ms per recording (bandpass 0.01–30 Hz, with a pre-trigger baseline period of 500ms). One sequence was applied to one subject.

First 30 impulses were accompanied with 30 questions shown on the computer screen which appeared in between the game the subjects had to play. Subjects were asked to answer two questions related to the odours applied into a nostril. The questionnaire consisted of 2 sentences: How pleasant is the smell, How intense is the smell. The visual analogue scale ranked from very unpleasant to very pleasant, from low intensity to very intensive and was approximately 25cm in length. One session lasted around 60 minutes.

2.7 Data Analysis

In our study statistical data analysis was performed using IBM SPSS Statistics 19 program. In the Phase I and II due to the small sample a non-parametric Spearman test was used to establish the correlations. To establish intergroup differences one-way ANOVA test was used and Tukey HSD ("Honestly Significant Difference") post-hoc test, to indicate which groups were significantly different from the others. To assess TOM test scores, a d-prime value was calculated by subtracting the z-score of FALSE ALARMS (incorrect Yes answers) by the z-score of HITS (correct Yes answers). In order to obtain an identification score, the total number of correct answers was divided by the total number of odours being presented.

In the Phase III to evaluate psychophysics of odours an independent t-test was applied. Additionally, there were build two association groups, based on having or not having a memory (memory and non-memory) and according to the odour (chocolate and apple strudel). Within memory association groups psychophysics of odours (pleasantness and familiarity) were evaluated using a non-parametric Wilcoxon test. To evaluate oERPs an analysis of covariance (ANCOVA) was chosen. The N1/P2 interpeak amplitudes were measured by calculating the difference from the N1 to the P2 in nV, P2 latencies were measured in ms as the time from which the stimulus was delivered until maximum peak for each component. To assess the amplitudes and N1-P2 latencies as a factor was chosen an odour (chocolate and strudel) and memory association (memory and non-memory), pleasantness was a covariate. To asses correlations between memory tests and N1-P2 latencies and amplitudes we used non-parametric Spearman test. ANCOVA tests (analysis of covariance) was proceeded to determine changes in N1-P2 latencies and amplitudes with odour (chocolate and strudel) or memory (non-memory and memory). Pleasantness was selected as a covariate, due to a significant difference in its ranking of both odours ($t=2.35$, $p=0.01$).

All EEG processing and analysis were carried out using Letswave 5 (http://nocions.webnode.com/letswave). The EEG data was filtered offline with a band-pass filter (FFT) of 0.1-15 Hz prior to segmentation of -0.5 to 2 s relative to stimulus onset. Then a baseline correction was made with a reference interval of 500ms before stimulus onset. After eliminating recordings affected by motor artifacts or blinks (>50 μV at Fp2), oERPs were sorted by condition and averaged. After eliminating the artifacts, there were proceeded at least eight trials for each condition (Hummel and Kobal, 2001). Finally peak amplitudes and latencies (N1 and P2) were measured.

3. Results

3.1 Phase I Memory study

Among 46 female participants who took part in the first study 22 participants were on oral contraception. 35 subjects were consuming alcohol from time to time and 2 were smokers. None of them had chronic nasal diseases nor Parkinson`s or Alzheimer`s disease in family history, no one was exposed at work to dangerous chemicals and gases. Four of them had operations in head area such as palatal tonsillectomy and correction of nasal septum. Three participants were vaccinated for influenza in the year 2016. All subjects were asked to evaluate their sense of smell according to the scale from 1 (very bad) to 7(excellent). The calculated mean value of the sense of smell was 5.8 and the lowest value 4. The majority of participants had subjective more than average sense of smell.

3.1.1. Screening for odour-evoked memories

Odour	**Subjects who had odour memory, %**	**Pleasantness of the memory (1 very unpleasant till 7very pleasant); Mean value, (SD)**	**How old is the memory (1 very old till 7 fresh); Mean value**
Vanilla	43.5	6.11 (0.87)	4.57 (1.54)
Be Delicious	34.8	6.00 (1.5)	4.82 (1.47)
Brut	54.3	5.16 (1.49)	3.88 (1.79)
Chocolate	69.5	5.64 (1.68)	4.79 (1.73)
After sun	32.6	5.67 (1.39)	3.80 (1.3)
Vernel	58.7	4.81 (1.8)	4.89 (1.74)
Angel	43.5	4.84 (1.46)	4.58 (1.5)
Apple strudel	47.8	5.05 (1.68)	4.21 (1.75)
Cotton candy	54.3	5.68 (1.28)	4.76 (1.5)
Nivea	32.6	6.13 (0.8)	4.31 (1.25)

Table 3 Odour evoked memories description

As demonstrated in the table 3, odours such as chocolate, Vernel, cotton candy and Brut evoked the most memories (69.5%, 58.7%, 54.3% accordingly). Using one-way ANOVA test was established the intergroup difference in pleasantness of the memory ($F=2.37$, $p = 0.01$), but no odour memory differed significantly from others according Tukey HSD post-hoc test. Using one-way ANOVA test to asses intergroup difference in how fresh was the memory significant difference was shown ($F=2076$, $p<0.0001$) and vanilla differed significantly from others in ranking that order memory as less fresh (Mean value 4.57, $p<0.0001$). Furthermore, the pleasantness of the autobiographical memories evoked by all odours was prevalent pleasant (Mean value 5.5 out of 7 scale). Described memories were mainly rather fresh than old (mean value 4.45), which could be explained to the fact of everyday exposure to the odourants and frequently usage in everyday life. Chocolate aroused memories associated with baking, warm evenings with family, childhood. Vernel was mostly associated with cleaning the bathroom and memories were described as rather fresh. Cotton candy was preferably associated with Christmas time and baking. Brut evoked memories connected with male relatives. Noticeable was the fact that perfumes such as Brut, Angel, Be delicious were mostly evoking referential memories, associated with objects, people, while food related odours were evoking mostly autobiographical odour memories. Although the study did not distinguish between referential and autobiographical odour memory both referred as odour memories. Nivea at the same time being familiar for some subjects was totally new for others, which could be connected with cultural background, as some of the participants were coming outside of Germany, from such countries as France, Russia and South Africa.

