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The Relation Between Valence and Arousal in Subjective Odor Experience

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Abstract

Introduction The main purpose of this study was to investigate the overall relation between the mean (at the nomothetic or group level) subjective valence and arousal ratings for odors. Although well established in other sensory modalities (e.g., visual, auditory, gustatory, tactile), this relation has not previously been investigated for odors covering a large range of the valence dimension. In addition, we evaluated the EmojiGrid (a recently introduced intuitive graphical affective self-report tool) for the affective appraisal of odors.

Methods Young and healthy participants (N = 56, 32 females) used the EmojiGrid to rate the perceived valence and arousal for 40 different and randomly presented odors, ranging in valence from unpleasant to pleasant.

Results The overall relation between mean valence and arousal can be described by a U-shaped (quadratic) form; odors scoring near neutral on mean valence have the lowest mean arousal ratings, while odors scoring either high (pleasant) or low (unpleasant) on mean valence show higher mean arousal ratings. The results for odors that were also used in previous studies in the literature agree with their earlier reported values.

Conclusion Mean arousal ratings increase with (positive or negative) emotional valence. Participants intuitively used the EmojiGrid to report their affective appraisal of odors without any verbal labels or written instructions.

Implications The current findings are relevant for various applications and environments (e.g., public, retail, entertainment) where odors are used to induce desired emotional states (e.g., relaxation, arousal) and behaviors. The EmojiGrid can efficiently be applied to assess whether specific odors evoke the desired subjective affective experiences.

Keywords Affective response · Olfactory perception · Odors · Valence · Arousal · EmojiGrid

Introduction

Odors and Affect

Odors effectively elicit various affective responses (Ehrlichman and Bastone 1992; Herz 2002), probably due to the high degree of overlap of the neural systems mediating olfaction and emotion (Soudry et al. 2011). Arousal and pleasantness (valence or hedonic tone) have been identified as the main dimensions of affective responses to environmental stimuli in general (Mehrabian and Russell 1974).The affective response to odors is typically determined by their valence and intensity (Anderson et al. 2003). Humans involuntarily categorize odors by their valence (Bensafi et al. 2002b), while perceived odor intensity is strongly correlated with subjective arousal (Bensafi et al. 2002a). Brain imaging studies show that unpleasant and pleasant odors activate different brain areas (Fulbright et al. 1998; Zald and Pardo 1997). Unpleasant odors increase skin conductance, heart rate (Zeier

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et al. 1995), and the startle reflex (Ehrlichman et al. 1995; Ehrlichman et al. 1997; Miltner et al. 1994), while pleasant odors allow them to return to their baseline. In general, it has been found that pleasant odors positively affect mood and decrease arousal, while unpleasant odors have the opposite effect (Herz 2009). As a result, odors can effectively be used to induce various emotional states and desired behaviors. For instance, odors have been deployed to reduce patient stress in healthcare environments (Braden et al. 2009; Kritsidima et al. 2010; Lehrner et al. 2000). Also, it has been shown that odors can influence shopping behavior in retail environments (Chebat and Michon 2003; Doucé and Janssens 2013) and littering behavior in public environments (de Lange et al. 2012). It has also been found that the addition of an olfactory channel to digital communication and information systems can reduce the user's cognitive workload, enhance the quality of the multisensory user experiences, and induce a desired behavior (for a review see Bordegoni et al. 2019). All these findings have recently spurred an increased interest in the digitization of olfactory information for applications in human-computer interaction (HCI: Bao and Yamanaka 2016; Kaye 2004) and mulsemedia (multiple sensorial media: Ghinea et al. 2014; Saleme et al. 2019).

