Chapter 6
Olfactory and Haptic Crossmodal Perception in a Visual Recognition Task

S. Invitto, A. Calcagnì, M. de Tommaso and Anna Esposito

Abstract Olfactory perception is affected by cross-modal interactions between different senses. However, although the effect of cross-modal interactions for smell have been well investigated, little attention has been paid to the facilitation expressed by haptic interactions with a manipulation of the odorous object's shape. The aim of this research is to investigate whether there is a cortical modulation in a visual recognition task if the stimulus is processed through an odorous cross-modal pathway or by haptic manipulation, and how these interactions may have an influence on early visual-recognition patterns. Ten healthy non-smoking subjects (25 years $\pm$ 5 years) were trained to have a haptic manipulation of 3-D models and olfactory stimulation. Subsequently, a visual recognition task was performed during an electroencephalography recording to investigate the P3 Event Related Potentials components. The subjects had to respond on the keyboard according to their subjective predominant recognition (olfactory or haptic). The effects of haptic and olfactory condition were assessed via linear mixed-effects models (LMMs) of the lme4 package. This model allows for the variance related to random factors to be controlled without any data aggregation. The main results highlighted that P3 increased in the olfactory cross-modal condition, with a significant two-way interaction between odor and left-sided

S. Invitto (✉)
Human Anatomy and Neuroscience Lab, Department of Environmental Science and Technology, University of Salento, Lecce, Italy
e-mail: sara.invitto@unisalento.it

A. Calcagnì
Department of Psychology and Cognitive Science, University of Trento, Trento, Italy

M. de Tommaso
Department of Medical Science, Neuroscience, and Sense Organs, University Aldo Moro, Bari, Italy

A. Esposito
Department of Psychology, University of Campania 'Luigi Vanvitelli', Caserta, Italy

A. Esposito
IIASS, Vietri Sul Mare, Italy

A. Esposito et al. (eds.), *Quantifying and Processing Biomedical and Behavioral Signals*, Smart Innovation, Systems and Technologies 103,
https://doi.org/10.1007/978-3-319-95095-2_6

lateralization. Furthermore, our results could be interpreted according to ventral and dorsal pathways as favorite ways to olfactory crossmodal perception.

Keywords Olfactory perception · Cross-modal perception · Haptic stimulation 3D shapes · Smell · P3

6.1 Introduction

The connectivity of brain sensory areas with other sensory modalities allows the integration of olfactory information with other sensory channels, which is the origination of multisensory and cross-modal perceptions [9, 15, 16].

The mechanisms by which different smells cause different brain responses have been described by the olfactory map model [7]. Olfactory receptors respond differently and systematically to the molecular features of odors. These features are encoded by neural activity patterns in the glomerular layer, which seem to create images representing odors. Such olfactory images play a role in the representation of perceived odors. The odor images are processed successively by microcircuits to provide the basis for the detection and discrimination of smells. The odor images, combined with taste, vision, hearing, and motor manipulation, provide the basis for the perception of flavors [26]. Such a complex reality reflects the need for the brain to develop strategies to quickly and effectively codify different sensorial inputs originating from different sensorial modalities.

Evidence of cross-modal activation in the olfactory system is highlighted by observing olfactory clinical dysfunctions, for example, anosmia. The most common symptom of anosmia is an interference with feeding; anosmic patients are not able to regularly detect the taste and smell of foods. In these cases, the patient may favor other senses.

The smell of food seems to be affected by tactile perception in young subjects and by visual impact in elderly subjects [18]. Experimental evidence investigating the cross-modal association between taste and vision showed that pleasant and unpleasant tastes are associated with round and angular shapes, respectively [9, 19].

Emotion-based information processing involves specific regions of the brain (insula and amygdala) that interact with the olfactory system. The amygdala then modulates the perception of facial expressions that describe specific emotional states. In fact, emotional face recognition is not merely a visual mechanism because it works through the integration of different multisensorial information (that is, voice, posture, social situations, and odors). In particular, the olfactory system appears highly involved in processing information about social interactions [16].

Although a large body of research exists on cross-modal interactions between olfaction and other senses, it has only been in the last decade that there has been a rise in the number of studies investigating the nature of multisensorial interactions between olfaction and touch. Results from our search of the literature highlighted that olfactory perception could modulate haptic perception in terms of different tactile dimensions, such as texture and temperature [5, 6]. Recent findings have shown that haptic and visual recognition are influenced in the same way by the orientation and size of objects [4].

A relevant role in cross-modal interaction is played by a subject's bias, either in naming or representing odors in mental imagery, even when not expressly required by the task. However, little attention has been paid to the facilitating role played by haptic interaction when manipulating the shape of an 'odorous' object.

The aim of the present research is to investigate whether there is cortical modulation during a visual recognition task if the stimulus, which represents a odorous object, is processed by an odorous cross-modal pathway or by haptic manipulation, and how these interactions may have an influence on early visual-recognition patterns. We investigate crossmodal perception through P3 Event Related Potential (ERP). P3 is an ERP component that we can be elicited through an odd ball task in an electroencephalic recording [17, 25]. Furthermore, P3 could be elicited in Olfactory task [20–22]. Moreover, although P3 is a non-specific component for the selection of shape patterns, it is a very sensitive component in the processing capacity [13], therefore the most suitable for this cross-modal protocol.