3.1.2 Influence of psychophysics of odours on odour-evoked memories

Odour	*Pleasant (1-7) Mean*	*SD*	*Intense(1-7) Mean*	*SD*	*Irritation(1-7) Mean*	*SD*	*Familiarity(1-7)*	*SD*
Vanilla	5.33	1.6	5.20	1.07	1.88	1.5	4.43	1.7
Be delicious	5.35	1.6	5.33	1.07	1.95	1.57	4.75	1.64
Brut	4.75	1.69	5.33	1.07	2.33	1.58	4.45	1.53
Chocolate	5.45	1.5	5.43	1.06	1.95	1.7	5.83	1.4
After sun	4.68	1.5	4.95	1.28	2.08	1.46	4.15	1.76
Vernel	4.55	1.96	5.73	0.85	2.53	1.83	5.73	1.4
Angel	3.70	1.7	5.35	1.07	2.65	1.81	4.33	1.53
Apple strudel	4.55	1.68	5.43	1.06	2.18	1.70	4.43	1.55
Cotton candy	5.08	1.5	5.33	1.14	1.78	1.25	4.88	1.28
Nivea	5.70	0.93	5.35	1.11	1.22	0.67	5.43	1.80

Table 4 Odours hedonic features and familiarity of odours

The general perception of odours were rated rather pleasant (Mean value= 4.91) and intense (Mean value=5.34) but at the same time not irritable (Mean value= 2.05). The odours were more often familiar for the participants rather than new (Mean value 4.84). The study also focused on finding the correlation between the odours hedonic features and number of memories. There was no correlation found to the familiarity, while odour intensity positively correlated with a number of memories (r= 0.58; p=0.03). Furthermore, it was noticed that the more familiar the odours were for subjects, the more memories they were evoking (r= 0.53; p=0.05).

The Spearman correlation analysis showed that pleasantness and irritation were negatively and significantly correlated (r= -0.84; P=0.002). Familiarity and Pleasantness were positively correlated 0.54. This suggests that the more pleasant is the odour the less irritable it is and the more familiar it seems to be for the subjects, evoking a larger number of memories.

		Pleasantness	Intensity	Irritation	Familiarity
Pleasantness	Spearman	1,000	-,176	-,841**	,540
	P	.	,626	,002	,107
Intensity	Spearman	-,176	1,000	,331	,585
	P	,626	.	,350	,076
Irritation	Spearman	-,841**	,331	1,000	-,323
	P	,002	,350	.	,362
Familiarity	Spearman	,540	,585	-,323	1,000
	P	,107	,076	,362	.

Table 5 Correlation between odour hedonic features and its familiarity

The last part of the questionnaire included the task to identify an odour. The results were as follows. The highest score in identification was Vernel, 33 subjects associated it with washing agent, followed by chocolate odour. 21 subjects identified it as chocolate and 8 as cacao. The less known revealed odour was “after sun”, identified by 6 participants. Other odours took the middle position according to identifying rate. Brut was described by 16 subjects as male perfume and aftershave lotion. The odour Angel 5 participants identified as lavender and 3 as Cologne water. Be delicious was associated by 6 subjects as citrus and pineapple by 20 people and as breeze by 4 subjects. Cotton candy was cued by 6 subjects correct, by 8 subjects as vanilla and 9 people associated it with Christmas cakes. 12 subjects felt apple scents in Apple strudel odour.

3.2 Phase II Additional examinations

3.2.1 Odour-evoked memories, age and importance of olfaction

To examine the influence of age, subjective sense of smell and number of memories Spearman correlation was used. No significant correlation between the number of memories, self-assessed smell scale and age were found, which could be connected with a narrow age diapason of the subjects from 18 to 33 years old.

		age	memory	Self-assessed smell scale
age	Spearman		-,024	,004
	P		,881	,978
memory	Spearman	-,024		,174
	P	,881		,283
Self-assessed smell scale (from 1 to 7)	Spearman	,004	,174	
	P	,978	,283	

Table 6 Correlation between age, amount of memories and self-assessed smell scale

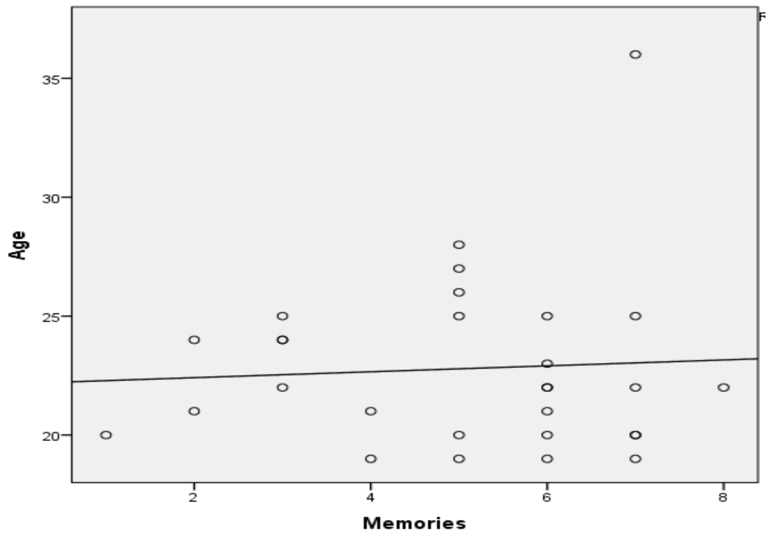

Figure 2 Distribution of memories along the lifespan

To estimate individual differences in significance of olfactory function a questionnaire “Importance of olfaction” (Croy et al. 2010) was assessed. The association between three subscales (association application and consequence) was analysed. There was a correlation between Association scale and Consequence scale r=0.48 P<0.003 and Application scale with Consequence r= 0.365 P= 0.03.

		Association	Application	Consequence
Association	Spearman	1	.365*	.483**
	P		.031	.003
Application	Spearman	.365*	1	.099
	P	.031		.570
Consequence	Spearman	.483**	.099	1
	P	.003	.570	

Table 7 Correlation between the subscales of the questionnaire score

The common score of subjective importance of olfaction was not correlated with a number of memories, evoked by given odours in the first part of the study (r= -0.06). Neither a correlation between age of the participants or importance of olfaction was estimated (r= -0.07).