Promising application areas for odor stimulation are affective online communication, gaming, training, entertainment and tourism, public safety, healthcare, wellbeing, and marketing (Ghinea and Ademoye 2011; Murray et al. 2016; Nakamoto 2013). For instance, olfactory-enhanced virtual and augmented reality systems can increase the affective quality of online communication (Xiang et al. 2016), enhance the sense of immersion in (serious) gaming and training (Bordegoni and Carulli 2016; Chen et al. 2018a), and provide a more realistic and immersive virtual environment for entertainment and tourism applications (Carulli et al. 2019; Guttentag 2010; Manghisi et al. 2017); in-car olfactory information displays can enhance the driver's attention (Bordegoni et al. 2016, 2017) and reduce mental workload (Dmitrenko et al. 2018; Wintersberger et al. 2019); scent-based digital warning or messaging systems can serve as subtle reminders or amplify the urgency of warning signals in other sensory modalities (Dobbelstein et al. 2017; Maggioni et al. 2018); olfactory-enhanced restorative virtual environments can promote relaxation in healthcare and wellbeing applications (Amores et al. 2018; Depledge et al. 2011), while communicating olfactory product information over the internet can influence online shopping behavior (Kim and Shin 2017; Petit et al. 2019). As a result of the increased application of olfactory information, a variety of wearable (Amores and Maes 2017; Bordegoni and Carulli 2016; Dobbelstein et al. 2017; Hashimoto and Nakamoto 2016) and spatially localized (Chen et al. 2018a; Herrera and McMahan 2014; Nakaizumi et al. 2006) scent delivery systems and technologies have recently become commercially available (for reviews see: Murray et al. 2016; Nakamoto 2013; Obrist et al. 2016). For all these applications, it is important to know the relation between valence and arousal at the nomothetic or group level (i.e., across persons), in order to achieve the overall desired effects. Although well established in other sensory modalities (e.g., visual, auditory, gustatory, tactile), this relation has not previously been investigated for odors covering a large range of the valence dimension.

Measuring the Affective Response to Odors

The degree to which sensorial stimuli (odors) evoke the desired affective response can be assessed through either physiological, behavioral, or cognitive measures (for a review of the advantages and disadvantages of the different assessment methods see: Kaneko et al. 2018a). Subjective self-report tools like questionnaires and rating scales are typically the most practical instruments to measure affective response. Although questionnaires using lists of affective terms may differentiate the subjective affective experiences induced by olfactory stimulation more accurately (Chrea et al. 2009; Delplanque et al. 2012; Delplanque et al. 2017; Ferdenzi et al. 2013a; Porcherot et al. 2010), they are typically not exhaustive while their use is time-consuming and requires considerable cognitive effort, which affects the experience itself and prohibits repeated application. Labeled rating scales can be deployed more efficiently than questionnaires but still require cognitive effort since users need to verbalize their affective state. In contrast, graphical rating tools (such as the Self-Assessment Mannikin (SAM): Bradley and Lang 1994) allow users to report their emotional state more intuitively by indicating or rating the (part of the) figure that best represents their current affective state. Some previous studies in the literature used the SAM to assess of odor-induced affect (e.g., Bao and Yamanaka 2016; Bestgen et al. 2015; Pützer et al. 2019).

In this study, participants used the recently introduced EmojiGrid graphical rating tool to report their affective appraisal (perceived valence and arousal) of different odors with a wide range of perceived hedonic valences (Toet et al. 2018). The EmojiGrid is a Cartesian grid (similar to the Affect Grid: Russell et al. 1989), labeled with facial icons (emoji) expressing different degrees of valence and arousal. In contrast to the SAM (which requires a successive assessment of the stimulus on two dimensions), users can efficiently report their subjective ratings of both valence and arousal with a single click on the location of the grid that best represents their affective state after perceiving a given stimulus. The EmojiGrid is robust, self-explaining (requiring minimal cognitive effort), and language independent; valence and arousal ratings are independent of framing and verbal instructions (Kaneko et al. 2018b; Toet et al. 2018). The emoji serve as anchors that facilitate affective over cognitive responses (Phan et al. 2019). They are typically more correctly interpreted than the SAM characters, which are sometimes misinterpreted (Hayashi et al. 2016; Yusoff et al. 2013), particularly along the arousal dimension (Betella and Verschure 2016; Broekens and Brinkman 2013; Chen et al. 2018b).