6.2 Method

6.2.1 Participants

Ten healthy non-smoking subjects (25 years ± 5 years) were recruited from the student population at the University of Salento to participate in the study. All subjects had normal smelling abilities and with normal vision. There were no reported current or past psychopathologies, neurological illnesses, or substance abuse problems.

Participants were instructed to not use perfume or drink coffee on the day of the test. Event-Related Potentials recording sessions were scheduled between 9 and 5 p.m. Each session had a duration of 1 h.

The experimental protocol was approved by the Ethical Committee of ASL (Local Health Company) of Lecce, and informed consent was obtained from participants according to the Helsinki Declaration.

6.2.2 Stimuli and Procedure

We arranged an experiment of olfactory stimulation by analyzing visual ERPs after a training of cross-modal haptic and olfactory interaction with nine diluted odorants and three-dimensional (3-D) shapes (Fig. 6.1). The smells were selected from five representative types of categorical spatial dimensions [12]. Six odors were presented in Cross-modal olfactory and haptic condition (i.e., Lemon, Cinnamon, Mushrooms, Banana, Grass, Eucalyptol) were presented in olfactory crossmodal haptic mode, 5 odors were presented in olfactory condition (i.e., mint, Rose, Geraniol, Almond, Flowers) and 27 odors were presented for the olfactory visual condition (e.g., Apple,

Fig. 6.1 Example of three-dimensional haptic shapes printed for the experiment

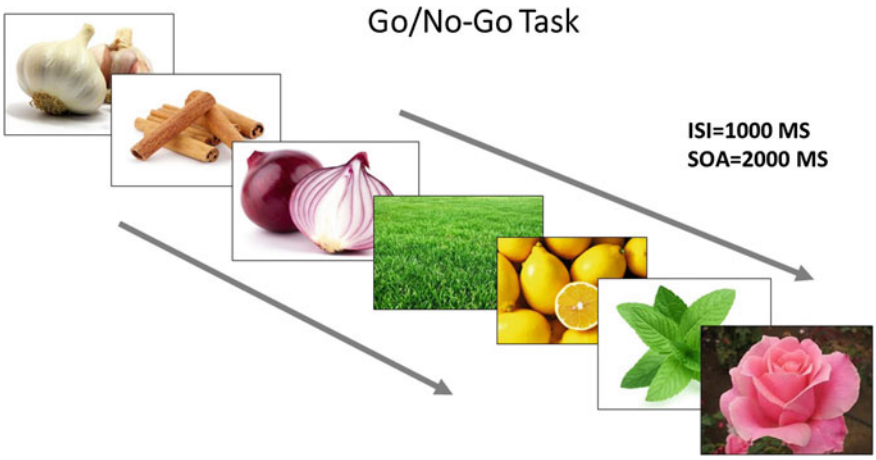

Fig. 6.2 Example of the Go/No-Go Task presented during the experiment. The instructions were: "Please, press the left-hand side button if your predominant recognition of the stimulus has been encoded through olfactory stimulation and the right-hand side button if it has been encoded through haptic stimulation"

Chocolate, Potato, Salt, Garlic, fishing, vanilla, strawberries, rice, salt, pasta, poop, Lemon, Cinnamon, Mushrooms, Banana, Grass, Eucalyptol, Mint, Rose, Geraniol, Almond, Flowers and so on).

Subjects were trained to have haptic manipulation of 3-D models (which were created using the 3-D Blender 2.74 platform) and olfactory stimulation in a black case through an olfactory stimulation device [11]. Stimulations were presented in a blind modality (the subject didn't have any visual information about the odorant or about the shapes). Each stimulation had a duration of 1000 ms.

After the training, subjects had to perform a computer-based visual recognition task. During the task, two-dimensional (2D) visual stimuli (a repertoire of images that represented edible and scented substances) were presented to the subjects. The images of the Go/No-Go Task were presented using the software ePrime 2.0 (Fig. 6.2). During the Go/No-Go Task, the interstimulus interval (ISI) had a duration of 1000 ms, the stimulus presentation had a duration of 1000 ms, and the stimulus-onset asynchrony (SOA) had a duration of 2000 ms. An EEG recording (64-channel actiCHamp, Brain Products) was made during the task for each subject.

During the 2-D session, the subjects were tasked with pressing a button on the left-hand side of the keyboard if the predominant recognition of the stimulus had been encoded through olfactory modality and a button on the right-hand side of the keyboard if the predominant recognition of the stimulus has been encoded in haptic modality. After the Go/No-Go Task a Visual Analogic Scale (VAS) was administrated to the subjects to investigate the pleasantness, the level of arousal and the familiarity of the different conditions.

6.3 Data Analysis

Statistical analyses were performed using linear mixed-effects models (LMMs) and the lme4 package [2], which were available through the R Project for Statistical Computing program (version 3.1.1). Unlike traditional analyses of repeated measures, LMMs allow for analyses of unbalanced datasets and simultaneous estimation of group (fixed) and individual (random) effects [23] without averaging across trials. These kinds of statistical models are becoming popular in psychophysiology over the last decades [28]. In the current study, separate LMMs were run to evaluate the effect of the conditions (odor and haptic vs. visual condition) and lateralization (left, median, right) on amplitude and latency of the P3 ERP components. In each model, we considered the condition and the lateralization as fixed effects, and participant variability was coded as a random effect. The interaction between the condition and the lateralization was also checked. Results are described by assessing fixed effects in terms of beta coefficients of regressors (βs), standard errors (*SE*s), and t-values (*T*s). Due to the distributional characteristics of the variables used in this study, models were estimated using the DAS-robust algorithm and implemented using the rlmer function in the R package [14]. In the context of robust-LMMs, significant effects were detected using the decision rule $|t| > 2.0$ because there were no common ways to compute degrees of freedom and, relatedly, *p*-values of regressors [1].