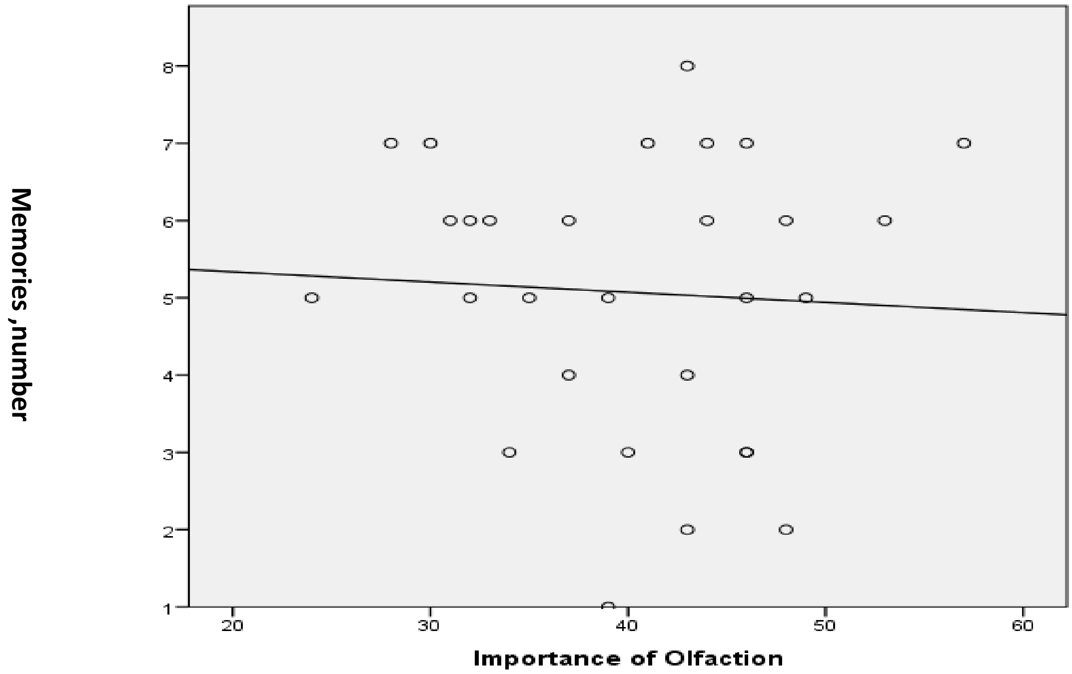

Figure 3 Correlation between importance of olfaction and number of memories

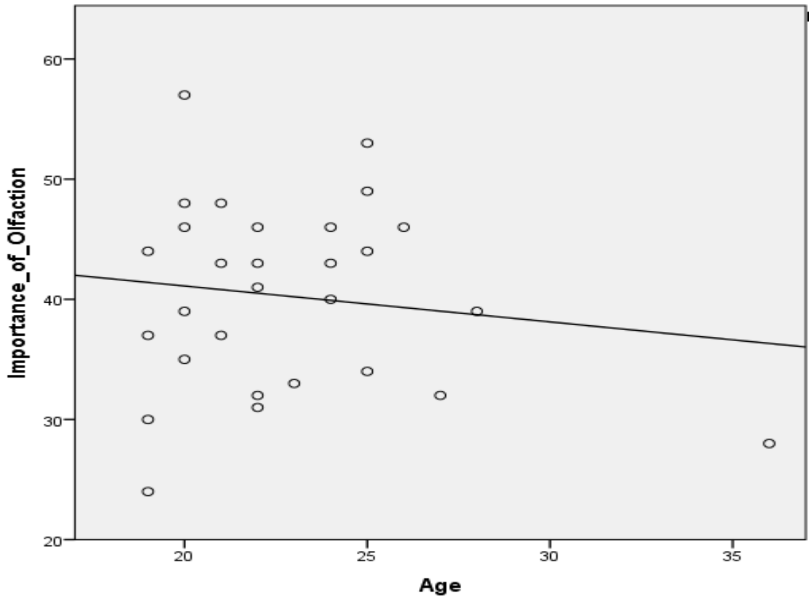

Figure 4 Correlation between “Importance of olfaction” and age

3.2.2. Descriptive analysis of olfactory and verbal memory

To obtain TOM test scores, number of correctly recognized odours was calculated summarizing Hits (correct Yes answers) with Correct Rejections (correct No answers). Overall, participants recognized 13.9 out of the 16 items correctly with a SD of 1.7.

TOM test scores included d-score and identification score. D-score value was 5.87 (SD= 1.7) and ranking from minimum 2 till maximum 8. For assessment of identification score, the total number of correct answers was divided through the total number of odours (16).

	N	Minimum	Maximum	Mean value	Std dev
HITS	35	5.0	8.0	7.0857	.91944
Correct rejections	35	4.0	8.0	6.8000	1.15809
Correct recognized	35	10.0	16.0	13.8857	1.69378
False alarms	35	,00	4.0	1.2286	1.13981
Not recognized	35	,00	3.0	.8857	.90005

Table 8 Descriptive analysis of Test of Odour Memory

The identification score varied from minimum 0.69 till 1.00 with a mean value 0.89 (SD= 0.09). Identification score and d-score were not correlated between each other (r=0.18).

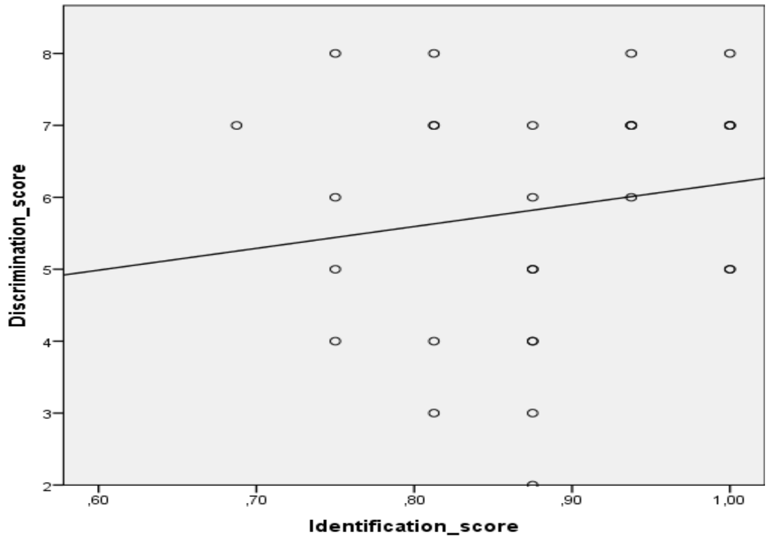

Figure 5 Correlation between discrimination and identification score

Upon the verbal memory test all participants scored in short-term verbal memory (Mean value 7.3 SD=1.2), after second try (Mean value 8.9 SD=1.0) words and in long term memory (Mean value 7.9 SD=1.4). In verbal fluency test participants named (Mean value 17.9 SD=4.4) words starting with B during one minute. From the following results could be stated the overall high intellectual level of the participants.