Current Study

This study was performed to investigate the overall relation between the mean (at the group level) valence and arousal ratings for odors. Although the relation between subjective ratings of valence and arousal depends both on personality and culture at the idiographic level (i.e., within individuals), the shape of this relation is typically characterized by a U-shape (quadratic form) at the nomothetic or group level (i.e., across persons: e.g., Kuppens et al. 2017). This has been established for a wide range of different affective stimuli such as sounds, music, paintings, images, movies, words, facial expressions, and food (Kaneko et al. 2018b; Kuppens et al. 2013; Mattek et al. 2017; Toet et al. 2018). However, to the best of our knowledge, there have been no previous studies investigating this relation for odors covering a large range of the valence dimension. In this study, we investigate whether the relation between the mean valence and arousal ratings for odors can also be characterized by a U-shaped relation, i.e., whether odors that are rated high (pleasant) or low (unpleasant) on valence are typically also rated as more arousing than odors rated near neutral on valence. There are only a few previous studies in the literature that provide some measures for the perceived valence and arousal of odors. However, these studies typically focused on different aspects of odor perception like autonomous nervous system response (Bensafi et al. 2002a), odor-evoked memories (Herz and Cupchik 1992), or odor identification (Bestgen et al. 2015) and used only a limited number of participants and smells. In this study, we systematically measured perceived valence and arousal for a set of 40 different odors, covering a wide range of the valence scale. To enable a comparison of our present results with those in the literature, we included several odors that were also evaluated in previous studies.

Materials and Methods

Participants

A total of 56 students (32 females and 24 males, mean age = 24.3 years, SD = 4.6) from the University of Utrecht (the Netherlands) participated in this experiment. Participants were recruited through postings on social media and direct messaging. The exclusion criteria were age (younger than 18 years and older than 60 years), olfactory deficiencies (e.g., diseases, having a cold, smoking, or drinking alcohol), allergies, and pregnancy. Participants were asked not to wear perfume, use deodorant, or wear scented clothing on the testing day. All participants signed an informed consent form. The experimental protocol was reviewed and approved by the TNO Ethics Committee and was in accordance with the Helsinki Declaration of 1975, as revised in 2013 (World Medical Association 2013). After completing the study, participants were offered a small financial compensation (5 Euro) or study credits for their participation.

Odors

In this study, we measured odor-evoked valence and arousal for 40 different odors (27 food and 13 non-food smells; see Table 1), ranging from unpleasant and arousing (e.g., feces, fish) via pleasant and calming (e.g., clove, cinnamon) to pleasant and stimulating (e.g., peach, caramel). To obtain a stimulus set with valence values distributed across the entire scale range, we complemented the revised 32-item "Sniffin' Sticks" odor identification test, which contains neutral and pleasant smells (www.burghart-mt.de, see also: Sorokowska et al. 2015), with eight additional odors that are typically perceived as unpleasant: burned wood, diesel fumes, dusty cave, metal, rhinoceros, tar (obtained from https://retroscent.com and indicated by the RS codes in Table 1), and with indole (unpleasant smell associated with feces) and wintergreen (typically perceived as less pleasant by Europeans: Herz 2009; both obtained from www.hekserij.nl). We explicitly included unpleasant smells since these are applied in mulsemedia and HCI applications, and an assessment tool should, therefore, be able to measure their corresponding affective response (Murray et al. 2017).The Sniffin' Sticks identification test consists of two sets (a blue capped set and a purple capped set) of 16 numbered felt pens each, with tips that are impregnated with 4 mL of fluid odor substance. This test is normally used to assess an individual's olfactory identification performance (Hummel et al. 2007; Hummel et al. 1997; Rumeau et al. 2016). We prepared eight extra sticks by injecting 4 mL of the additional unpleasant odor substances in empty Sniffin' Sticks. Hence, our total stimulus set consisted of 40 sticks (pens), numbered from 1 to 40 (see Table 1). Out of the 40 odors used in this study, four coincided with the odors used in the study of Bensafi et al. (2002a), 12 with the odors in the study of Bestgen et al. (2015), eight with the odors in the study of Herz and Cupchik (1992), 28 with the odors in the study of Dravnieks et al. (1984), and five with the odors in the study of He et al. (2016). This enables a comparison of the results of the present study with the outcome of those previous studies. Prior to the experiments, three of the authors (SE, YL, AT) verified that all samples had a similar intensity. The same set of sticks was used during the entire experiment. Although no evidence of odor fatigue (Mills et al. 1963) was noted here, any potential effects are likely to cancel out as a result of the randomization of the presentation order over the participants.

