

Assessing olfactory perception in young persons: a neuroscience perspective

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Abstract. This paper is aimed at demonstrating the correlation between a neuroscientific index - the Approach/Withdrawal one (A/W), which is related to the brain performance - and the level of perceived pleasantness in young subjects undergoing diverse olfactory stimuli. The above mentioned index is employed in the assessment of audio-visual stimuli, and has been hereby estimated by using the electroencephalogram (EEG), thanks to which it has been possible to study the activity of the Pre-Frontal Cortex (brain region connected with the pleasantness emotion experienced during a sensorial stimulation). In order to do so, this study recorded the EEG signals from several healthy no-smokers subjects (12 males and 12 females, $25 \pm 2,6$ years) during the perception of 10 diverse odors. Each olfactory stimulus has returned a cerebral A/W index for every subject: the related values have been statistically compared with the appreciation numeric scores assessed by the subjects in a questionnaire. Originality and value of this research lie in the following finding: the level of pleasantness towards odorous substances is measurable by analysing the EEG signals returned when presenting such substances to a pre-determined sample. From a managerial perspective, this method represents a bias-free technique for the assessment of a perfume performance.

Keywords: Electroencephalogram, Prefrontal cortex, Alpha asymmetry, Approach-Withdrawal, Emotion, Motivation, Pleasantness, Neuromarketing.

1. Introduction

The Pre-Frontal Cortex (PFC), a brain area that controls the motivational processes, is composed of several regions - situated in the frontal lobe of the brain - that play an important role in the underlying processes of human decision-making: the ventromedial prefrontal cortex (VMPFC) is involved in the processing of different alternatives and potential outcomes through the assessment of their (perceived) value (Tremblay&Schultz, 1999), while the orbitofrontal cortex (OFC) is associated with the evaluation of trade-off and the expected capacity of outcomes to satisfy a person's needs (Wallis, 2007).

In particular, the activity in the medial parts of the OFC at the time a reward is being enjoyed, correlates with subjective reports about the pleasantness or valence of the experience. Brain activity in the lateral OFC and left dorsal anterior insula/operculum is correlated, instead, with unpleasantness (Small et al., 2001). These findings can be integrated with those of other studies of neuroscience, according to which the human behaviour – that relies on two motivational systems: it can be motivated by an anticipated desirable outcome or, on the contrary, by a possible aversive outcome. These

findings have been then supported by empirical proofs: some EEG studies have found the left frontal cortex is involved in a system that motivates approach behaviour (Davidson, 2004) while, reversely, the right frontal cortex is involved in a system that motivates withdrawal behaviour (Davidson, 2004). Consequentially, a greater activity in the left frontal region with respect to the right frontal region means approach motivation (generally associated with positive emotions in front of the sensory perception proposed) and a relatively greater activity in the right frontal region normally means withdrawal motivation - generally associated with negative emotions in front of the sensory perception proposed (Harmon- Jones, 2003). This asymmetry of the PFC activity, known as well as the "Approach/Withdrawal motivation" (Davidson, 1999), falls into the "EEG frontal asymmetry theory", and can be calculated by employing the electroencephalogram (EEG).

In fact, thanks to the EEG signal spectral power difference in the alpha band (8-12 Hz), between the right PFC and the left PFC (Davidson et al., 1990), it is possible to estimate the A/W cerebral index of a subject undergoing a sensorial stimulus - so his/her level of pleasantness towards that very same stimulus: the index will be positive if the subject appreciates the stimulus and, conversely, negative if he/she does not appreciate the latter.

The point is that this indicator (A/W Index) has been broadly endorsed by the neuroscientific literature about visual stimuli (Jackson et al., 2000, 2003) and also in the studies about the acoustic stimuli (Schmidt and Trainor, 2001; Vecchiato et al., 2012), but not in the field of the olfactory stimuli, where Kim and Watanuki (2003) have been the only ones to make an experiment that goes in the direction of the assessment of the A/R (they compared a couple of odors' level of pleasantness).

There is therefore a gap, in this sense: there is the need to validate the brain A/W index in reaction to a sufficiently large number of olfactory stimuli and in controlled experimental conditions - and this paper's goal is to fill it, since is aimed at proving empirically that such brain A/W index is actually correlated with the "pleasant" or "no-pleasant" perception of an olfactory stimulus.

In the paragraphs dedicated to the results and discussion, the data are presented in the form of a comparison between the cerebral A/W index values of all the subjects - for each odorous stimulus - and the experimental subjects evaluation explicit scores, collected by a questionnaire, for the whole proposed sample.