6.4 Results

Behavioural Results: Descriptive statistics values of VAS dimensions are described in Table 6.1. Table 6.1 indicates that crossmodal condition is valued as more pleasant, more arousing and more familiar than Visual condition.

During the Go/No-Go task the subjects respond with the same proportion to their stimulus encoding (51% olfactory encoding; 49% haptic encoding) (Fig. 6.3).

Descriptive value of Reaction Time Response (RTR) indicated a faster mean RTR in Olfactory Encoding (909.43 ms; SD = 39.30) than in Haptic Encoding (1046.84 ms; SD = 71.32) (Fig. 6.4).

Psychophysiological Results: Table 6.2 shows results for the Amplitude component of P3. They revealed a significant effect of Condition ($\chi^2_2 = 79.27$, $p < .001$),

Table 6.1 Descriptive statistics of VAS dimensions: mean values and standard deviations

	Haptic and odor condition	Visual condition
Pleasantness	3.37 (1.41)	2.60 (1.68)
Arousing	3.69 (1.12)	3.40 (0.51)
Familiar	4.35 (0.78)	3.20 (1.20)

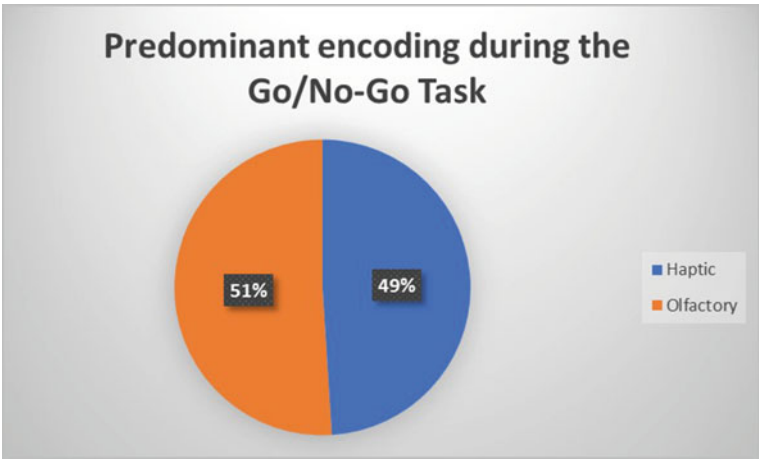

Fig. 6.3 Proportion of predominant encoding during the Go/No-Go task

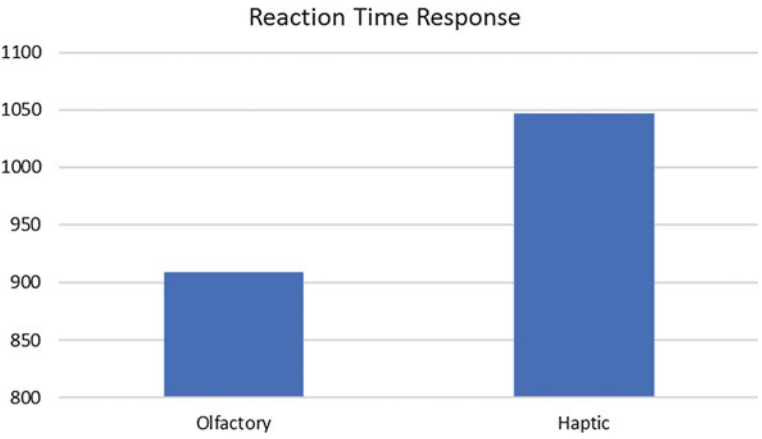

Fig. 6.4 Behavioral reaction time response during the Go/No-Go task

Lateralization ($\chi_1^2 = 5.99$, $p = .01$), and Localization ($\chi_4^2 = 61.04$, $p < .001$) as well as a significant interaction of Condition × Localization ($\chi_8^2 = 20.89$, $p = .002$) on P3 Amplitude. Particularly, a more positive P3 waveform was observed in the Smell-condition ($B = 1.84$, $t_{1289} = 2.05$, $p = .03$), in the left-side lateralization