Valence and Arousal: The EmojiGrid

The EmojiGrid (Fig. 1, see also Toet et al. 2018) was used as a self-report tool to assess the valence and arousal of the

Table 1 Odors used in this study and in previous studies by Dravnieks et al. (1984) (bold printed labels), He et al. (2016) (underlined labels), Bestgen et al. (2015), Bensafi et al. (2002a), and Herz and Cupchik (1992). The Sniffin' Sticks B and P codes refer to the blue and purple identification test sets (www.burghart-mt.de). The RS codes refer to the RetroScent product code (https://retroscent.com)

		Odor			
Item	Label	This study	Bensafi e.a. (2002)	Bestgen e.a. (2015)	Herz and Cupchik (1992)
1	**Anise**	Sniffin' B15		Anisyl phenylacetate	
2	**Apple**	Sniffin' B11		2-Methylbutyl isovalerate	
3	**Banana**	Sniffin' B5	Isoamyl acetate	Isobutyraldehyde	Isoamyl acetate
4	Burned wood	RS-420			
5	**Caramel**	Sniffin' P15		Ethyl maltol	
6	**Cinnamon**	Sniffin' B3		Ethyl cinnamate	
7	**Cloves**	Sniffin' B12			Clove bud oil
8	**Coconut**	Sniffin' P9			Coconut
9	**Coffee**	Sniffin' B10			
10	Coke	Sniffin' P2			
11	Diesel fumes	RS-423			
12	**Dusty cave**	RS-425			
13	**Eucalyptus**	Sniffin' P7	1-8 Cineole		
14	**Fish**	Sniffin' B16			
15	**Garlic**	Sniffin' B9	Tiophenol	Garlic oil blend, artificial	
16	Ginger	Sniffin' P8			
17	Grapefruit	Sniffin' P4			
18	**Grass**	Sniffin' P5		cis-3-Hexen-1-ol	Aldehyde AA triplal
19	**Feces**	Indole		Skatole	Dimethyl disulhide
20	**Lavender**	Sniffin' P10		1-Octen-3-yl acetate	
21	**Leather**	Sniffin' B2			
22	**Lemon**	Sniffin' B6		Lemon oil, rectified	
23	Lilac	Sniffin' P3			
24	Liquorice	Sniffin' B7			
25	**Melon**	Sniffin' P11			
26	**Metal**	RS-426			
27	**Mushroom**	Sniffin' P13			Amyl vinyl carbinol
28	**Onion**	Sniffin' P16		Onion oil, artificial	
29	Orange	Sniffin' B1			
30	**Peach**	Sniffin' P12			
31	**Pear**	Sniffin' P1			
32	**Peppermint**	Sniffin' B4	L-Mentol		Peppermint oil
33	**Pineapple**	Sniffin' B13			
34	Raspberry	Sniffin' P6			
35	Rhinoceros	RS-424			
36	**Rose**	Sniffin' B14		Phenetyl alcohol	
37	Smoked meat	Sniffin' P14			
38	**Tar**	RS-401			Beech-wood creosote
39	**Turpentine**	Sniffin' B8			
40	Wintergreen	Gaultheria oil			

different odor samples used in this study. The EmojiGrid is a Cartesian axes system similar to the Affect Grid (Russell et al. 1989), but the verbal labels on the midpoints and endpoints of the axes are replaced with emoji showing facial expressions. Also, additional emoji are inserted between the midpoints and the endpoints of each axis (resulting in five emoji on each side of the grid), and one (neutral) emoji is placed in the center of the grid, resulting in a total of 17 emoji on the grid. The central emoji with a neutral expression serves as a baseline or anchor point. The facial expressions of the emoji vary from disliking (unpleasant) via neutral to liking (pleasant) along the horizontal (valence) axis and gradually increase in intensity along the vertical (arousal) axis. The facial expressions are defined by the eyebrows, eyes, and mouth configuration of the face and are inspired by the Facial Action Coding System (Ekman and Friesen 2003). The arousal dimension is represented by the opening of the mouth and the shape of the eyes, while the valence dimension is represented by the concavity of the mouth, the orientation and curvature of the eyebrows, and the vertical position of these features in the face area (representing a slightly downward looking face for lower arousal values and a slightly upward looking face for higher valence values). These facial features represent a minimal set needed to express the range of emotions over the Affect Grid. Users respond by placing a checkmark at the location that corresponds to the emoji (facial expression) that best represents their affective appraisal of the stimulus. A simple instruction asking participants to respond by clicking on the EmojiGrid is sufficient to clarify its use and meaning, making it a useful tool for cross-cultural research (Toet et al. 2018).