2. Material and Methods

2.1. Experimental design

Sample and Setup

After having obtained an informed consent from each subject upon the explanation of the study (which was approved by the local institutional ethics committee), the present experiment has involved a healthy and no-smoker sample, gender balanced and consisting of people averagely 25 years old ($\pm 2,6$ years). The 24 subjects involved have been systematically selected within a larger sample: only the ones that showed an olfactory sensitivity coherent to the age range considered (2-phenylethanol maximum concentration threshold = 0,063%) were suitable to the experiment.

In order to assess every subject's olfactory performance, the "Threshold odor test" (Kobal et al., 1996; Hummel et al., 1997), also known as "Sniffin' sticks", has been employed. This is about a multiple test of nasal chemosensory performance, based on pen-like odor dispensing devices and developed by Heinrich Burghart Elektround Feinmechanik (GmbH, Wedel, Germany). The "Sniffin' Sticks" comprises three tests of olfactory function, namely: tests for odor discrimination (16 pairs of odorants, triple forced choice), tests for odor identification (16 common odorants, multiple forced choice from four verbal items per test odorant) and tests for odor threshold (n-butanol, testing by means of a single staircase). As far as it concerns the last ones, it is worth to mention that, in this experiment, using a triple-forced-choice paradigm it has been possible to determine the individuals' detection thresholds, by employing a single staircase method - as described by Doty (1991). The methodology has been the following one: three sticks have been randomly presented to each of the subjects (who were blindfolded, so unable to see and thus recognize the sticks containing odorant). Two out of three sticks contained just propylene glycol in water, at a concentration of 4%, so an odorless solvent, while and the remaining stick contained the odorant (2-phenylethanol) diluted in the very same solvent. The subjects have been asked to indicate which was, in their opinion and according to their olfactory perception, the stick with the odorant, and whenever somebody was not able to

recognize the correct stick, the task was proposed again, and again every 20 seconds, until the subject correctly distinguished the odorant. Every two consecutive correctly accomplished tasks, a reversal of the staircase: the geometric mean of the last four staircase reversal points of a total of seven reversals was used as the threshold estimate.

Experimental task

The experimental task (represented in Figure 1) consisted in presenting to every experimental subject the odors of 10 different scented substances, placed respectively in 10 sticks and diluted with an over-threshold concentration. In particular, the essences (Rose, Banana, Mint, Leather, Cloves, Orange, Pineapple, Fish, Mold, Mushrooms) have been selected within the “Screening test-odor identification” set (Sniffin’ sticks, Burghart). The order with which the odors have been presented to the subjects has been randomized, in order to prevent a possible source of confusion for the subjects (and a possible bias in the data analysis).

Like in the set-up stage, in the experimental task too the subjects have been blindfolded, in order to prevent the visual identification of the odorant containing sticks. For each odor presentation, the cap was removed by the experimenter for ~3 seconds, and the stick tip has been placed ~2 cm in front of both nostrils (Hummel et al., 1997). In between the odors presentation, the subjects were free to open their eyes: in this time interval a questionnaire was submitted to them, who had to produce their explicit smell appreciation judgments, with a numeric score between 1 and 10 (1 as the worst and 10 as the better judgment in terms of smell appreciation). The coffee odor (by means of some milled coffee) was presented to the subjects after the questionnaire and before the subsequent odor presentation, in order to neutralize the previous odor.

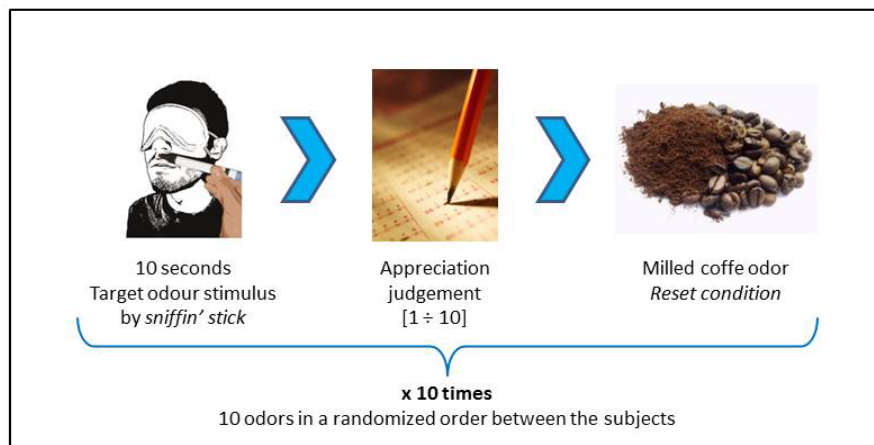


Figure 1. The experimental task that subjects were asked to perform.