	N	Minimum	Maximum	Mean value	Std dev
Short term memory	35	5.00	9.00	7.3714	1.16533
Short term memory II	35	7.00	10.00	8.9143	1.03955
B- test	35	9.00	30.00	17.9429	4.39882
Long term memory test	35	5.00	10.00	7.9714	1.42428

Table 9 Verbal memory scores

Significant correlation was (p=0.47; p= 0.005) established between long and short term memory. No coherence was observed between measured olfactory function including odour identification and discrimination score (d-score) and verbal memory tests and test of verbal fluency (B-test). A weak correlation was shown between verbal fluency test (B-test) and cued task score (r= 0.34, p<0.05).

		Short term	Short term2	B test	Long term	Identification score	Discrimination score
Short term	P	1.000	.433**	-.024	.465**	.273	-.189
	p	.	.009	.891	.005	.112	.276
	N	35	35	35	35	35	35
Short_term2	P	.433**	1.000	.185	.744**	.165	.120
	p	.009	.	.287	.000	.343	.491
	N	35	35	35	35	35	35
B test	P	-.024	.185	1.000	.032	.152	.011
	p	.891	.287	.	.857	.382	.948
	N	35	35	35	35	35	35
Long term	P	.465**	.744**	.032	1000	.227	.055
	p	.005	.000	.857	.	.189	.752
	N	35	35	35	35	35	35
Identification score	P	.273	.165	.152	.227	1.000	.219
	p	.112	.343	.382	.189	.	.207
	N	35	35	35	35	35	35
Discrimination score	P	-.189	.120	.011	.055	.219	1.000
	p	.276	.491	.948	.752	.207	.
	N	35	35	35	35	35	35

Table 10 Correlation between Verbal tests and olfactory function

To find out the coherence between subjective olfactory sensitivity measured olfactory function, a weak correlation was found between the self-assessed olfactory sensitivity and identification score (r = 0.39, p= 0.035) and no correlation with the discrimination score (r= 0.27).

3.3 Results Part III oERP

3.3.1. oERP analysis

Correlations within two groups: apple strudel and chocolate were analyzed and N1-P2 amplitudes and latencies in oERP were compared. It was established a significant difference for N1-P2 amplitudes between subjects having a memory and not having a memory, associated with apple strudel odour [F(2.16) = 3.93, p = 0.01]. No such difference was shown according to chocolate odour [F(2.18) = 0.06, p = 0.80]. N1-P2 amplitudes were larger when subjects had odour memories evoked by apple strudel compared to not having memories associated with that odour (see Figure 7). No differences in N1-P2 latencies were established between memory and non-memory groups for either chocolate [F(2, 18) = 0.92, p = 0.42] or strudel [F(2, 16) = 1.21, p = 0.23].

Additionally memory and non-memory groups were analysed. According to the memory group, there were no differences amplitudes and latencies between apple strudel and chocolate shown [F(2, 18) = 2.52, p = 0.15 and F(2, 18) = 0.45, p = 0.80, respectively].

Regardless the non-memory group showed no differences in amplitudes and latencies between the odours for apple strudel and chocolate [F(2, 16) = 1.64, p = 0.09 and F(2, 16) = 0.46, p = 0.37, respectively].

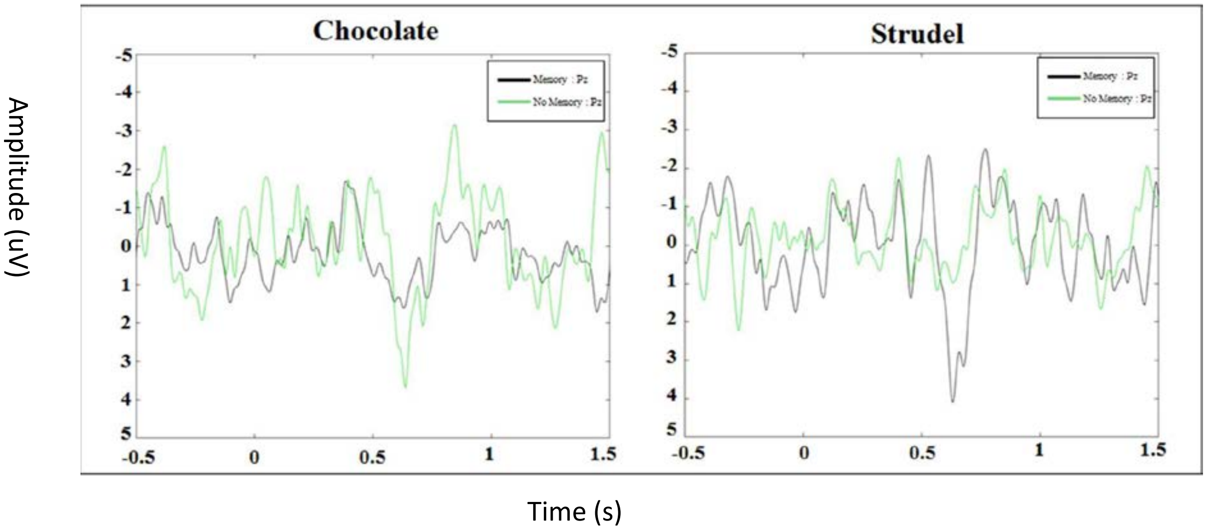

Figure 6 Grand means of olfactory ERPs (oERPs) extracted for position Pz recorded from a single subject

3.3.2 Psychophysics of odours and oERP

Hedonic features of chocolate and apple strudel were compared. No differences in intensities ($t = 0.35$, $p = 0.36$) or irritation ($t = 0.03$, $p = 0.51$) between two odours were found. At the same time chocolate odour was more pleasant ($t = 2.35$, $p = 0.01$) and familiar ($t = 3.63$, $p < 0.001$) than strudel odour among all subjects.