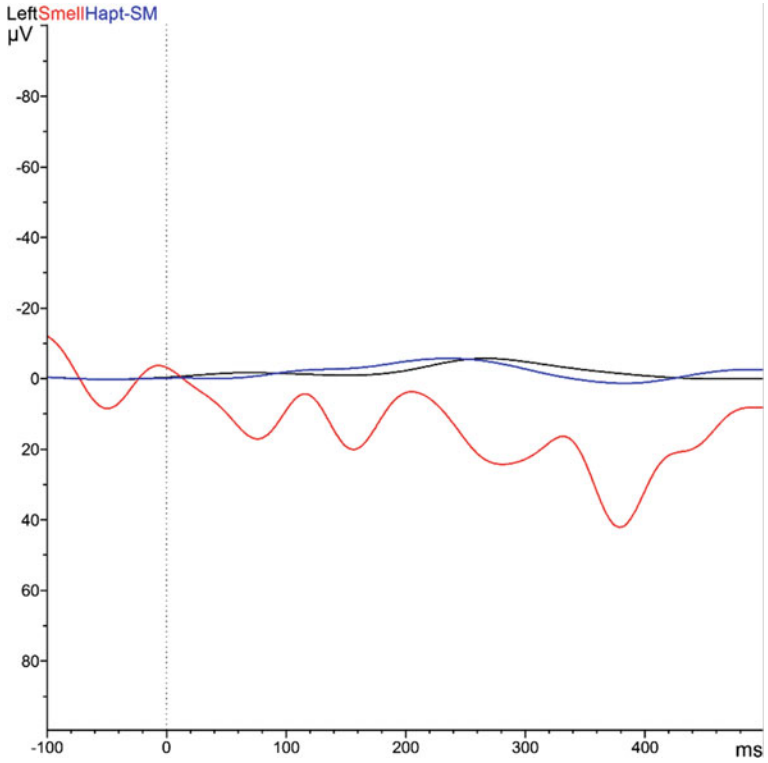

Fig. 6.5 Left comparison: cross-modal smell condition (red line); haptic condition (blue line); visual condition (black line)

(B = 2.22, t_{1287} = 2.59, p = .009) (Fig. 6.5), and in the Parietal area (B = 2.35, t_{1287} = 2.29, p = .02) (Fig. 6.6). Moreover, positive waveforms of P3 were also found in the Central area during Haptic manipulation (B = 2.80, t_{1287} = 2.18, p = .02) (see Loreta source reconstruction for Haptic Condition Fig. 6.7). Similarly, the left-side Temporal region over the Smell condition revealed a positive P3 Amplitude (B = 5.30, t_{1289} = 2.99, p = .002) (see Loreta source reconstruction for Smell Condition Fig. 6.8) respect Visual Condition (Fig. 6.9).

Table 6.3 shows instead results for the Latency component of P3. Significant effects were found for Condition (χ^2_2 = 21.28, p < .001), Localization (χ^2_4 = 48.80, p < .001), and for the interaction Localization × Lateralization (χ^2_4 = 12.27, p = .01). Particularly, latency increased in the Left-side lateralization (B = 21.79, t_{1812} = 3.28, p = .001) as well as in Central (B = 42.39, t_{1287} = 5.83, p < .001), Occipital (B = 27.19, t_{1287} = 3.17, p = .001), Parietal (B = 30.95, t_{1287} = 3.97, p < .001), and Temporal (B = 15.75, t_{1287} = 2.37, p = .01) areas. On the contrary, latency decreased in the Central area during Haptic manipulation (B = −27.24, t_{1812} = −2.65, p = .008)

Table 6.2 Results of linear mixed-effects model: fixed effects for manipulation, lateralization, and localization on amplitude (P3)

	χ^2(df)	B(SE)	t
Baseline		0.264(0.902)	0.293
Condition	79.27(2)***		
Smell versus non-smell		1.8480.8979)	2.059*
Haptic versus non-smell		−0.514(0.8831)	−0.583
Lateralization	5.99(1)*		
Left-side versus right-side		2.224(0.857)	2.595**
Localization	61.04(4)***		
Central (C)		1.417(0.9033)	1.569
Occipital (O)		1.172(1.1593)	1.011
Parietal (P)		2.3596(1.0285)	2.294*
Temporal (T)		0.913(0.8578)	1.065
Condition × Lateralization	0.09(2)		
Smell × Left-side		−2.298(1.2349)	−1.862
Haptic × Left-side		−1.417(1.2425)	−1.141
Condition × Localization	20.89(8)**		
Smell × Central (C)		2.001(1.3309)	1.504
Haptic × Central (C)		2.805(1.2869)	2.180*
Smell × Occipital (O)		0.272(1.748)	0.156
Haptic × Occipital (O)		0.699(1.6856)	0.415
Smell × Parietal (P)		2.114(1.55)	1.364
Haptic × Parietal (P)		1.584(1.483)	1.068
Smell × Temporal (T)		0.142(1.2549)	0.114
Haptic × Temporal (T)			−0.137
Lateralization × Localization	5.82(4)		
Left-side versus Central (C)		−1.837(1.2369)	−1.485
Left-side versus Occipital (O)		−2.206(1.6561)	−1.332
Left-side versus Parietal (P)		−2.633(1.4274)	−1.845
Left-side versus Temporal (T)		−2.136(1.1984)	−1.783
Condition × Lateralization × Localization	14.68(8)		
Smell × Left-side × Central (C)		2.336(1.8143)	1.288
Haptic × Left-side × Central (C)		0.403(1.7743)	0.227
Smell × Left-side × Occipital (O)		2.506(2.5448)	0.985
Haptic × Left-side × Occipital (O)		1.383(2.4531)	0.564
Smell × Left-side × Parietal (P)		2.028(2.1456)	0.945
Haptic × Left-side × Parietal (P)		2.586(2.0715)	1.248

(continued)

Table 6.2 (continued)

	χ^2(df)	B(SE)	t
Smell × Left-side × Temporal (T)		5.302(1.7715)	2.993**
Haptic × Left-side × Temporal (T)		2.689(1.7658)	1.523

Notes
Subjects were treated as random effects, degrees of freedom of the model were calculated with the Satterthwaite approximation. Reference levels for contrasts: Non-smell (Condition), Frontal (Localization), Right-side (Lateralization). Values of χ^2 are computed with the type-II Wald test. $N_{obs} = 1324$, $N_{groups} = 12$, $ICC_{groups} = 0.15$
* $p < .05$ ** $p < .01$ *** $p < .001$