2.2. EEG recording and signal processing

During the whole experiment, the EEG data was collected, for each subject, by a portable 64-channel system (BE+ and Galileo software, EBneuro, Italy), at a sampling rate of 256 Hz; the impedances have been kept below the 10 k Ω . Nineteen electrodes (Fz, Cz, Pz, Fp1, Fp2, F3, F4, F7, F8, C3, C4, P3, P4, P7, P8, T7, T8, O1, O2) were located on a cap according to the 10–20 international system. FCz was used as reference, AFz as ground.

Each EEG trace was then converted into the Brain Vision format (BrainAmp, Brainproducts GmbH, Germany) in order to perform signal pre-processing such as artifacts detection, filtering and segmentation: thus, raw EEG traces were first band pass filtered (high pass = 2 Hz; low pass = 40 Hz), and then analyzed with the Independent Component Analysis (ICA), in order to detect and remove components due to the eye movements, blinks, and muscular artifacts. Subsequently, the pre-processed EEG signals have been transformed by means of the Common Average Reference (CAR). In the end, for each subject the Individual Alpha Frequency (IAF) was calculated on the 60-seconds Closed Eyes segment, recorded at the beginning of the experimental task, in order to define the EEG bands of interest according to the method suggested in the current scientific literature, i.e. each band is defined

as “IAF ± x”, where IAF is the Individual Alpha Frequency, in Hertz, and x an integer in the frequency domain (Klimesch, 1999).

2.3. Approach/Withdrawal Index

In order to define an approach-withdrawal index (AW) according to the theory related to the earlier introduced EEG frontal asymmetry theory, it has been computed such imbalance as difference between the average EEG power of right and left channels.

In fact, from the pre-processed EEG data, each channel was filtered in the Alpha band, defined as [IAF-4, IAF+2] according to the IAF definition. Then, the asymmetry of the EEG signal power (also known as the aforesaid Approach/Withdrawal Index) was estimated in the Alpha band on the electrodes above the prefrontal and orbitofrontal cortex, and defined by using the following formula:

$$\begin{aligned}
 AW &= \frac{1}{N_P} \sum_{i \in P} x_{\alpha_i}^2(t) - \frac{1}{N_Q} \sum_{i \in Q} y_{\alpha_i}^2(t) = \\
 &= \textit{Average Power}_{\alpha_{right,frontal}} - \textit{Average Power}_{\alpha_{left,frontal}} \quad (1)
 \end{aligned}$$

where

x_{α_i} and y_{α_i} = i^{th} EEG channel in the alpha band that have been recorded from:

P = {Fp2,F4,F8}, right lobes

Q = {Fp1,F3,F7}, left frontal lobes

So, for each frontal site (i.e. P and Q) the Global Field Power (Vecchiato et al., 2012) was estimated,

where

N_P e N_Q = the cardinality of the two sets of channels.

Therefore, the AW index zero value represents an experimental condition where the left and right PFC activity values are equivalent. In such a way, an increase of AW will be related to an increase of pleasantness and vice versa.

For each subject for each olfactory stimulus, the AW signal was calculated and averaged throughout the 10 seconds of the stimulation. In conclusion, the correlation value was estimated between the mean AW value and the subjects’ evaluation explicit score.

3. Results

Figure 2 displays the distribution of the appreciation scores that the subjects gave to each odorous stimulus: herein, the vertical bars represent the appreciation average stated scores obtained by the subjects’ whole experimental sample for every odorous substance, indicated along the abscissa axis.

As it is possible to see from the graph, the fish smell scored the worst estimation (a mean value of 2,1), while, on the contrary, the Rose, the Banana and the Mint smells scored the better judgments. The red horizontal line indicates the pleasantness threshold, equal to 6,1, as the total mean score for all the odorous stimuli.

