Emotional Correlates of Unirhinal Odor Identification

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Abstract

It seems self-evident that smell profoundly shapes emotion, but less clear is the nature of this interaction. Here we sought to determine whether the ability to identify odors co-varies with self-reported feelings of empathy and emotional expression recognition, as predicted if the two capacities draw on common resource. Thirty six neurotypical volunteers were administered the Alberta Smell Test, The Interpersonal Reactivity Index and an emotional expression recognition task. Statistical analyses indicated that feelings of emotional empathy positively correlated with odor discrimination in right nostril, while the recognition of happy and fearful facial expressions positively correlated with odor discrimination in left nostril. These results uncover new links between olfactory discrimination and emotion which, given the ipsilateral configuration of the olfactory projections, point towards intra- rather than inter-hemispheric interaction. The results also provide novel support for the proposed lateralisation of emotional empathy and the recognition of facial expression, and give reason to further explore the diagnostic sensitivity of smell tests because reduced sensitivity to others' emotions can mark the onset of certain neurological diseases.

Key words: smell, affect, hemisphere, normative sample.

Introduction

Olfactory cortex is the only primary sensory area that projects diffusely to the limbic structures without first passing through the thalamus (Soudry, Lemongne, Malinvaud, Consoli & Bonfils, 2011; Zald & Pardo, 1997). This direct connectivity supports the idea that olfaction provides a rapid, albeit relatively primitive, means of identifying and responding to environmental threat. In recent years, the close association between olfaction and affective information processing has received particular interest from the clinical community. This interest is centred around the finding that a number of neuropsychiatric diseases are associated with olfactory dysfunction, which in turn suggests that simple tests of smell may hold diagnostic value. In the present study, we sought to identify novel associations between olfaction and emotion with a view to better clarifying how these two cognitive domains interact, and in the longer-term informing neurological diagnoses.

The link between olfaction and other elements of cognition has been most extensively, and perhaps vividly, demonstrated in neurological patients. Reliable associations have been found between the ability to identify odors and the absence/presence of Lewy body disease in Parkinson's Disease (Mahlknecht et al., 2015), Kallman Syndrome (Koenigkam-Santos et al., 2011), Wilson's Disease (Mueller et al., 2006) and Refsum's Disease (Gibberd, Feher, Sidey & Wiezbicki, 2004). With respect to affective processing, reduced olfactory identification has been observed in individuals suffering from major depressive disorder (see Schablitzky and Pause, 2014), schizophrenia (Brewer et al., 1996; Compton et al., 2006), and anxiety (Takahashi et al., 2015). More generally, dysosmia patients report a reduced quality of life compared to age- and gender-matched controls (Deems et al., 1991).

By their very nature, neurotypical participants usually show smaller variation in olfactory sensitivity and affective state than their atypical counterparts, which can make associations harder to find. This search may be made easier by using methods that respect the ipsilateral configuration of the olfactory pathways because there is some evidence that ipsilateral affective processes show a stronger relationship with nostril sensitivity than those that are contralateral (e.g. Postolache et al., 1999, Spinella, 2002). For example, Postolache et al. (1999) showed that chronic feelings of negativity (more commonly associated with right than left hemisphere) correlate with reduced odor identification in right but not left nostril. As reviewed below, ratings of emotional empathy (more commonly viewed as a right rather than left hemisphere function) correlate with right but not left nostril odor identification (Spinella, 2002), while response times for making hedonic judgments of unpleasant odors are significantly shorter than for pleasant odors during right but not left nostril stimulation, an effect that is accompanied by larger ERP amplitudes in right hemisphere (see Kobal & Kettenmann, 2000). These results support the idea that emotional and olfactory competencies which share a common hemispheric basis will co-vary more closely than those that reside in separate hemispheres.

The main anatomical pathway through which olfactory-limbic transmission occurs is relatively well-characterised. The pathway begins at the level of the nasal cavity where bipolar axons from peripheral sensory receptors project ipsilaterally to glomeruli in the olfactory bulb which in turn connect to the primary olfactory cortex via the lateral olfactory tract (Shipley & Reyes, 1991). The primary olfactory cortex is a heterogeneous structure containing mostly, entorhinal, piriform and peri-amygdala cortex. Secondary connections of the olfactory bulb project to several other limbic structures including thalamus, insula and orbito-frontal cortex (see Royet & Plailly, 2004). Only a few contralateral connections via the anterior commissure have been identified (Shipley & Ennis, 1996), supporting the idea that the initial limbic response to smell is predominantly intra- rather than inter-hemispheric.