Experimental Procedure

The experiments were performed in a quiet, well-ventilated room to avoid the presence of any residual odors. Upon their arrival at the laboratory, the participants were welcomed by the experimenter and received a verbal introduction and instructions. Then, they read and signed an informed consent. Participants were informed that they would be presented with 40 different (harmless) smells and would be asked to rate each smell using the EmojiGrid. The participants were shown the

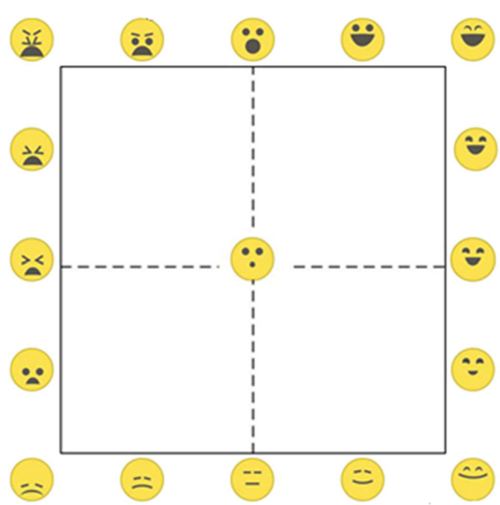

Fig. 1 The EmojiGrid is an emoji labeled Affect Grid for the measurement of odor-related affective associations. The facial expressions of the emoji vary from disliking (unpleasant) via neutral to liking (pleasant) along the horizontal (valence) axis and gradually increase in intensity along the vertical (arousal) axis

EmojiGrid that was presented on a computer screen and were asked to study it carefully. They were informed that they could respond after smelling a given scent by clicking on a point inside the grid that best represented their emotional state. The explanation of the EmojiGrid included no reference to the concepts of valence and arousal since we wanted the participants to use the tool intuitively. The computer stored each response and randomly selected the next odor that was to be presented by the experimenter. The participants were explicitly asked not to attempt to identify the smells since knowledge of odor sources is known to exert a top-down influence on their perceived valence (e.g., Ferdenzi et al. 2013b) and intensity (e.g., Distel and Hudson 2001).

During the experiment, the experimenter (wearing odorless cotton gloves) presented each of the 40 scent pens once (after removing the cap of the pen) for about 5 s at a distance of about 2 cm from the edge of both nostrils of the participant. The participants sniffed following a brief verbal command (natural sniffing is known to provide optimal odor perception: Laing 1983). Immediately after sniffing, the pen was removed (and its cap replaced by the experimenter), and participants were given at least 30 s to smell odorless (ambient room) air (to reduce potential effects of olfactory adaptation and habituation: Grosofsky et al. 2011). The participants reported their affective appraisal of each odor by clicking on the EmojiGrid. The entire experiment lasted about half an hour.

Data Analysis

To enable a comparison of the present results with those from previous studies, the valence and arousal ratings obtained in this study with the EmojiGrid and the corresponding data from previous studies (Bensafi et al. 2002a; Bestgen et al. 2015; Dravnieks et al. 1984; He et al. 2016; Herz and Cupchik 1992) were all (re-)scaled to a common range (from − 4 to 4).

IBM SPSS Statistics 25 (www.ibm.com) for Windows was used to perform all statistical analyses. There was no indication of systematic responding (i.e., a bias for using a limited part of the grid), so no responses were excluded. Intraclass correlation coefficient (ICC) estimates and their 95% confident intervals were based on a mean rating, consistency, 2-way mixed-effects model (ICC(3,k): Koo and Li 2016; Shrout and Fleiss 1979). ICC values less than 0.5 are indicative of poor reliability, values between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 indicate good reliability, while values greater than 0.9 indicate excellent reliability (Koo and Li 2016). For all other analyses, a probability level of $p < 0.05$ was considered as statistically significant.

For each of the odor stimuli, we computed the mean valence and arousal responses across all participants. Matlab 2018b (www.mathworks.com) was used to investigate the relation between the (mean) valence and arousal ratings and plot the data. The Curve Fitting Toolbox (version 3.5.7) in Matlab was used to compute a least squares fit of a quadratic function to the data points.

