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"Neurophysiological Impacts of a Multisensory Nature Experience: Exploring Effects on Attention and Emotional States"

Damien Gabriel[1,2,*], Pierre-Edouard Billot[2,3], Sylvie Tufeu[4], Eric Fernandez[4], Stéphanie Brédif[4], Florine Maylié[1], Virginie Fera[4] and Julie Giustiniani[3,5]

[1] Neuraxess: Functional Neuroimaging and Neuromodulation Platform; F-25000 Besançon, France [2] CHU Besançon, INSERM CIC1431 Centre d'Investigation Clinique, F-25000 Besançon, France [3] Université Marie et Louis Pasteur, INSERM, UMR 1322 LINC, F-25000 Besançon, France; [4] Groupe Rocher, Issy les Moulineaux, [5] CHU Besançon, Département de psychiatrie de l'adulte, Besançon, France

1. Introduction

Behavioral research has consistently demonstrated a strong relationship between exposure to natural environments and a reduction in negative affect, with a concurrent preference for such settings over constructed environments [1, 2]. Exposure to nature leads to a reduction in aggression and anxiety in individuals, as well as an increase in positive feelings, relaxation, and cognitive abilities. The presence of a natural environment also seems to improve attentional abilities in the context of depression and contribute to stress reduction [3, 4].

The positive effects of nature in cosmetics are also well-documented. Beyond the advantages of natural ingredients in cosmetic formulations—such as reduced irritation and greater biocompatibility— cosmetics that mimic natural environments can engage the brain's multisensory processing systems, potentially enhancing emotional well-being, reducing stress, and improving attentional states. This aligns with findings in environmental psychology and affective neuroscience, where even indirect exposure to natural elements (e.g., nature-inspired visuals or olfactory cues) has been shown to activate neural pathways associated with relaxation and positive affect. Thus, cosmetics that recall nature not only care for the skin but also support a more holistic sensorial experience with potential benefits for mood and cognitive function.

There is consequently a growing interest in the neurophysiological benefits of products that evoke nature through scent, texture, and visual design. Neurophysiological measures provide objective insights into the effects of nature on cognitive processes, emotional regulation, and stress modulation, complementing the subjective assessments often used in behavioral studies. Numerous neurophysiological methods can be employed, such as electrodermal activity, heart rate, electroencephalography (EEG), near-infrared spectroscopy (NIRS), or even functional magnetic resonance imaging (fMRI), among others [5, 6]. If a large number of studies has explored the neurophysiological responses to a natural environment, this not yet the case for cosmetics that mimic natural environments. Moreover, most studies evaluating the beneficial effects of nature focus on the visual modality only, whereas exposure to a natural environment is in essence a multisensory experience. It is also the case with cosmetics. Given their inherently multisensory nature— stimulating the visual, olfactory, tactile, and occasionally auditory senses —cosmetic products require a comprehensive, integrative approach to fully understand their neurophysiological and psychological impacts.

The present study aimed to investigate how the neurophysiological responses to nature can be similar to neurophysiological responses to natural cosmetics. We focused on the neurophysiological impact of multisensory exposure to natural environments, with a particular focus on attention and emotional states. Specifically, the objectives were twofold:

1. First to identify neurophysiological markers that are indicative of the restorative role of nature under stressful condition, and to evaluate how the sensory richness of natural and urban environments impact this restorative role.
2. Second, based on these neurophysiological markers, to compare specific responses to nature to those recorded while using a cosmetic ingredient with textures and fragrances evoking nature.

2. Materials and Methods

Thirty-two healthy, right-handed subjects, all females, aged between 25 and 49 years (mean age: 37 ± 7) participated in the current study. All declared that they were neither pregnant nor breastfeeding at the time of the study. Prior to participating in the study, participants received information regarding the aims and procedures of the experiment and gave their written informed consent to participate. In accordance with French law, the study was classified as psychology observational research outside of the Jardé law and so did not require submission to an ethics committee. All methods were carried out in accordance with the protocol and with principles set out in the Declaration of Helsinki.

Course of the experiment

Figure 1 shows the course of the experiment. Subjects were seated in a comfortable chair in a dark quiet testing room. At the beginning of the experiment the participant was equipped with high-density EEG as well as devices measuring electrodermal activity, heart rate, and respiration. The experiment was then divided into a nature session and an urban session, the order of presentation of each session being counterbalanced across participants. Each session started with a stress task to maximize the differences between a natural and an urban environment, as several studies have shown that exposure to nature reduces the level of physiological and psychological stress [7]. Then, participants made two series of neurophysiological recordings. The first one was a 20-minute Go/No Go task during which visual, auditory, and olfactory sensory modalities were presented in the background, either separately or grouped. The second session of neurophysiological recordings consisted of the passive presentation of a 4-minute video of the environment of interest (nature or urban), with sounds and odors. At the end of the whole experience, neurophysiological activity of participants was measured while they were applying a cosmetic product evoking nature.