In the present study, we focused on the relationship between smell and two types of affective process; empathy and the recognition of emotional expression. These relationships are for the most part unexplored but may be clinically relevant because impairments in empathy and recognising emotional expression are evident in a number of disabling impairments such as fronto-temporal dementia and Autism. If it can be shown in neurotypical individuals that these affective capacities associate with olfactory sensitivity, in this case odor identification, then it may be possible to increase the detection of such neuropsychiatric disorders via brief, inexpensive smell tests.

Empathy can be defined as the vicarious feeling of others' emotional states, occurring when the observation or imagination of affective states in another induces shared states in the observer (de Vignemont & Singer, 2006). Commonly, the empathy construct has been separated into two types: cognitive and emotional (Davis, 1983; Decety & Jackson, 2006). Cognitive empathy involves the ability to know what another person is thinking or feeling and is similar to the concept of 'theory of mind'. Emotional empathy, involves actually experiencing a similar emotion. Convergent sources indicate that elements of empathy processing are preferentially lateralised to the right hemisphere. A recent study of 27 patients with acute right ischaemic stroke, particularly those with lesions to the temporal pole and anterior insula, showed a higher incidence of impaired affective empathy than a control sample of hospitalised transient ischaemic attack patients (Leigh et al., 2013). Neuro-degenerative patients show a stronger association between empathy impairment and atrophy in right compared to left hemisphere (Eslinger et al., 2007; Eslinger, Moore, Anderson & Grossman, 2011). For example, in one voxel-based morphometry study of 123 patients with Alzheimer's Disease, progressive supranuclear palsy, corticobasal degeneration or frontotemporal dementia, caregiver ratings of empathic concern and perspective–taking correlated most significantly with the volume of grey matter in right temporal pole (Rankin et al., 2006). In neurotypical volunteers, the degree of right-left frontal EEG asymmetry is predictive of empathic concern such that individuals with stronger right-sided, frontal alpha activity tend to show greater empathic concern towards distressing images than those with a left-sided predominance (Tullett, Harmon-Jones & Inzlicht, 2012).

The only attempt to find an association between monorhinal presentation and empathy has been reported by Spinella (2002) who showed that right-, but not left-sided, identification of the smells presented in the Alberta Smell Test (Green & Iverson, 2001) correlated with the empathy scores on the Mehrabian and Epstein Empathy questionnaire (Mehrabian & Epstein, 1972). Although the Mehrabian and Epstein Empathy questionnaire produces a unitary empathy score, post hoc analysis indicated that the association was strongest for those items that tended to probe affective rather than cognitive empathy. With respect to the current study, stronger evidence for this association would be gained if it could be reproduced using a more widely-used measure of empathy, such as the Interpersonal Reactivity Index (IRI) (Davis, 1980), and which unlike the Mehrabian and Epstein Empathy questionnaire, is designed to independently assess the emotional and cognitive components of empathy.

The degree to which recognition of emotional expression is lateralised continues to attract debate, although there does seem to be consensus that any underlying pattern of laterality is moderated by subjective experience and perception of the emotion (see Davidson, 1995). Some contend that the right hemisphere has a special role in emotional processing, dominating all emotional responses regardless of valence, while others have found no interaction between hemisphere and the discrimination of emotional expression (see Abbott, Cumming, Fidler & Lindell, 2013; Abbott, Wijeratne, Hughes, Perre & Lindell 2014). Supporters of the valence hypothesis contend that the processing of negative emotions is preferentially lateralised to the right hemisphere, while positive emotions are preferentially lateralised to the left hemisphere. Unilateral damage of the right and left hemisphere has been shown to impair judgements of negative and positive emotions respectively (Mandal, Tandon & Asthana, 1991) while in neurotypical volunteers the lateralised visual field presentation of positive and negative facial expressions produces shorter reaction times following right visual field-left hemisphere and left visual field-right hemisphere respectively (Reuter-Lorenz & Davidson, 1981). An alternative version of this valance hypothesis recasts lateralisation in terms of whether the emotion motivates approach or withdrawal behaviour (Davidson, Ekman, Saron, Senulis & Friesen, 1990; Harmon-Jones, 2004). Expressions of happiness, surprise and anger are deemed to engage left-lateralised approach processes while expressions of sadness, fear and disgust engage right-lateralised withdrawal processes (see also Najt, Bayer & Hausmann, 2013). Both valence hypotheses therefore propose the same pattern of emotional lateralisation except for anger which lateralises to the right and left hemispheres according to the emotional and approach/withdrawal hypotheses respectively.