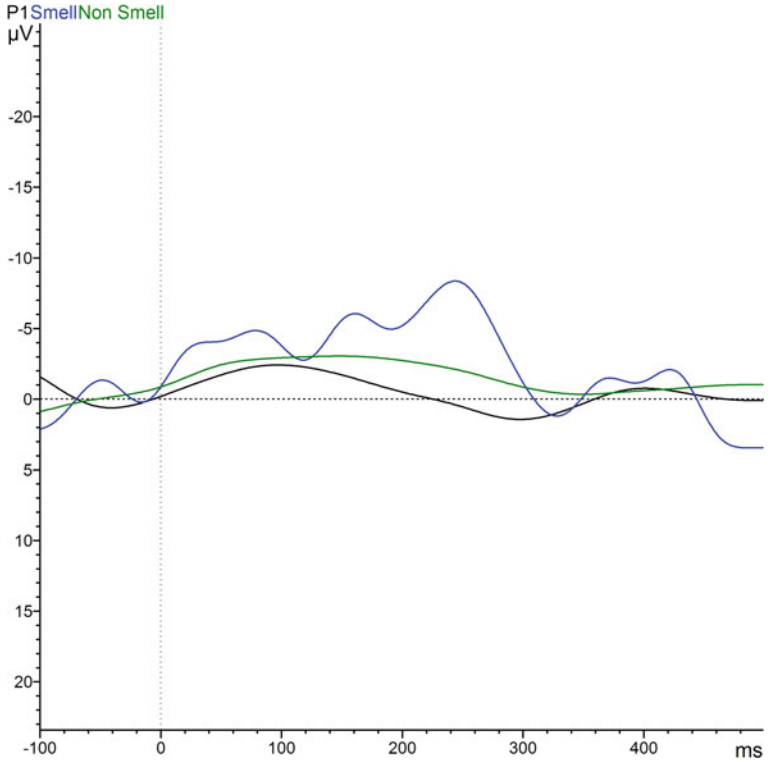

Fig. 6.6 Parietal left comparison: cross-modal smell condition (blue line); haptic condition (black line); visual condition (green line)

and in left-side of Central ($B = -24.20$, $t_{1812} = 2.41$, $p = .01$), Occipital ($B = -32.43$, $t_{1812} = -2.67$, $p = .007$), and Parietal ($B = -22.98$, $t_{1812} = 2.10$, $p = .03$).

This Areas is involved in different aspects of memory than the medial temporal lobes Retrograd memory.

Table 6.3 Results of linear mixed-effects model: fixed effects for manipulation, lateralization, and localization on Latency (P3)

	χ^2(df)	B(SE)	t
Baseline		271.274(6.369)	42.594
Condition	21.271(2)***		
Smell versus non-smell		11.551(6.794)	1.700
Haptic versus non-smell		6.714(6.636)	1.012
Lateralization	0.871(1)		
Left-side versus right-side		21.798(6.636)	3.285**
Localization	48.803(4)***		
Central (C)		42.393(7.269)	5.832***
Occipital (O)		27.198(8.567)	3.175**
Parietal (P)		30.955(7.781)	3.978***
Temporal (T)		15.750(6.636)	2.374*
Condition × Lateralization	1.683(2)		
Smell × Left-side		−15.733(9.595)	−1.640
Haptic × Left-side		−10.131(9.384)	−1.080
Condition × Localization	13.540(8)		
Smell × Central (C)		−17.445(10.511)	−1.660*
Haptic × Central (C)		−27.248(10.280)	−2.651**
Smell × Occipital (O)		−13.826(12.387)	−1.116
Haptic × Occipital (O)		−22.298(12.115)	−1.840
Smell × Parietal (P)		−9.894(11.251)	−0.879
Haptic × Parietal (P)		−15.464(11.004)	−1.405
Smell × Temporal (T)		1.406(9.595)	0.147
Haptic × Temporal (T)		−8.786(9.384)	−0.936
Lateralization × Localization	12.278(4)*		
Left-side versus Central (C)		−24.200(10.027)	−2.413*
Left-side versus Occipital (O)		−32.437(12.115)	−2.677**
Left-side versus Parietal (P)		−22.985(11.004)	−2.089*
Left-side versus Temporal (T)		−16.143(9.384)	−1.720
Condition × Lateralization × Localization	5.150(8)		
Smell × Left-side × Central (C)		13.984(14.499)	0.964
Haptic × Left-side × Central (C)		6.580(14.193)	0.464
Smell × Left-side × Occipital (O)		33.766(17.519)	1.927
Haptic × Left-side × Occipital (O)		24.437(17.133)	1.426
Smell × Left-side × Parietal (P)		15.966(15.912)	1.003
Haptic × Left-side × Parietal (P)		8.173(15.562)	0.525
Smell × Left-side × Temporal (T)		2.220(13.560)	0.164
Haptic × Left-side × Temporal (T)		0.071(13.271)	0.005