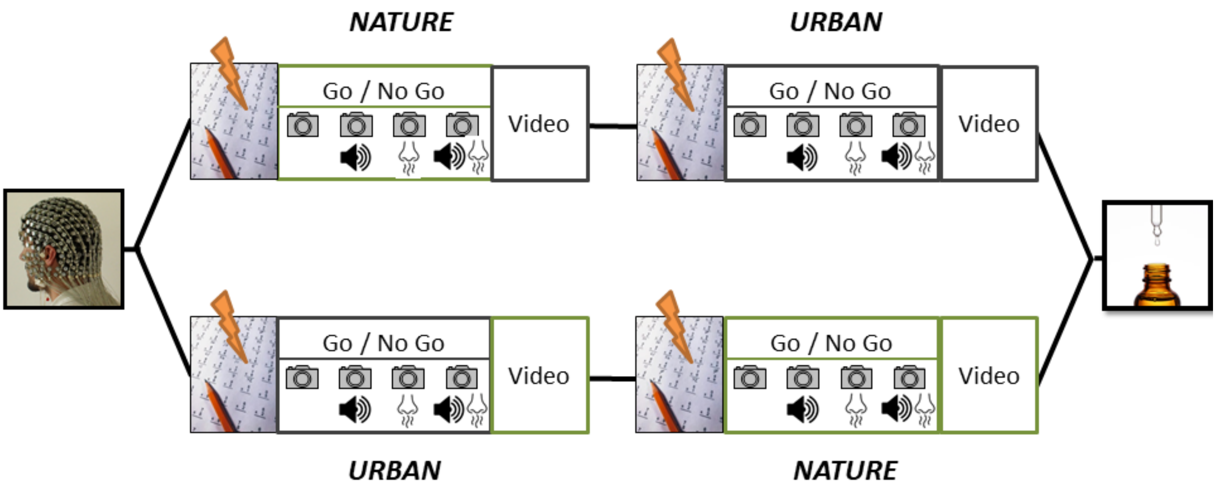

Figure 1: Course of the experiment.

Stress task
This task was replicated from [8]. This is a mental arithmetic task that involves deciding, within 3 s, whether an equation displayed on the screen is correct or false. The task lasted approximately 3 minutes.

Go/No Go task
The participants performed a Go/No Go task inspired by [9]. The subjects perceived nature or urban images on which appeared a letter, either W or M. Participants were asked to press a button when the letter M appeared and do nothing when the letter W appeared. The aim of this task was to keep the subjects' attention high throughout the experiment. Each image was presented for 1,500 milliseconds. The letter appeared for 100 milliseconds, between 600 milliseconds and 800 milliseconds after the image appeared. One hundred images were presented to the participants. Fifty trials contained the letter W, and 50 trials the letter M. The duration of the task was 2 min 30 sec. This task was repeated 4 times, once with pictures alone, once with the addition of a background sound from the corresponding environment (nature or urban images), once with the addition of odors from the corresponding environment, and once with odors and sounds from the corresponding environment. The order in which the backgrounds were presented was random.

The nature pictures all depicted a forest environment, without any human beings. The urban pictures were selected from different cities, showing modern streets and buildings, with as few human beings as possible. Sounds were extracted from the nature and urban videos and were played through headphones with the volume adjusted to a comfortable listening level for each subject. Selected odors were cedar, oak moss, and musty as fragrances evoking a natural environment, and plastic, thrift store, and solvent as fragrances evoking an urban environment. Odors were diluted to guarantee iso-intensity, i.e., the intensities of the odors were judged to be almost equivalent, intense enough to be perceptible, but low enough not to be unpleasant. In the Go/No Go task, odors were delivered for 1 second at the beginning of each trial.

Passive-viewing of videos

Four-minute videos representing a first-person walk in a natural or urban environment were used. The nature video depicted a walk in a forest. The urban video depicted a walk through a city environment with streets, buildings, and traffic. Videos comprised sounds related to the environment. During videos, odors were delivered every 4 seconds, with 2 seconds of presentation and 2 seconds of baseline.