Results

Many participants spontaneously remarked that the experiment was a pleasurable experience and did not cause fatigue or boredom in any way.

Figure 2 shows the mean valence and arousal ratings obtained with the EmojiGrid for the 40 different odors used in this study, together with the results from the previous studies by Bensafi et al. (2002a), Bestgen et al. (2015), and Herz and Cupchik 1992. This figure shows that the odors successfully elicited a wide range of different emotions. For instance, fruit (e.g., peach, raspberry, banana) typically has the highest positive mean valence ratings, while fish, garlic, and onion have the most negative mean valence ratings. Similar results were obtained in the previous studies by Bensafi et al. (2002a), Bestgen et al. (2015), and Herz and Cupchik (1992). Most food-related smells have mean valence ratings ranging from neutral to positive, except for smoked meat, mushroom, onion, garlic, and fish, which all have negative mean valence ratings. As Fig. 2 shows, most of the corresponding odors from all four studies received similar mean valence and arousal ratings. Some exceptions are for instance garlic (with highly similar ratings between the present study and Bestgen's study, but much higher values in the Bensafi study) and banana (with similar ratings between the present study and the Bensafi study, but lower values in Bestgen's study).

Figure 2 shows that odors that score near neutral on mean valence (e.g., dusty cave, ginger, Coke) typically have the lowest mean arousal ratings, while odors scoring either high (pleasant) or low (unpleasant) on mean valence typically show higher mean arousal ratings. Overall, it appears from Fig. 2 that the mean arousal ratings increase from the center of the valence scale towards its extremes, suggesting that these data can be described by a U-shaped curve. To quantify this observation, we computed a least squares quadratic fit to our data points (the red U-shaped curve in Fig. 2). The adjusted R-squared value (representing the agreement between the data and the quadratic fit) is 0.59, indicating a good fit. Figure 2 also shows that the fitted curve not only closely describes the relation between the mean valence and arousal ratings obtained with the EmojiGrid in the present study, but also describes the results from three previous studies, obtained with different assessment tools (a 9-point rating scale: Bensafi et al. 2002a; SAM: Bensafi et al. 2002a; a 7-point rating scale: Herz and Cupchik 1992). Together, these results suggest that the relation between mean valence and arousal for smells can be characterized by a U-shaped relation at the nomothetic level,

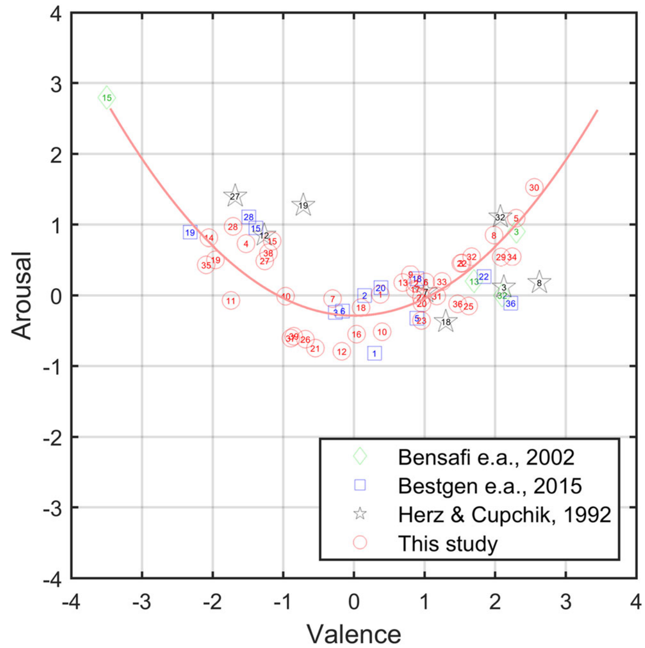

Fig. 2 Relation between mean valence and arousal ratings for different odors and obtained with the EmojiGrid (red circles: this study), a Semantic Differential Scale (green diamonds: Bensafi et al. 2002a), the Self-Assessment Mannikin (blue squares: Bestgen et al. 2015), and a 7-point rating scale (black stars: Herz and Cupchik 1992). The numbers inside the symbols correspond to the item numbers in Table 1. The red curve represents a quadratic fit to data points obtained in this study using the EmojiGrid ($R^2 = 0.59$)

similar to the relation that is commonly found for a wide range of affective stimuli in different sensory modalities.