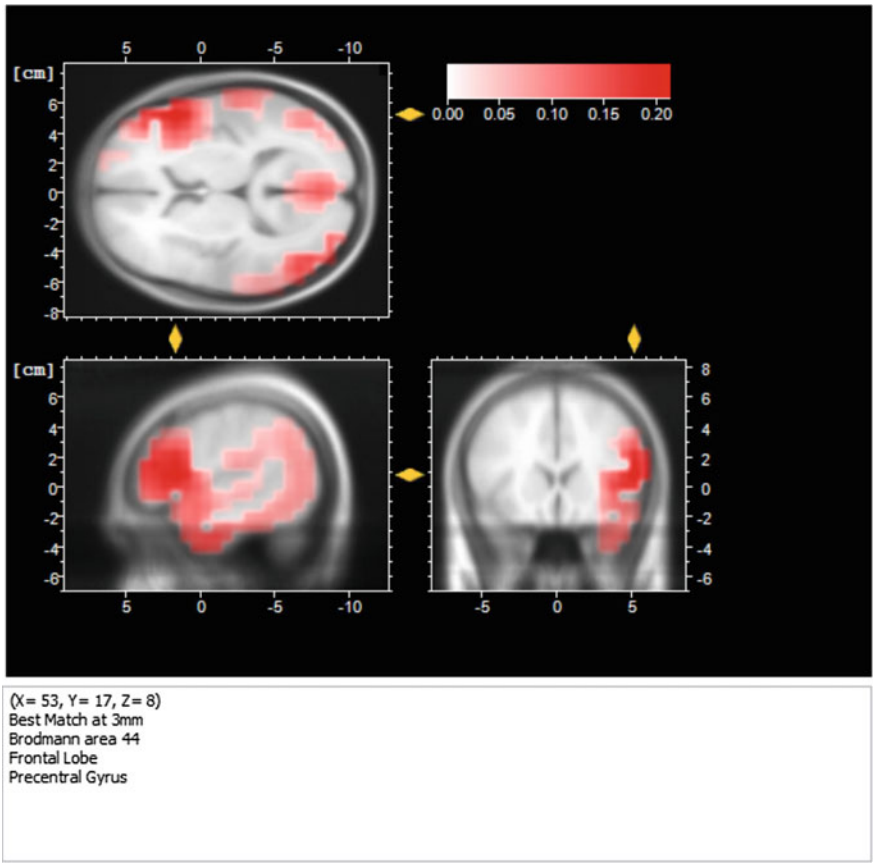

Fig. 6.7 Loreta Haptic condition. Brodmann area 44—this area involves the premotor functions

6.5 Discussion

The present research results highlight changes in the P3 ERP components. P3 is a perceptual and cognitive component of ERPs, that is related to stimulus detection. P3 is recorded in relation to familiar, but infrequent stimuli [24, 27]. ERP variations are evident in the odorous state and in the manipulation condition. In fact, as shown in Fig. 6.3, the condition of simply visual recognition in this paradigm does not produce an obvious P3 component, which is in fact considerably elicited in the odorous condition. The Odorous and Haptic condition is lateralized in the left hemisphere, particularly in the occipital, temporal, and parietal areas, which can be defined as 'occipital–temporal–parietal streams'. In addition to being particularly relevant because it is located in the left hemisphere, this area is where the "semantic" function of language and categorical perception reside [10]. These findings could also suggest a dorsal pathway on the visual path of localization known as 'how to do'

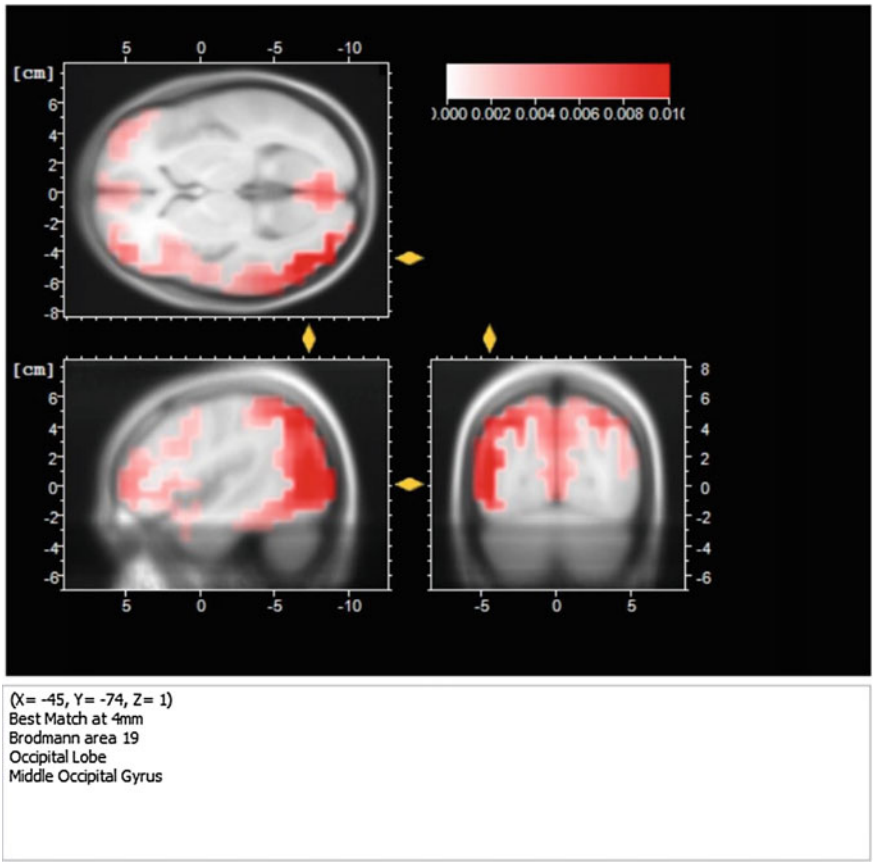

Fig. 6.8 Loreta smell condition: Brodmann area 19, that is activated by somatorosensory stimuli