Cosmetic product
We chose to test a specific face care product, formulated as a serum, with 99% ingredients of natural origin, and containing a 2 active ingredients, a plant extract and a micro algae extract. The fragrance of this product has been developed to convey sensory and emotional emotions. In order to evoke nature, land and sea combined, this fragrance has been worked to translate an olfactory direction through an aromatic, mineral and salty notes of natural origin. Floral, fresh, marine, watery, green and woody notes are present.

Cortisol
Saliva samples were collected prior to the experiment, following the completion of the questionnaires, and prior to and following the nature and urban experiences.
These samples were collected using Salivette ® Cortisol (Sarstedt, Nümbrecht, Deutschland) and were frozen the day after the experiment at -40°C, then thawed and subjected to centrifugation at 1,000 x g for 2 minutes prior to analysis. Salivary cortisol levels, expressed in nmol/L, were measured using an automated electrochemiluminescence method (ECLIA) on a COBAS e801 immunoassay analyzer (ROCHE).

Neurophysiological recordings
EEG signals were recorded using a 256-channel Geodesic Sensor Net (Electrical Geodesics Inc.; EGI, Eugene, OR). Data were acquired with a sampling rate of 1,000 Hz and with a reference to the vertex (Cz). Data were bandpass-filtered between 1 and 30 Hz (Butterworth), and a notch filter fixed to 50 Hz was applied.
The EEG data of all four different conditions (picture, picture + sound, picture + odor, picture + odor + sound) were grouped together and compared between the nature and urban conditions. Only correct responses were analyzed. Three periods of interest were analyzed: the P1-N1 complex (130-230 ms), the EPN (230-330 ms), and the P300 (330-530 ms). For statistical purposes, electrodes were clustered into nine regions of interest: anterior left, anterior central, anterior right, medium left, medium central, medium right, posterior left, posterior central, and posterior right. Source localization was applied using a distributed linear inverse solution based on a Local Auto-Regressive Average (LAURA) model.
During the video, only electrodes F8, AF4, AF3, F3, F7, FC5, T7, P7, O1, O2, P8, T8, FC6, and F4 were conserved. To remove ocular artifacts, we used a principal component analysis.

Psychophysiological recordings
Psychophysiological data were recorded using an MP36R device (Biopac Systems, Inc., Santa Barbara, CA) with a sampling rate of 1,000 Hz. Respiration was monitored with a respiratory effort transducer attached to a nylon strap placed around the chest. The ECG was measured by placing disposable Ag/AgCl electrodes embedded in an adhesive and conductive liquid hydrogel in a standard DII configuration. Lastly, the electrodermal activity (EDA) was recorded via two Ag/AgCl disposable electrodes gelled with isotonic gel (0.05 molar NaCl) and placed on the volar surfaces of the distal phalanges of the index and middle fingers.
The Electrodermal activity (EDA) signal was first visually checked for each participant and then cleaned with a 1 Hz low-pass filter.The phasic EDA signal was extracted from the tonic using

a 0.05 Hz high-pass filter. Skin Conductance Response (SCR) mean amplitude (µS) and SCR frequency (SCR/minute) were calculated for each time interval corresponding to the experimental conditions. For mean skin conductance level (SCL), the phasic component of the EDA signal was removed using a 0.05 Hz low-pass filter to avoid over-estimating the true SCL, as such averages will also contain SCRs, thus artificially elevating the measure. SCL was then averaged for each condition.
The respiration signal was resampled at 125 Hz and filtered with a band-pass filter between 0.05 and 0.65 Hz. After peak detection, the respiration rate was calculated for each period and then averaged for each condition.
The ECG signal was band-pass filtered between 0.05 and 35 Hz. After QRS detection, the R-R interval was calculated and averaged for each condition. Heart rate variability (HRV) was computed based on the filtered ECG signal for each condition using AcqKnowledge 5.0's HRV processing algorithm, which allowed us to extract low-frequency (LF) and high-frequency (HF) HRV. An LF/HF ratio was then calculated for each condition.

Statistics
In the Go/No Go task, behavioral and psychophysiological measures were analyzed with two-way repeated measures ANOVAs, with the factors being environment (nature/urban) and the sensory modality (pictures alone, pictures + sounds, pictures + odors, pictures + sounds + odors), as well as the effect of the interaction between these two factors. For EEG data, a three-way repeated measure ANOVA was used for each ERP of interest, with the factors environment (nature/urban), laterality (left, median, right), and anteriority (anterior, central, posterior). When ANOVAs were significant, a post-hoc Bonferroni test was used to assess the nature of the difference.
Regarding cortisol statistical analyses were conducted on 17 individuals because of missing data due to relatively low levels in some participants (<3 nmol/L). The statistical analysis involved comparing cortisol levels before and after the nature experience, as well as before and after the urban experience. The Wilcoxon test was used to analyze the data. We also compared cortisol levels after the nature experience and after the urban experience.
The psychophysiological and EEG data during viewing of nature and urban videos were compared using a paired Student t-test.