	Chocolate		Apple Strudel	
	Mean value (points)	SD	Mean value (points)	SD
Pleasant (1-7)	5,48	1,66	4,21	1,75
Intensity (1-7)	5,43	1,21	5,32	0,75
Irritation (1-7)	2,14	1,21	5,32	0,75
Familiarity (1-7)	6	1,14	4,37	1,67

Table 11 Comparison of chocolate and apple strudel hedonic features

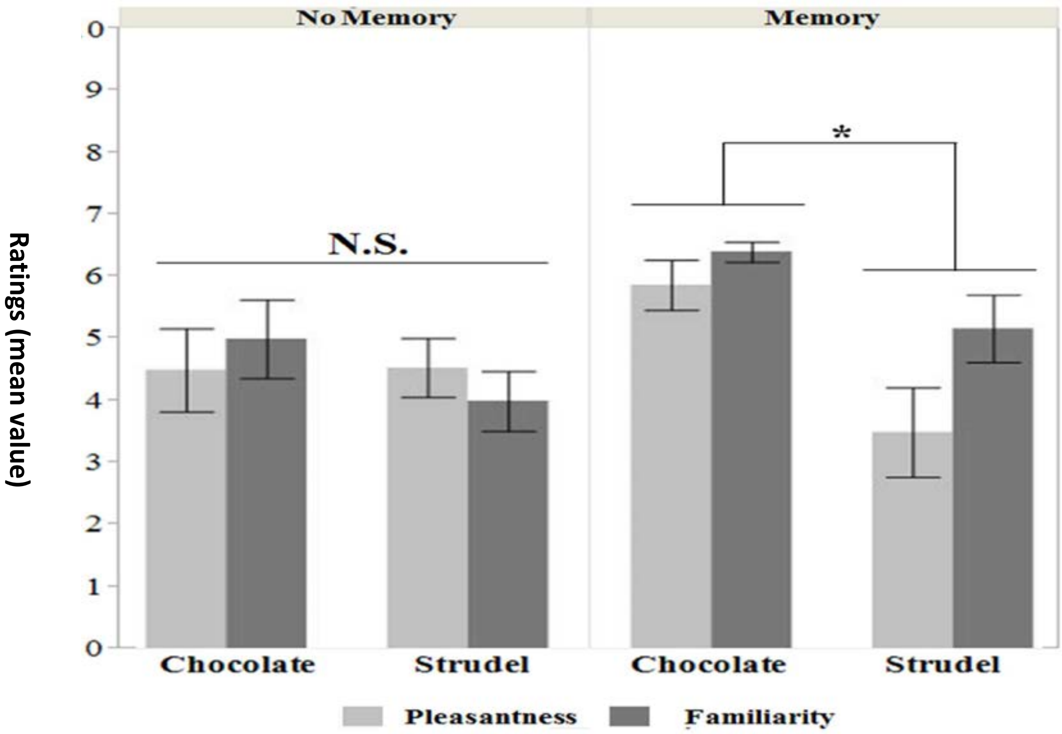

Figure 7 Pleasantness and familiarity of odour when associated or not associated with a memory

Hedonic features were analysed within memory and non-memory groups. Pleasantness (z = 2.8, p = 0.006) and familiarity (z = 2.24, p = 0.03) were significantly different only between memory-associated odours.

Within no-memory groups no correlations were found between psychophysics of odours (pleasantness, intensity, familiarity and irritation) and N1-P2 amplitudes and latencies. In contrast, a strong negative correlation was established within memory group between Intensity and N1-P2 latencies (r=- 0.58; p=0.006) and between Irritation and N1-P2 amplitudes (r=- 0.44; p=0.05).

Within chocolate group there was found a significant positive correlation between Intensity of odours and N1-P2 latencies (r = 0.46; p= 0.03) and negative correlation with N1-P2 amplitudes (r=- 0.51; p=0.02). Additionally, Irritation and N1-P2 Amplitudes negatively correlated (r=-0.46; p=0.03). To conclude, the stronger the intensity of chocolate odour the longer N1-P2 latencies and lower the amplitudes, and the higher the irritation the smaller were the amplitudes.

Grouping	Variables	Spearman p	*p*
No Memory	No correlation s		
Memory	Intensity & N1-P2 latencies	-0,58	0,006
	Irritation & N1-P2 Amp	-0,44	0,05

Table 12 Correlations in oERPs within memory and no memory odour groups

Grouping	Variables	Spearman p	*p*
Chocolate	Intensity & N1-P2 latencies	0,46	0,03
	Intensity & N1-P2 Amp	-0,51	0,02
	Irritation & N1-P2 Amp	-0,48	0,03
Apple strudel	No correlation s		

Table 13 Correlations in oERPs within chocolate and apple strudel groups

3.3.3 Memory tests and oERP

Memory scores were divided into two groups associated with memory to apple strudel or chocolate. No significant correlation was shown between memory score and odour groups.

No memory scores correlated neither with unassociated memory-odour nor with associated memory-odour.

3.4 The main results

Odour-evoked memories were ranked as rather fresh than old (mean value 4.45 /7). According psychophysics of odours, more memories were evoked by more intense odours (r= 0.58; p=0.03) and the odours, which were more familiar to subjects (r= 0.58; p=0.03). Age and number of memories were not correlated. The score “Importance of olfaction” did not influence the odour-evoked memories. Through analyzing the memory scores we found that long and short-term verbal memory strongly correlated but no correlation was established between verbal and olfactory memory and only a weak correlation between verbal fluency and cued identification score (r= 0.34, p<0.05). Furthermore identification score and discrimination score did not correlate. A weak correlation was found between the self-assessed olfactory sensitivity of subjects and identification score (r = 0.39, P= 0.035) and no correlation with the discrimination score (r= 0.27).

Through analyzing oERP, a significant difference for N1-P2 amplitudes between subjects having a memory and not having a memory was shown, associated with apple strudel odour [F(2.16) = 3.93, p = 0.01]. Analyzing the influence of psychophysics of odours: intensity, familiarity, pleasantness and irritation onto oERP, there was established a correlation for chocolate but not for apple strudel odour. The stronger the intensity of the chocolate odour the longer N1-P2 latencies and lower the amplitudes, and the higher its irritation the smaller the amplitudes. Furthermore, no memory scores correlated neither with unassociated memory-odour nor with associated memory-odour.

4. Discussion

In the present study we focused on odour evoked memories and demonstrated the influence of odours on eliciting memories, established correlations to olfactory and verbal memory, studied the importance of olfaction and subjective sense of smell in a context of odour-evoked memories, and oERP differences between memory-associated odours compared to non-associated odours.