[3, 8]. In this case, we could connect haptic and olfactory manipulation to the dorsal pathway (for example, "I smell and I manipulate a shape and, thus, I create imagery of haptic action"). Furthermore, we could, in part, link the visual condition to the 'ventral' pathway (that is, temporal and occipital locations), which is linked more to the representation of the imagery of the smelled object and which is then recognized in a visual mode Globally, we could interpret these results on the two components just as a predominant olfactory encoding in the crossmodal task, which is evident in the P3 ERP. Moreover, the activation, for the olfactory encoding component, of the Brodmann Area 19 (Fig. 6.8), area connected to somatorosensory stimuli and to the retrograde memory, seems particularly interesting. This seems to be precisely the key to understanding the greater amplitude and lateralization found in olfactory modality. The arousal in this case could be due to a greater stimulus processing that requires greater memory resources, and which allows on the one hand a wider potential, on the other hand, wider behavioral reaction times.

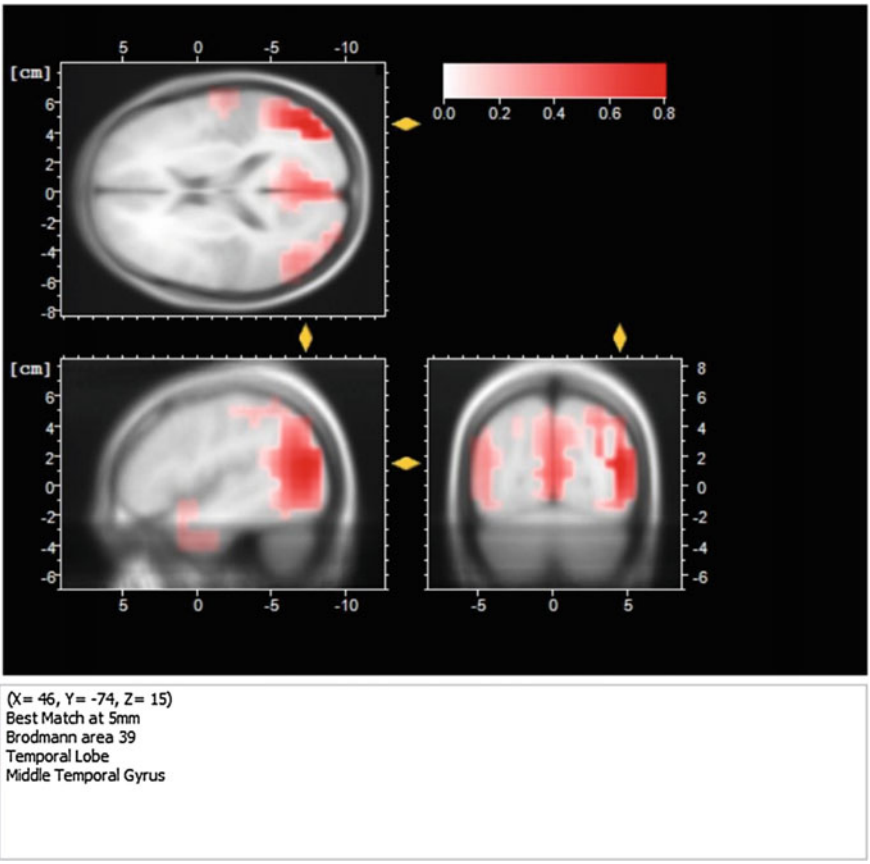

Fig. 6.9 Loreta non smell condition: Brodmann area 39. This area is involved in semantic memory

Acknowledgements We would like to thank to Graziano Scalinci, who printed the 3-D shapes; and Federica Basile and Francesca Tagliente, who collaborated with the EEG data recording. Paper co-funded through 5× Thousand Research Fund-University of Salento.

References

1. Baayen, R.H.: Analyzing Linguistic Data: A Practical Introduction to Statistics Using R. Cambridge University Press (2008). https://doi.org/10.1017/CBO9780511801686
2. Bates, D., Maechler, M., Bolker, B., Walker, S.: Package lme4. J. Stat. Softw. **67**(1), 1–91 (2015). http://lme4.r-forge.r-project.org
3. Bornkessel-Schlesewsky, I., Schlesewsky, M.: Reconciling time, space and function: a new dorsal-ventral stream model of sentence comprehension. Brain Lang. **125**(1), 60–76 (2013). https://doi.org/10.1016/j.bandl.2013.01.010