To quantify the agreement between the ratings obtained for corresponding odors with the Emojigrid in the present study and ratings obtained in previous studies with alternative validated rating tools (a 9-point rating scale: Bensafi et al. 2002a, a SAM scale: Bestgen et al. 2015, a 7-point rating scale: Herz and Cupchik 1992, a 9-point rating scale: Dravnieks et al. 1984 and a VAS: He et al. 2016), we computed intraclass correlation coefficient (ICC) estimates. Table 2 shows that the ICC values for the mean valence ratings are all larger than 0.85, suggesting good reliability. The intraclass correlation between the mean arousal ratings in this study and those of Bestgen et al. (2015) and Herz and Cupchik 1992 are moderate (0.583 and 0.611), while the intraclass correlation with the mean arousal ratings of Bensafi et al. (2002a) is poor (0.428). The ICC values for arousal did not reach significance (as shown by the large 95% confidence intervals in Table 2). This may reflect a difference in odor intensities between the different studies, which could result in a large variability in arousal ratings since our current study has only a limited number of odors in common with these previous studies (12 with Bestgen et al. 2015, 4 with Bensafi et al. 2002a and 8 with Herz and Cupchik 1992).

Conclusion and Discussion

The present study was performed to investigate the overall relation between the mean (at the group level) valence and arousal ratings for odors. Thereto 56 participants rated the perceived valence and arousal for 40 different odors (ranging in valence from unpleasant to pleasant). The results show that the overall relation between mean valence and arousal ratings reflects the well-known U-shaped (quadratic) form that is also commonly observed for affective stimuli in other sensory modalities (e.g., visual, auditory, tactile, gustatory). In addition, the mean valence and arousal ratings for the different odors agree with their corresponding values reported in previous studies in the literature and obtained with alternative self-report tools. These results may be used to select odors with affective properties that are likely to induce the desired behavioral responses in a given application. For instance, pleasant and arousing odors may be deployed to enhance alertness in driving conditions, pleasant and less arousing odors for use in restorative environments, and highly arousing pleasant and unpleasant odors may be used to engage and immerse users in (serious) gaming applications.

In addition, we found that people can reliably report their affective appraisal of odors using the EmojiGrid without any verbal labels or written instructions. This suggests that the EmojiGrid may be a useful tool for professionals from diverse domains (e.g., food and cosmetic industry, developers of multisensory user interfaces, and mulsemedia content) to efficiently assess whether specific odor substances elicit the desired subjective affective experiences. Since the EmojiGrid provides an instantaneous overview of the affective input space, it enables users to provide continuous affective feedback, for instance in HCI studies by moving a mouse-controlled cursor over the support of the grid. This feature may be useful for the real-time affective annotation of mulsemedia (Runge et al. 2016), for personalized affective video retrieval (Lopatovska and Arapakis 2011; Xu et al. 2008), for real-time affective evaluation of entertainment (Fleureau et al. 2012), or as an affective input tool for serious gaming applications (Anolli et al. 2010). A simplified version of the EmojiGrid has already been implemented in the Sensiks Sensory Reality Pod (www.sensiks.com) to enable the user to select a multisensory (visual, auditory, tactile, and olfactory) experience with a prespecified affective quality.

A limitation of this study is that we only measured valence and arousal through subjective self-report. We did not measure any physiological (objective) responses to odor perception. Also, we did not investigate the relation between valence and arousal at the ideographic (within-person) level. It is known that this relation depends on individual characteristics like odor sensitivity (Houghton et al. 2018), mood (Flohr et al. 2017), physiological state (hunger, satiety: Albrecht et al. 2009), sex (Sorokowski et al. 2019), age (Venstrom and Amoore 1968), and cultural background (Ayabe-Kanamura et al. 1998; Kuppens et al. 2017; Rouby et al. 2009). We also did not account for other factors known to influence the affective appraisal of odors such as attention (Forster and Spence 2018) and odor familiarity (Delplanque et al. 2008; Distel et al. 1999).