The study has shown the odour-evoked memories were prevalent pleasant (mean value=5.5 out of 7 scale), which supports the theory being observed in previous studies describing odour memories as positive, emotional and more pleasant (Willander und Larsson 2007; Masaoka et al. 2012). Described memories were more often fresh than old (mean value=4.45), in contrary to previous studies which suggested that odours retrieve autobiographical memories from the early childhood (Chu und Downes 2000; Willander und Larsson 2006). That difference in findings could be explained by the fact of everyday exposure to the given odourants and frequent usage in everyday life. The possible explanation of rating memories as fresh might be caused by such quality of odour memories as making a stronger feeling of being brought back in time (Herz und Schooler 2002).

Analysing the influence of psychophysics of odours and odour-evoked memories it was observed that the more familiar the odour the more pleasant it seemed to be, evoking larger number of memories. Such positive relationship between familiarity and pleasantness of the odours is a well-established fact (Engen 1988; Distel et al. 1999). At the same time the more intense the odour the more memories it was evoked, which could be associated with a higher activation of amygdala by responding to pleasant and unpleasant smells being observed in fMRI studies (Anderson et al. 2003; Winston et al. 2005). These findings might be interesting for the future investigations to study the influence of odour hedonic features on odour evoked memories.

Furthermore, in our study there was no coherence established between the number of memories and the age in comparison to the study Zucco and collegues, which described that living longer the number of autobiographical odour memories increased, whereas the number of referential odour memories linked to a person or subject decreased along the lifespan (Zucco et al. 2012). The youngest subjects taking part in our study could explain the lack of evidence on distribution of odour memories along the life span. Additionally, upon the answers in the first part for subjects were sometimes hard to distinguish the difference between autobiographical or non-autobiographical odour memory (names, objects), associating chocolate, apple strudel, vanilla odours preferably with autobiographical memories compared to male or female perfumes, which were mostly evoking referential (object-associated) memories. It might be interesting for the future studies to make a stronger division of odour evoked memories to establish the differences between both groups and the influence of hedonic judgments of odours on evoking different memories. In the previous study, odour evoked memory was divided into autobiographical memory, connected to personal events from the past, and referential (factual memory) (Zucco et al. 2012). Both types of odour memory differ in the ability of participants to recall the memories sniffing an odourant. In other words, odours evoking autobiographical memory resulted in a faster reaction time (the time it took for participants to reproduce a memory), compared to referential memory (Zuccoet al. 2012). Therefore, it might be interesting to explore the difference between autobiographical and referential memories in oERP, to establish the difference in their amplitudes and latencies and their correlation to verbal memory tests.

Participants in this study were from various countries which made it hard to use the odours with an equal frequency and to specify the results per odour and relate this to the respective frequency of occurrence of the odour in the life of people from different cultures. Perception of everyday odours and its hedonic features differs across cultures (Ayabe-Kanamura et al. 1998) and even across regions of one country. There were differences described between participants coming from different corners of the USA: Americans, who were from the North-east rated popcorn as less evocative memory item, compared with other participants (Herz, 2004). It would be of a great importance to take cultural differences into consideration for the future odour memory related studies.

In our study we did not observe a correlation between the score “Importance of olfaction” and age, and in this way supported the idea, that importance of odours doesn’t deteriorate with the time and even increase in the second decade of life (Croy et al. 2010; Oleszkiewicz et al., 2016). Additionally, the importance of olfaction had no influence on the number of odour-evoked memories, which might find explanation in the results of one study, showing a great influence of personal experience on autobiographical odour-evoked memory(Zucco et al., 2012).

All subjects in our study showed a high performance in both odour memory tests (odour discrimination and odour identification) along with verbal memory tests. The findings are connected with high motivation of the young subjects taking part in the study and the fact that all of them were current students at University of Dresden. In our study there was no coherence observed between measured olfactory function including odour discrimination score and identification and verbal memory tests and test of verbal fluency (B-test). In one of the studies there was also no correlation found between number of correctly recognized odours and performance in verbal tests (Croy et al. 2015). Only a weak correlation between verbal fluency and cued identification score ($r= 0.34$, $p<0.05$) was observed, which supported the results of one study showing a strong correlation between B-test and cued identification score but not to uncued score (Oleszkiewicz et al., 2016). These results could be explained by the fact that uncued odour identification might require larger lexical knowledge and cognitive working memory compared to cued identification task (Oberg et al., 2002).

In our study an identification and discrimination score did not correlate which is a contrasting result to other studies which indicated a reliable relationship between identification and recognition memory performance such that a higher ability to identify odours was related to better memory (Olsson et al. 2009; Croy et al. 2015) and positive influence of cognitive speed and verbal fluency on odour identification (Larsson et al. 2005). Furthermore the study of Hedner et al. (2010) demonstrated that semantic memory contributed significantly to odour discrimination and identification performance. The lack of correlation in our study could be explained by a small sample size (46 subjects). Furthermore, a weak correlation was found between the self-assessed olfactory sensitivity and olfactory tests, supporting the results from previous study, that indicate that there is only a weak to moderate correlation between rated olfactory function and measured function for anosmic and hyposmic patients, while subjects with average olfactory function tend to underestimate their own olfactory sensitivity (Welge-Luessen et al. 2005).

In the present study we demonstrated oERP differences between odours associated and not associated with memory. Several studies have examined the perceptual and neural features involved in the encoding and recollection of odour-evoked memory. These studies have demonstrated, that odour memories are encoded in young childhood (< 10 years of age) and activate strongly areas related to memory (hippocampus), emotion (limbic system), and visual vividness (occipital gyrus) (Herz, 2004; Willander & Larsson, 2006; Arshamian et al. 2013). In line with those findings, we demonstrated that N1-P2 amplitudes were higher when smelling apple strudel linked to a memory. Moreover, we demonstrated no differences in latencies evoked by apple strudel and chocolate odours.