Other lines of enquiry play down a strict pattern of lateralisation and allude to a more distributed network. Studies of emotional prosodic perception in brain-lesioned individuals point to a wide-spread bi-hemispheric network for emotional control (Witteman, van Ijzendoorn, van de Velde, van Heuven & Schiller, 2011), a finding that resonates with the functional neuroimaging literature which shows bilateral hemispheric responses to all emotional expressions. In a recent meta-analysis of 105 relevant functional MRI studies, Poli et al. (2009a, 2009b) reported that the presentation of happy, fearful, sad, angry and disgusted faces was each associated with bilateral activation of the precuneus, amygdala and multiple gyri including the para-hippocampal, fusiform, lingual, inferior/middle occipital, posterior cingulate, middle temporal, inferior/superior frontal. The only valence-specific lateralised brain response was in left amygdala to faces with negative emotions. The 'functional atlas' produced by these imaging data suggest that previous behavioural paradigms have produced reaction time and accuracy data that preferentially tap lateralised components of what is in fact a bilateral network. The question therefore arises as to whether alternative paradigms, such as those that involve smell, can reveal components that reside on the opposite side of this supposed bilateral network.

To better understand the relationship between olfaction and affect, we therefore administered in each of thirty six neurotypical volunteers the Alberta smell test (under monorhinal presentation), the IRI, and two computerised tasks of facial emotion identification - one performed at short (50ms) stimulus exposure and the other at longer (2000ms) exposure. Exposure duration was manipulated to help determine the source of any underlying effect. Shorter exposures place a greater emphasis on early, more automated stages of processing while longer exposures incorporate a stronger cognitive component characterised by deliberate and consciously-mediated responses (LeDoux, 1996).

Method

Participants

Eighteen female and 18 male student volunteers (age range 18-46) were recruited for course credit from the University of Kent. All participants were right-handed, as assessed by the modified version of the Annett's Handedness Questionnaire (Briggs & Nebes, 1975). Self-report revealed that 1 participant smoked (5 cigarettes per day). Individuals with a self-reported history of psychopathology or olfactory disorder were excluded. The study adhered to the Declaration of Helsinki guidelines and was approved by the University Research Ethics Committee with all participants providing written informed consent prior to participation.

Measures

The Alberta Smell Test

Scented, coloured markers with authentic essences of lemon, orange, liquorice, cinnamon, mint, raspberry, grape and melon were presented by the experimenter half an inch below one nostril at a time, each for 3s. Participants were required to close their eyes (to ensure that they did not see the colour of each marker which might influence their decision), close one nostril and then sniff when told to do so. Participants were then asked to open their eyes and identify each odor from a list of eight options printed on a sheet of paper. The options did not differ from trial to trial, and participants indicated their choice, without subsequent feedback, by placing a tick next to their chosen scent (clean, un-ticked versions of this list were provided for each trial). 10 trials were administered to each nostril in the following, validated order: 4 right (liquorice, cinnamon, grape, orange), 4 left (mint, lemon, orange, liquorice), 4 right (liquorice, melon, raspberry, mint) 4 left (grape, orange, melon, cinnamon), 2 right (orange, lemon), 2 left (raspberry, liquorice). The scented markers are widely-available and marketed under the trade name *Mr Sketch*. The minimum score for the number of correct responses per nostril was 0 and the maximum score was 10. To provide a non-lateralised measure of identification ability, the overall number of correct smell responses (number of correct responses in left nostril + number of correct responses in right nostril) was calculated for each participant (see L+R column in Table 1 which provides group summary statistics).