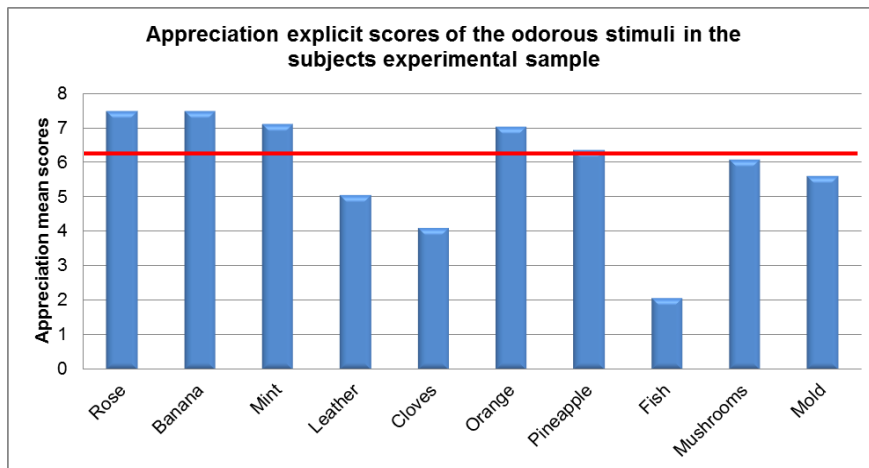


Figure 2. The graphic shows the mean values of the explicit appreciation (range between 1 and 10) stated by the subjects during the experimentation, for each odorous substance. The red line refers to the total mean score, equal to 6,1. It is evident that Rose, Banana, Mint, Orange and Pineapple smells are above this threshold.

The Fig. 3, instead, shows the distribution of the A/W index values estimated in the sample during the task (olfactory stimuli presentation and assessment). The A/W value has been averaged for every odor along the whole subjects sample. On the ordinate axis, the AW scores, where a positive value refers to the approach motivation (i.e. appreciation), whilst a negative value refers to the withdrawal motivation (i.e. rejection) towards the specific odorous stimulus (Davidson et al., 1990).

Afterwards, the correlation between the appreciation stated mean scores and the brain A/W mean indexes was estimated by means of the Pearson's coefficient: this allowed to verify the validity of the A/W index in response to the olfactory stimuli.

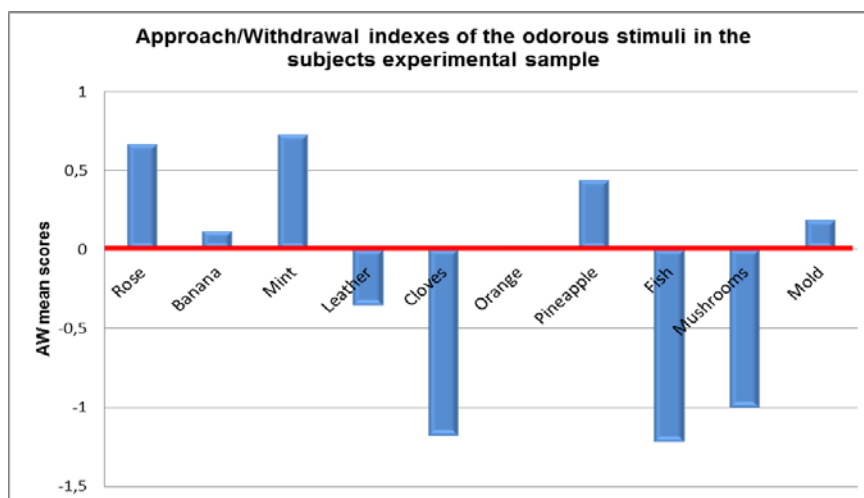


Figure 3. The graphic displays the mean values of the A/W index estimated, in the experimental sample, from the EEG data collected during the odors presentation. The red line corresponds to the A/W index zero value, i.e. the indifference situation towards the stimulus. A positive value refers to the approach motivation (i.e. appreciation), whilst a negative value refers to the withdrawal motivation (i.e. rejection) towards the specific odorous stimulus. It is evident which are the smells above this zero level: Rose, Banana, Mint, Pineapple and Mold.

Finally, the scatterplot graphic for the 10 odorous substances used in the experiment is illustrated in Figure 4. The advantage of this type of representation is that the scatterplot shows very clearly the correlation between two variables: in this case, the appreciation stated mean scores (ordinate axis) and the brain A/W mean indexes (abscissa axis).

It is important to underline that the estimated Pearson's correlation index here is $R = 0,79$, with a statistical significance index $p < 0,006$ (so largely inferior to the statistical significance threshold, $p = 0,05$).