Apple strudel, but not chocolate odour, elicited larger oERP when being associated to a memory. These findings may be supported by studies which have shown larger activations across primary and secondary olfactory cortex in response to odour-evoked memories (Herz et al. 2004; Willander und Larsson 2006; Arshamian et al. 2013). Such differences in oERP amplitudes to odour and chocolate, may be caused by the fact that the strudel odour or the associated memory to it was assessed as less pleasant than chocolate odour. Analysing psychophysics of odours, pleasantness and familiarity ratings were significantly lower for the strudel odour than chocolate and were significantly lower for strudel only when it was associated with a memory. Due to a small sample of subjects rating the memory to apple strudel odour, the correlation between oERPs and pleasantness of the memory remains as a hypothesis. As it was shown in the study of Boesveldt et al. (2010) results suggest that subjects respond faster to unpleasant odours than to pleasant odours, and faster to food odours than to non-food odours (Boesveldt et al. 2010). It is well known, that most odourants stimulate the trigeminal system in addition to the olfactory nerve (Doty et al., 1978). It is therefore possible that the observed differences between the odours are due to a separation in their degree of ability to stimulate the trigeminal system. Furthermore, previous studies have demonstrated the differences in oERPs N1/P2 amplitudes evoked by unpleasant odour of hydrogen sulfide compared to the pleasant vanillin odour (Kobal et al. 1992). In consonance with these findings, we demonstrated that memory to a less pleasant odour created higher N1-P2 amplitudes in oERP. At the same time, through analyzing the influence of pleasantness on oERP components we noticed significant differences, which could not explain the above correlation to a full extent. Those results, made us think that there might be other factors influencing the oERP, such as a feeling of being brought back in time, emotional potent and specificity of odour memory. Recognition memory involves two states of awareness: recollection, which includes contextual and associative details along with the memory, and familiarity, when an odour is remembered without context (Yonelinas 2002). Furthermore, those both processes differ in temporal resolution (familiarity tend to be processed more quickly) and spatial resolutions: familiarity depends on hippocampal and frontal lobe, while recollection rely on temporal lobes (Yonelinas 2002). In our study, due to a low spatial resolution of ERPs we couldn't investigate those differences in brain activity, initiated by odour evoked memory. The dual-process model can be an explanation for a difference in a number of memories evoked by chocolate and apple strudel in comparison (32 and 22 odour memories respectively). That difference might be influenced by a daily life, in which chocolate is a common odour for most people and thus more familiar, while strudel may be more rare and specific to a season for example Christmas or time-event, evoking contextual memories. In our study most subjects had an association with chocolate and not strudel, and assessed strudel odour as less familiar than chocolate and less pleasant. The above listed observations explain the significant difference in N2-P1 amplitudes cued by odour memories to apple strudel, while being rare, more specific and for that reason making a stronger feeling of being brought back in time. This concept finds support in the following research (Herz et al. 2004), through analysing the brain activity evoked by odours associated with memories using functional magnetic resonance imaging (fMRI). Their results demonstrated higher activations in amygdala-hippocampal region to odours, evoking memories with a higher emotional potency. In line with other studies, odour-evoked memories are characterized as by a stronger feeling of being brought back in time (Herz 2004; Willander und Larsson 2006) and are described as more vivid (Chu & Downes, 2002). In our study odour-evoked memory was analysed according to its pleasantness and novelty. For the deeper understanding and analysis of oERPs differences to odour-evoked memory, future studies might find it interesting to ask more specific questions about odour memory, its emotionality, vividness and to ask to date back the odour memory. Through analyzing the influence of psychophysics of odours and results in oERPs, following results were observed: the stronger was the intensity of chocolate odour the longer were N1-P2 latencies und lower the amplitudes, the higher was the irritation the smaller were the amplitudes. Our findings did not correlate the previous studies, demonstrating that the latency of the N1 component becomes shorter with increasing concentrations and rated intensity of odours (Covington et al., 1999, Hiruma et al., 2005; Frasnelli et al., 2003).

Moreover, our study demonstrated no correlations between olfactory and verbal memory scores and oERP evoked by memory-associated odours. To be precise, verbal and olfactory memory ability do not influence the time (latency) nor increase the amplitudes of memory-evoking odours, at least not in young, healthy subjects. These findings were not corresponding with previous studies, which have demonstrated decreased oERP related to lower memory scores (Hummel et al. 1998; Stuck et al. 2006). It was observed the decrease in amplitudes of P2 and increase of latencies of N1 with age (Stuck et al. 2006). Additionally, odour identification scores were significantly correlated with latencies of P2, the higher identification score was corresponded with shorter latency (Stuck et al. 2006). The same observations were noticed in one study conducted among 140 individuals from seven age groups (16–79) with equal number of males and females, and indicated statistically significant age effect on oERP amplitudes and latencies to amyl acetate (Murphy et al. 2000). Furthermore, subjects with impaired memory such as Alzheimer’s patients had reduced oERPs (Morgan und Murphy 2002; Peters et al. 2003). The lack of correlation between memory scores and results in oERP may be explained by the sample among which were young healthy subjects. Future auto-biographical memory studies may find it interesting to compare age groups and cognitive, memory abilities of subjects.

Besides, oERP took place throughout the day from the morning till late evenings. As observed in one study, olfactory sensitivity changes with circadian phase, described as more sensitive in the late afternoon and less sensitive in the early morning (Nordin et al., 2003; Herz 2016). In our study we were not focusing on the difference in recorded oERP along the day, which might be important for the future studies to consider. Our study was focused on eliciting differences in oERP between odours from the same odour category (food related) and the same odour valence (pleasant). Future odour memory studies might find it of a great interest to investigate differences in memories evoked by other odour categories.

5. Summary

Odours have a unique feature to evoke memories and connect us with special moments from the past and make us live through them with a high vividness. Smelling a personally significant odour activates a large number of neural structures, including hippocampus, amygdala and prefrontal cortex (Canli et al. 2000). No other sensory system has such a high level of neural connections with structures, involved in emotion processing, memory and associative learning. Odour-evoked memories can not only change the mood and influence our decisions, but also modulate our psychological and physiological health, making us feeling relaxed or on the contrary arousing intense flashbacks (Herz, 2016). The studies on odour-evoked memories are rare, compared to memories evoked by other sensory cues. Playing an important role in everyday life, odour memory was chosen as a subject for a current study to investigate the sense of olfaction in terms of autobiographical memory. In our study we focused on analyzing the factors influencing odour-memory and studies of odour-evoked memories using event-related potentials (ERP) technique.

The experiment was carried out in three sessions. 46 female volunteers, who reported being healthy, were recruited into the first phase of the study. The age of participating subjects ranged from 18 to 33 years of age [(mean age 22.96+- 3.21 (SD)]. In the first phase the subjects were asked to describe their memories evoked by 9 odours: chocolate, after sun, Brut, apple strudel, cotton candy, Nivea, vanilla, Be delicious, Angel, Vernel. The second phase (30 subjects from the previous phase) was focused on analyzing verbal and olfactory memory along with establishing the significance of olfaction in everyday life. The third phase (neurophysiological study) included 24 subjects from the previous stage, and used electroencephalogram to record olfactory event-related potentials to memory and non-memory odours (chocolate and apple strudel).