Emotion Recognition tasks

The computerised face images for the short and long exposure series were taken from the Penn Emotion Recognition Task - 40 Faces version (Gur et al., 2002) and Penn Emotion Recognition Test - 96 Faces version respectively (Gur et al., 2002). To equate the number of faces presented in each exposure series, 40 different pictures, matched for intensity and emotional expression, were taken from the 96 Faces version. All images were colour photographs of adult male and female actors performing neutral or mild/extreme happy, sad, fearful, and angry facial expressions. The faces varied in gender and ethnicity and, over the course of the experiment, each actor was seen performing all emotions. Face images appeared on screen, in random order, until the participant indicated via keyboard press in an unspeeded manner, if the image was ‘happy’, sad’, ‘angry’, ‘fearful’, or ‘neutral’. Faces subtended approximately $6^0 \times 4^0$ of visual angle at a viewing distance of 50cm. The presentation of each face was preceded by a central fixation cross that appeared for 500msecs. Response accuracy, but not reaction time, was recorded. For each emotional expression, the minimum score for the number of correct responses was 0 and the maximum score was 8. Although neutral expressions were presented to reduce the high ratio of negative to non-negative expressions, responses to neutral faces were not analysed given the theoretical focus on negative and positive affect.

Interpersonal Reactivity Index (IRI)

The IRI is a 28-item self-report questionnaire made up of 4 empathy subscales*;* (1) Perspective Taking (PT) which assesses the tendency to spontaneously adopt the psychological point of view of others, (2) Empathic Concern (EC) which taps the respondents’ feelings of warmth, compassion, and concern for others, (3) Fantasy (F), which taps respondents’ tendencies to transpose themselves into the feelings of fictitious characters, and (4) Personal Distress (PD) which assesses self-oriented feelings of discomfort resulting from tense interpersonal settings or emergency situations. While both the EC and PD scales assess emotional components of empathy, the EC scale is more outwardly focused on others’ suffering, while the PD scale is relatively more self-focused and may in part assess anxiety and the inability to monitor and inhibit emotional reactions (see Baron-Cohen & Wheelwright 2004; Konrath, 2013). The PT scale, on the other hand, is seen to best operationalise cognitive empathy. The IRI has good internal consistency, with alpha coefficients ranging from 0.68 to 0.79. Furthermore, the IRI has been shown to correlate with other measures of empathy, providing support for the construct validity of the measure (Davis, 1980). The minimum and maximum score for each subscale is 0 and 28 respectively, with the total score then obtained by summing each of these 4 subscale scores.

Procedure

After providing written informed consent, participants were seated at a desk in a quiet room and completed the tests in random order with the exception of the two emotion recognition tests, the order of which was counterbalanced. For the recognition tests, participants were seated approximately 50cm from the display monitor.

Results

Mean, standard deviation and minimum/maximum scores were calculated for each test and are presented in Table 1. Regression analyses were conducted to determine the strength of relationship between odor identification accuracy and the scores from each of the other measures. Normal probability plots confirmed that all statistically significant effects reported were from normally distributed scores. Our statistical approach was to minimise the potentially large number of tests that could be performed by conducting stepwise regression analyses. This analysis ensures that only variables that explain a significant amount of variance remain in the model whilst taking into account the intercorrelations between variables. Separate regressions were performed on the left and right nostril accuracy scores (i.e. each of the dependent variables) respectively.

Table 1 about here

There was a reliable association between IRI total score and the ability to identify odors presented to right nostril ($r(34)=.404$, $p=.015$). The association between total IRI score and left nostril failed to reach significance ($r(34)=-.02$, $p=.93$). A step-wise regression with right nostril as the dependent variable and the four IRI sub-scales as predictor variables indicated that only the PD sub-scale entered the model ($F(1,34)=13.93$, $p=.001$, $\beta=.54$). As a consequence of the strong PD-right nostril association, left and right nostril responses combined also showed a reliable association with the PD sub-scale ($F(1,34)=7.33$, $p=.01$,

β=.42). The lateralisation quotient (right-left / right+left) also reached statistical significance on the EC sub-scale indicating a right-sided preponderance for higher EC IRI and odor identification scores ($F(1,34)=5.16$, p=.029, β=.36).