A further limitation of this study is that we did not account for potential effects of repeated olfactory stimulation. Repeated or prolonged odor exposure can reduce both the perceived intensity of an odor and its hedonic value (Croy et al. 2013; Dalton 2000; Ferdenzi et al. 2014; Jacob et al. 2003). These changes in odor sensitivity and appraisal occur both at a peripheral (receptor) level (adaptation: Dalton 2000) and at a central (postreceptor) level (habituation: Chaudhury et al. 2010; Croy et al. 2013; Deshmukh and Bhalla 2003; Sinding et al. 2017; Wilson 1998). They are typically smell specific Sinding et al. 2017 and depend on hedonic polarity (pleasant vs unpleasant: Croy et al. 2013; Jacob et al. 2003). Although adaptation to a specific odor may generalize to odorants that share structural or perceptual features with the odorant (i.e., cross-adaptation: Pierce et al. 1996), this effect only occurs at high odor concentrations (Berglund and Engen 1993). In this study, we followed the protocol associated with the validated and extended 32-item Sniffin' Sticks olfactory identification test (Haehner et al. 2009; Hummel et al. 2007; Hummel et al. 1997; Rumeau et al. 2016; Sorokowska et al. 2015). Each of the 40 different odorants was presented for 5 s and the interval between two consecutive odor presentations was at least 30 s. Previous studies found no evidence of odor adaptation for exposure durations below 20 s (Chaudhury et al. 2010) and for 30 s breaks between consecutive trials (Pössel et al. 2019).

Given the brief exposure duration, the moderate intensity levels and the randomized sequential presentation of the various dissimilar odorants used in this study, it is unlikely that

Table 2 Intraclass correlation (with their 95% confidence intervals) between the mean valence and arousal ratings obtained with the EmojiGrid (this study) and a Semantic Differential Scale (a 9-point rating scale: Bensafi et al. 2002a), the Self-Assessment Mannikin (SAM: Bestgen et al. 2015), and a 7-point rating scale (RS7: Herz and Cupchik 1992). Also listed are the intraclass correlations between the mean valence ratings obtained in this study with the EmojiGrid and with a 9-point rating scale in the study by Dravnieks et al. (1984) and with a visual analog scale (VAS) in the study by He et al. (2016). N indicates the numbers of items that studies have in common.

	N	Valence	Arousal
EmojiGrid–RS9	4	0.851 [− 1.296–0.990]	0.428 [− 7.827–0.963]
EmojiGrid–SAM	12	0.899 [0.651–0.971]	0.583 [− 0.449–0.880]
EmojiGrid–RS7	8	0.959 [0.795–0.992]	0.611 [− 0.943–0.922]
EmojiGrid–RS9	28	0.924 [0.836–0.965]	-
EmojiGrid–VAS	5	0.898 [0.022–0.989]	-

(cross-)adaptation or habituation effects influenced the present results. However, since we do not yet fully understand the underlying neurobiological mechanisms mediating olfactory (cross-)adaptation and habituation (Chaudhury et al. 2010) and how these effects depend on the (dis-)similarity in the molecular characteristics of the consecutively presented odorants (Sinding et al. 2017) and on their perceived hedonic quality (Croy et al. 2013; Ferdenzi et al. 2014), it cannot be completely ruled out that these effects may have influenced the present results. We also did not check whether the presentation of the 40 different odorants induced mental fatigue. However, since the participants remained highly curious and interested in their task throughout the experiment (during the debriefing several participants spontaneously remarked they had enjoyed the experiment and asked if they could be included in a follow-up study), it also seems unlikely that mental fatigue affected the present results.

The good fit of a quadratic (U-shaped) relation to the data indicates that valence and arousal are not independent at the nomothetic level: mean odor induced arousal increases with mean absolute valence. This suggests that the odors used in the present study had a clear valence, since it is typically found that the correlation between mean valence and arousal increases with decreasing valence ambiguity (Mattek et al. 2017). To get a full picture of the relation between mean valence and arousal, future studies should investigate a wider range of odors, including more surprising odors, i.e. odors with ambiguous mean valence (near neutral mean valence and higher mean arousal levels).

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Compliance with Ethical Standards

Conflict of Interest The authors declare they have no conflicts of interest.

Ethical Approval The study was carried out in accordance with the Declaration of Helsinki and was approved by the Local Ethics Committee.

Informed Consent The research involved human participants. They provided written informed consent.

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