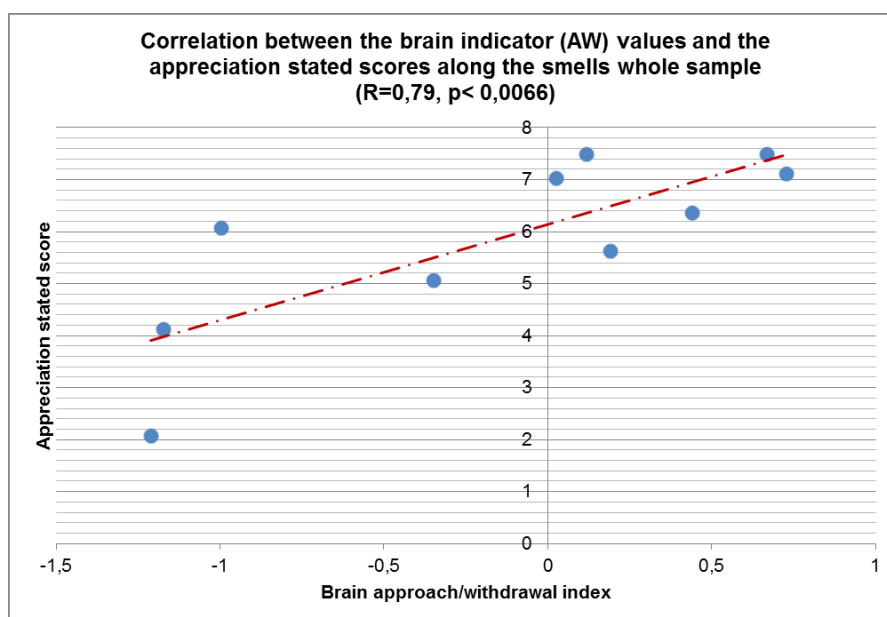


Figure 4. The figure shows the scatterplot between the brain A/W index (on the abscissa axis) and the appreciation stated score, between 1 and 10 (on the ordinate axis). Each dot in the graphic refers to a specific odorous stimulus used in the experiment. The estimated correlation coefficient R is 0,79, with the following statistical significance: $p < 0,006$.

4. Discussion and Conclusions

This research work has analyzed the cerebral responses to a set of diverse olfactory stimuli of a group of young and healthy subjects with an olfactory sensitivity (2-phenylethanol maximum concentration threshold = 0,063%) coherent to the age range considered ($25 \pm 2,6$ years).

The findings revealed that it is possible to evaluate the pleasantness or no-pleasantness of odorous substances by means of the analysis of EEG signals collected during the presentation of such substances, and the outcomes endorse the research aim - to validate empirically the A/W index in reaction to a sufficiently large number of olfactory stimuli and in controlled experimental conditions.

From the data analysis, in fact, (see "Results") it can be read the greatly significant correlation (index value $R = 0,79$, and statistical significance: $p < 0,006$) between the A/W index (the brain indicator) and the explicit appreciation stated by the experimental sample (traditional verbal judgment) towards the odorous stimuli.

This result has meaningful practical and managerial implications, if one thinks to all those scenarios (i.e. experimental methodologies or protocols, marketing researches) where collection of verbal scores of the olfactory stimulus appreciation from the subjects, whether or not real-time - is not possible or wants to be avoided by the researchers for the experimental goals. Additionally, another important application field could be the one of the food sciences, for at least a couple of reasons: better understanding how the smells influence the consumers in the food choice, better investigating the brain motivational processes towards the food (finding that could be used to improve the quality of the nutrition, making it more pleasant and healthy at the same time).

It is important to underline, in the end, that this is the first time that the Approach/Withdrawal theory is applied to an experimental protocol in the field of the olfactory stimuli, besides the widely accepted demonstration with visual and acoustic ones. Therefore it can be asserted with a certain confidence, that the brain A/W index is actually correlated with the "pleasant" or "no-pleasant" perception of an olfactory stimulus, and has demonstrated to be

A worthwhile note goes to the zero level of the A/W index, indicating indifference towards the odour presented (see the interpolation line in Figure 4). In fact, it is possible to appreciate how the

brain AW index zero value corresponds nearly to the same edge level (=6,1) obtained from the appreciation scores assessed by the subjects involved in the experiment: this is exactly the threshold that discriminates the pleasant from the no-pleasant stimuli, and it corresponds for both the indicators.

In conclusion, the brain activity's assessment during an olfactory stimuli perception can not only be implemented more and more ecological experimental environments, but has also new and increasingly diverse application fields.

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