Our next question focused on possible associations between emotion recognition and odor identification. As above, two nostril-specific stepwise regression analyses were initially carried out to address which combination of duration (50ms, 2000ms) and facial emotion (happy, sad, angry or fearful) could best explain the accuracy with which odors were identified. The accuracy with which odors were identified following left nostril presentation indicated a significant model ($F(2,33)=4.781$, p=.015, R^2=.225) with two predictor variables that were positively associated with odor accuracy: recognition accuracy of happy faces at short durations (β=.339, sr^2=.335, p=.036) and recognition of fearful faces at short durations (β=.39, sr^2=.385, p=.017). No statistically significant regression model was found between odor identification in right nostril and emotional recognition.

Discussion

The experiment produced two notable outcomes: (1) emotional empathy, as indexed by both the IRI PD sub-scale (a measure of self-oriented, aversive feelings evoked by observing others in distress) and the IRI EC sub-scale (a measure of respondents' feelings of warmth, compassion, and concern for others) correlated positively with the ability to identify odors presented to right nostril, and (2) the recognition of happy and fearful expressions correlated positively with the ability to identify odors presented to left nostril. These outcomes extend our understanding of how olfaction interacts with emotion perception and inform current models of cerebral lateralisation.

The significant correlation between emotional empathy and right nostril olfactory performance is the first to replicate the result obtained by Spinella (2002), providing further evidence that the emotional and cognitive elements of empathy dissociate (See Decety & Jackson, 2006; Shamay-Tsoory, Aharon-Perez & Perry, 2009). The replication is also important because lateralised, sensory-perceptual effects in neurologically healthy individuals are especially sensitive to subtle changes in stimulus and task demand and thereby notoriously difficult to reproduce (Bryden, 1982, Hellige, 1993). From a biological perspective, the nostril-specific effect points to an intra-hemispheric rather than inter-hemispheric interaction, and ties in with the idea that feelings of empathy rely preferentially on processes in right hemisphere. Based on the fact that intra-hemispheric transmission is often swifter and more efficient than inter-hemispheric transmission (Banich & Belger, 1990; Dimond, 1969; Poffenberger, 1912), this co-lateralisation may make it easier for smell to modulate ‘early emotional’ rather than ‘late cognitive’ processes and thereby play a key role in priming avoidance or approach responses (see Stevenson & Attuquayefio, 2013). In line with such a possibility, we note that the initial (but not later) stages of empathic responding are associated with unilateral electrophysiological changes in right as opposed to left hemisphere (Choi et al., 2014).

The observed association between recognising happy and fearful faces and identifying odors presented to left nostril has not, as far as we are aware, been reported. The association only held when faces were presented briefly (50ms) which may point to processes occurring at a relatively early stage of perceptual/affective processing that, as also seems to be the case with the olfactory-empathy association reported above, are more emotional than cognitive in nature. In line with this interpretation, those areas of brain (i.e. amygdala and prefrontal cortex) implicated in the identification of both smell and facial emotion respond at very short (<120ms) post-stimulus latencies (Steinberg et al., 2012).

While the association between left-sided odor identification and the categorisation of happy faces provides a new type of evidence for the long-held view that the processing of happy faces is primarily left lateralised (e.g. Reuter-Lorenz & Davidson, 1981), the observed association between left-sided odor identification and the categorisation of fearful faces does not fit any of the prevailing models of emotional lateralisation. According to the emotional valence, approach/withdrawal and right hemisphere hypotheses, the processing of fearful faces is right lateralised. However, these hypotheses are based on behavioural measures of performance, and overlook conclusions drawn from systematic reviews of the functional imaging data (Poli et al., 2009a, 2009b) which highlight a bilateral pattern of activation that features a left lateralised amygdala response to fearful faces (though note that the reviews report a left-sided preference for other negative emotions too). Of course, the insensitivity of systematic reviews to subtle but potentially important methodological factors can limit their inferential value, but evidence for a bi-hemispheric model of emotional recognition can be found at the single study level too (see Beraha et al, 2012). Functional imaging aside, volumetric MRI measurements also show left-sided involvement in fear recognition (e.g. Fisler et al., 2013; Rogers et al., 2009; Zhao, Yan, Chen, Zuo & Fu, 2013). For example, Zhao and colleagues (2013) found that the size of the left, but not right, amygdala correlated with the ability to recognise fearful expressions. By contrast, left amygdala volume did not correlate with the ability to recognise anger, disgust, sadness, surprise or happiness. The present data lead us to suggest that this discrepancy between the behavioural and biological literature may reflect paradigm selection rather than the true underlying pattern of lateralisation. A behavioural correlate of the left hemisphere physiological activation seen during the recognition of fearful faces can in fact be uncovered if the discriminatory abilities of other sensory modalities, in the present case the olfactory system, are taken into account. Of course, it now needs to be determined whether the association between odor identification and the apprehension of facial affect simply reflects a shared reliance on common, intra-hemispheric substrate or whether it is more functional in nature. But the main point is that it seems possible to resolve some of the ambiguity that surrounds the lateralisation of emotional expression recognition by modelling cross-modal interactions with smell.