4. Craddock, M., Lawson, R.: Repetition priming and the haptic recognition of familiar and unfamiliar objects. Percept. Psychophys. **70**(7), 1350–1365 (2008). https://doi.org/10.3758/PP.70.7.1350
5. Dematte, M.L.: Cross-modal interactions between olfaction and touch. Chem. Senses **31**(4), 291–300 (2006). https://doi.org/10.1093/chemse/bjj031
6. Fernandes, A.M., Albuquerque, P.B.: Tactual perception: a review of experimental variables and procedures. Cogn. Process. **13**(4), 285–301 (2012). https://doi.org/10.1007/s10339-012-0443-2
7. Giessel, A.J., Datta, S.R.: Olfactory maps, circuits and computations. Curr. Opin. Neurobiol. (2014). https://doi.org/10.1016/j.conb.2013.09.010
8. Goodale, M.A., Króliczak, G., Westwood, D.A.: Dual routes to action: Contributions of the dorsal and ventral streams to adaptive behavior. In: Progress in Brain Research, vol. 149, pp. 269–283 (2005). http://doi.org/10.1016/S0079-6123(05)49019-6
9. Hanson-Vaux, G., Crisinel, A.S., Spence, C.: Smelling shapes: Crossmodal correspondences between odors and shapes. Chem. Senses **38**(2), 161–166 (2013). https://doi.org/10.1093/chemse/bjs087
10. Holmes, K.J., Wolff, P.: Does categorical perception in the left hemisphere depend on language? J. Exp. Psychol. Gen. **141**(3), 439–443 (2012). https://doi.org/10.1037/a0027289
11. Invitto, S., Capone, S., Montagna, G., Siciliano, P.A.: MI2014A001344 Method and system for measuring physiological parameters of a subject undergoing an olfactory stimulation (2014)
12. Jourdan, F.: Spatial dimension in olfactory coding: a representation of the 2-deoxyglucose patterns of glomerular labeling in the olfactory bulb. Brain Res. **240**(2), 341–344 (1982). https://doi.org/10.1016/0006-8993(82)90232-3
13. Kok, A.: On the utility of P3 amplitude as a measure of processing capacity. Psychophysiology **38**(3), 557–577 (2001). https://doi.org/10.1017/S0048577201990559
14. Kuznetsova, A., Brockhott, P.B., Christensen, R.H.B.: lmerTest: Tests in Linear Mixed Effects Models. R Package Version (2015). http://CRAN.R-project.org/package=lmerTest
15. Leleu, A., Demily, C., Franck, N., Durand, K., Schaal, B., Baudouin, J.Y.: The odor context facilitates the perception of low-intensity facial expressions of emotion. PLoS ONE **10**(9), 1–19 (2015). https://doi.org/10.1371/journal.pone.0138656
16. Leleu, A., Godard, O., Dollion, N., Durand, K., Schaal, B., Baudouin, J.Y.: Contextual odors modulate the visual processing of emotional facial expressions: An ERP study. Neuropsychologia **77**, 366–379 (2015). https://doi.org/10.1016/j.neuropsychologia.2015.09.014
17. Luck, S.J.: An Introduction to Event-related Potentials and Their Neural Origins. An Introduction to the Event-Related Potential Technique, 2–50 (2005)
18. Merkonidis, C., Grosse, F., Ninh, T., Hummel, C., Haehner, A., Hummel, T.: Characteristics of chemosensory disorders—results from a survey. Eur. Arch. Otorhinolaryngol. **272**(6), 1403–1416 (2014). https://doi.org/10.1007/s00405-014-3210-4
19. Ngo, M.K., Misra, R., Spence, C.: Assessing the shapes and speech sounds that people associate with chocolate samples varying in cocoa content. Food Qual. Prefer. **22**(6), 567–572 (2011). https://doi.org/10.1016/j.foodqual.2011.03.009
20. Nordin, S., Andersson, L., Olofsson, J.K., McCormack, M., Polich, J.: Evaluation of auditory, visual and olfactory event-related potentials for comparing interspersed- and single-stimulus paradigms. Int. J. Psychophysiol. **81**(3), 252–262 (2011). https://doi.org/10.1016/j.ijpsycho.2011.06.020
21. Pause, B.M., Krauel, K.: Chemosensory event-related potentials (CSERP) as a key to the psychology of odors. Int. J. Psychophysiol. (2000). https://doi.org/10.1016/S0167-8760(99)00105-1
22. Pause, B.M., Sojka, B., Krauel, K., Fehm-Wolfsdorf, G., Ferstl, R.: Olfactory information processing during the course of the menstrual cycle. Biol. Psychol. **44**(1), 31–54 (1996). https://doi.org/10.1016/S0301-0511(96)05207-6
23. Pinheiro, J.C., Bates, D.M.: Mixed Effects Models in S and S-Plus. Springer, New York (2000). http://doi.org/10.1198/tech.2001.s574

24. Polich, J., Criado, J.R.: Neuropsychology and neuropharmacology of P3a and P3b. Int. J. Psychophysiol. **60**(2), 172–185 (2006). https://doi.org/10.1016/j.ijpsycho.2005.12.012
25. Polich, J., Kok, A.: Cognitive and biological determinants of P300: an integrative review. Biol. Psychol. **41**(2), 103–146 (1995). https://doi.org/10.1016/0301-0511(95)05130-9
26. Shepherd, G.M.: Smell images and the flavour system in the human brain. Nature, **444**(7117), 316–321 (2006). Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/17108956
27. Silverstein, B.H., Snodgrass, M., Shevrin, H., Kushwaha, R.: P3b, consciousness, and complex unconscious processing. Cortex; J. Devoted Study Nerv. Syst. Behav. **73**, 216–227 (2015). https://doi.org/10.1016/j.cortex.2015.09.004
28. Tremblay, A., Newman, A.J.: Modeling nonlinear relationships in ERP data using mixed-effects regression with R examples. Psychophysiology **52**(1), 124–139 (2015). https://doi.org/10.1111/psyp.12299