The current study showed that odours evoke mostly positive and fresh memories, that according to the hedonic features of odours they are able to evoke both autobiographical and referential memories. Comparing the odour hedonic features, it was observed that the more pleasant the odour the more familiar it seemed to be and at the same time the more intense the odour the more memories it evoked. Besides, a number of memories were not age-related nor correlated with importance of olfaction. Additionally, in our study no correlation was found between measured olfactory function including odour discrimination score and identification and verbal memory tests and test of verbal fluency (B-test). None of those results correlated with the number of memories, leading us to conclude that odour evoked memories are not affected by performance in olfaction tests, but are more related to a personal past experience. Through analyzing oERP a significant difference was shown in electrophysiological responses to memories associated and not associated with a memory. A significant difference was noticed in N1-P2 amplitudes between subjects having a memory and not having a memory, associated with apple strudel odour. No changes in amplitudes were shown. The explanation for the following results might be based on the specificity of memory associated with apple strudel, as being more rare compared with chocolate odour. Furthermore, no memory scores correlated with oERP recordings, associated and not associated with an odour memory. Furthermore, no memory scores correlated either with unassociated memory-odour nor with associated memory-odour. Those results of oERP study, made us conclude, that there might be other factors influencing the oERP, such as a feeling of being brought back in time, emotional potency and specificity of odour memory.

Zusammenfassung

Gerüche haben ein einzigartiges Merkmal, das Erinnerungen hervorruft, wodurch Verbindungen zu besonderen Momenten aus der Vergangenheit hergestellt werden und dabei helfen sich mit einer hohen Lebendigkeit an diese zu erinnern. Riechen eines persönlich bedeutenden Geruchs aktiviert eine große Anzahl von neuronalen Strukturen, darunter Hippocampus, Amygdala und präfrontale Kortex (Canli et al., 2000). Kein anderes sensorisches System hat ein so hohes Maß an neuronalen Verbindungen mit Strukturen, die in Emotionsverarbeitung, Gedächtnis und assoziatives Lernen involviert sind. Geruch-evozierte Erinnerungen können nicht nur die Stimmung und Entscheidungen verändern, sondern auch die psychologische und physiologische Gesundheit beeinflussen, zur Entspannung beitragen oder im Gegenteil intensives Wiedererleben erregen (Herz, 2016). Die Untersuchungen über olfaktorische Erinnerungen sind selten, verglichen mit Erinnerungen, die von anderen sensorischen Signalen hervorgerufen werden. Das Geruchsgedächtnis spielt eine wichtige Rolle im Alltag, deshalb wurde das als Thema für unsere aktuelle Studie ausgewählt, um den Geruchsinn im Rahmen von autobiographischen Erinnerungen zu untersuchen. In der Studie lag der Fokus auf der Analyse von Faktoren, die das Geruchsgedächtnis beeinflussen können. Die Untersuchungen des Geruchsgedächtnisses wurden mit Hilfe der ereigniskorrelierte Potentialen (ERP) -Technik durchgeführt.

Das Experiment wurde in drei Sitzungen umgesetzt, hierzu wurden in der ersten Phase der Studie 46 gesunde weibliche Freiwillige rekrutiert. Das Alter der Probanden lag zwischen 18 bis 33 Jahren [(Mittelwert 22,96 + - 3,21 (SD)]. In der ersten Phase wurden die

Teilnehmerinnen aufgefordert ihre Erinnerungen zu beschreiben, die durch die neun verschiedenen Gerüche hervorgerufen wurden: Schokolade, Aftersun, Brut, Apfelstrudel, Cotton candy, Nivea, Vanille, Be delicious, Angel, Vernel. Die zweite Phase des Experiments, mit 30 Teilnehmerinnen aus der vorherigen Phase, konzentrierte sich auf die Analyse der verbalen und olfaktorischen Gedächtnisse und der Bedeutung des Geruchsinns im Alltag. Die Dritte Phase (neurophysiologische Studie) umfasste 24 Probanden aus der vorherigen Phase. In dieser Phase waren die olfaktorische ereigniskorrelierte Potentiale, die mit Erinnerungen assoziiert bzw. nicht assoziiert waren, mittels Elektroenzephalogramm aufgezeichnet.

Die aktuelle Studie zeigte, dass Gerüche meist positive und frische Erinnerungen hervorrufen und sowohl autobiographische als auch referentielle Erinnerungen hervorrufen können. Durch den Vergleich der hedonischen Eigenschaften von Gerüchen, wurde beobachtet, dass, je angenehmer der Geruch war, um so bekannter erschien es für die Teilnehmer, und zugleich je intensiver war der Geruch desto mehr Erinnerungen hat es hervorgerufen. Außerdem war die Anzahl von Erinnerungen nicht altersbedingt und hat nicht mit der Bedeutung des Geruchsinns korreliert. Darüber hinaus wurde in der Studie keine Korrelation zwischen dem gemessenen olfaktorischen Gedächtnis einschließlich des Diskriminierungstests, des Identifizierungstests, des verbalen Gedächtnistests und dem verbalen Sprachtest (B-Test) gefunden. Keines dieser Ergebnisse korrelierte mit der Anzahl der Erinnerungen. Das bedeutet zusammengefasst, dass geruch-evozierte Erinnerungen weniger von der Leistung in olfaktorischen Tests beeinflusst sind, sondern eher im Zusammenhang mit persönlicher Erfahrung stehen. Durch die Analyse von OERP wurde ein signifikanter Unterschied in elektrophysiologischen Reaktionen zu Gerüchen gezeigt, die mit Erinnerungen assoziiert waren bzw. nicht. Ein signifikanter Unterschied wurde in N1-P2-Amplituden zwischen Probanden, die Erinnerungen und keine Erinnerungen, die mit Apfelstrudel assoziiert sind, festgestellt. Es wurden keine Amplitudenänderungen beobachtet. Die Erklärung für die folgenden Ergebnisse könnte die Spezifität des Gedächtnisses zur Apfelstrudel sein, und im Vergleich zu Schokoladengeruch als seltener beschrieben werden. Keine Gedächtnistests korrelierten mit OERP Ergebnissen. Des Weiteren gab es weder eine Korrelation bei den mit dem Geruch assoziiertem Erinnerungen noch bei den nicht mit Geruch assoziiertem Erinnerungen. Die Ergebnisse der OERP-Studie, kommen zu dem Schluss, dass es andere Faktoren sein könnten, die das OERP beeinflussen, wie zum Beispiel emotionale Potenz und Spezifität des Geruchsgedächtnisses.

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