Several study limitations reduce the weight of our conclusions, notably the brevity of the smell and affective tests administered. Also, the relatively small sample size made it difficult to justify further statistical procedures to determine whether the observed associations were mediated by gender, ethnicity and stimulus intensity. Previous study has shown that interactions between the gender and ethnicity of the observer and that of the individual showing an emotional expression can influence lateralisation (Bourne, 2005; Gasbarri et al., 2007; Rahman & Anchassi, 2012; Ran, Chen & Pan, 2014). For example, men can show greater right-sided lateralisation than women when viewing happy faces (Bourne, 2005), and at a finer level, men show greater right-sided lateralisation than women when noticing vigilance and threat in male rather than female faces (Rahman & Anchassi, 2012). Others have shown that the intensity of emotional expression (i.e. mild vs. extreme) can also influence the degree of lateralisation (Bourne, 2010). It is possible that the present associations are strongly determined by interactions between these various factors, and future work will need to recruit larger samples to assess this possibility.

As mentioned in the Introduction, the discovery of new associations between smell and affect in neurotypical volunteers is of potential clinical significance. The reduced ability to either show empathy or recognise particular emotional expressions can accompany and sometimes foreshadow the manifestation of other, often more gross, symptoms associated with fronto-temporal dementia (Cerami et al., 2014), Parkinson's Disease (Clark, Neargarder & Cronin-Golomb, 2010), Autism (Happé & Frith, 2014), Schizophrenia (Konstantkopoulos et al., 2014) and post-traumatic stress disorder (Poljac et al., 2011). All these conditions can be difficult to distinguish from other syndromes, especially in the initial stages, and given the links demonstrated here, there is renewed reason to build on the small number of studies that have started to explore the diagnostic sensitivity of smell ability in these populations. Our data suggest that a key methodological procedure within these studies should be to assess smell performance unirhinally rather than birhinally, a procedure not routinely adopted.

In sum, the current study provides further evidence that smell and emotion are deeply intertwined. The specific associations observed lend support to the functional relevance of the ipsilateral olfactory projections and to the relative lateralisation of emotional empathy and the recognition of facial expressions. The data also justify the piloting of diagnostic smell tests for neurological syndromes that impact empathy and the recognition of facial emotion. More generally, we wish to highlight the role that olfactory investigations can play in understanding patterns of cerebral lateralisation seen in other cognitive domains.

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Table 1. Summary of Group Scores.
Group mean scores shown for the smell and faces tests are based on the number of correct responses. Key to abbreviations: SD=standard deviation, Min=minimum score, Max=maximum score, L=left nostril score on Alberta Test, R=right nostril score on Alberta Test, L+R=left and right nostril scores combined, FS=fantasy, EC=empathic concern, PT=perspective talking, PD=personal distress, T=total score, H=happy, N=neutral, S=sad, A=angry, F=fearful.

	Smell			**IRI**					**Faces 50ms_Faces 2000ms**				
	L	**R**	**L+R**	**FS**	**EC**	**PT**	**PD**	**T**	**H**	**N**	**S**	**A**	**F**
Mean	7	8	14	17	19	18	12	67	7_8	6_6	5_6	4_5	7_6
SD	2	2	3	6	5	5	5	14	1_1	1_2	2_1	1_1	1_2
Min	3	5	9	3	7	10	0	38	5_8	3_2	0_2	1_2	2_0
Max	10	10	19	28	26	26	25	93	8_8	8_8	8_8	7_7	8_8