3. Results

Cortisol statistical analyses compared pre-nature vs. post-nature, pre-urban vs. post-urban, and post-nature vs. post-urban. Among these three tests, a significant difference was found for the pre-nature vs. post-nature comparison (W=80; Z=2.411; p=0.013), with a higher mean (mean=5.692; sd=2.056) for the pre-nature condition compared to the post-nature condition (mean=4.510; sd=1.525).

3.1 Behavioral and neurophysiological impact of sensory richness

Behavior. The mean number of correct responses in the Go/No Go task was evaluated for each environment and sensory modality. A significant difference in the number of correct responses was shown between the two environments, with the mean number of correct responses being higher in the natural environment ($F(1,31) = 27.818$; $p < 0.001$). There were also differences between the sensory modalities employed (F(3,93) = 6.431; p < 0.001). Bonferroni post-hoc analyses showed that when images were associated with odors, the number of correct responses was significantly lower than when images were presented alone (p < 0.001), and lower than when images were presented with sounds (p < 0.05). This was also the case when odors and sounds were combined, with the number of correct responses being lower than when images were presented alone (p < 0.05). However, the interaction between environment and sensory modalities was not significant (F(1.877, 58.183) = 0.959; p = 0.384).

Psychophysiology. Significant differences in SCR frequency were observed as a function of environment type (F(1,31) = 5.344; p = 0.028) (Figure 2). Urban stimuli, regardless of sensory modality, increased SCR frequency compared with nature stimuli. A significant interaction was also observed between environment type and sensory modality (F(3,93) = 2.783; p = 0.045). The significant difference between urban and natural stimuli were observed only when all sensory modalities were presented together (post-hoc t = -3.476; pbonf = 0.022), with a higher SCR frequency for urban stimuli. No significant differences were observed for other psychophysiological variables.

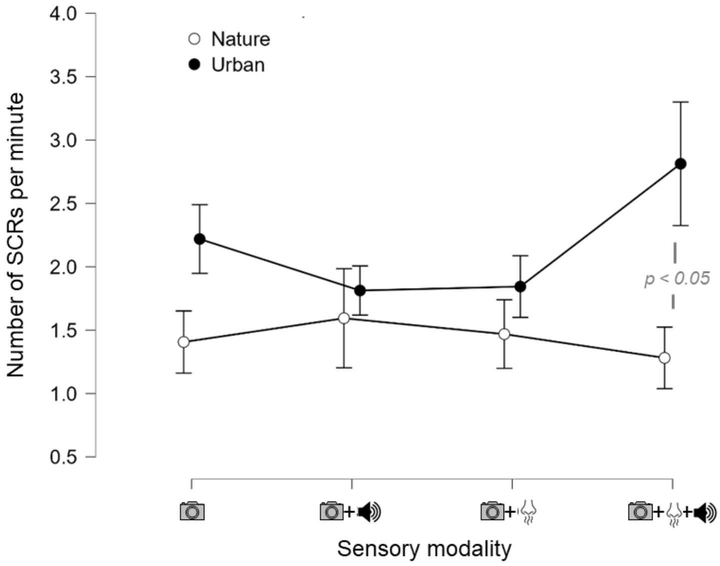

Figure 2: SCR frequencies for nature and urban experiences as a function of sensorial modality (images; images and sounds, images and odors; images, sounds, and odors).

High-density EEG. With regard to the P1-N1 complex, only a significant difference in laterality was found between the two environments (F(2,62) = 3.324; p = 0.043). The greatest difference was found at the central level, where the amplitude of the potential was larger in the urban environment. The EPN-evoked potential also showed a significant difference in cerebral laterality between the two environments (F(2, 62) = 3.571; p = 0.034). The difference was mainly observed in the right hemisphere, with a larger amplitude of the EPN in the natural environment. An interaction between the type of environment and anteriority was also present (F(1.253, 38.844) = 5.293; p = 0.02), with larger amplitudes in the frontal and occipital regions for the natural environment. No differences were observed between all conditions for the P300.

Figure 3 shows the topography of the P1-N1 complex, the EPN, and the P300 in the natural and urban environments. A source localization procedure was performed to determine the origin of the differences between the natural and urban environments for the significant ERPs. Source localization revealed activation differences in the right inferior frontal gyrus for the P1-N1 complex, and in the right parietal and right occipital regions for the EPN.

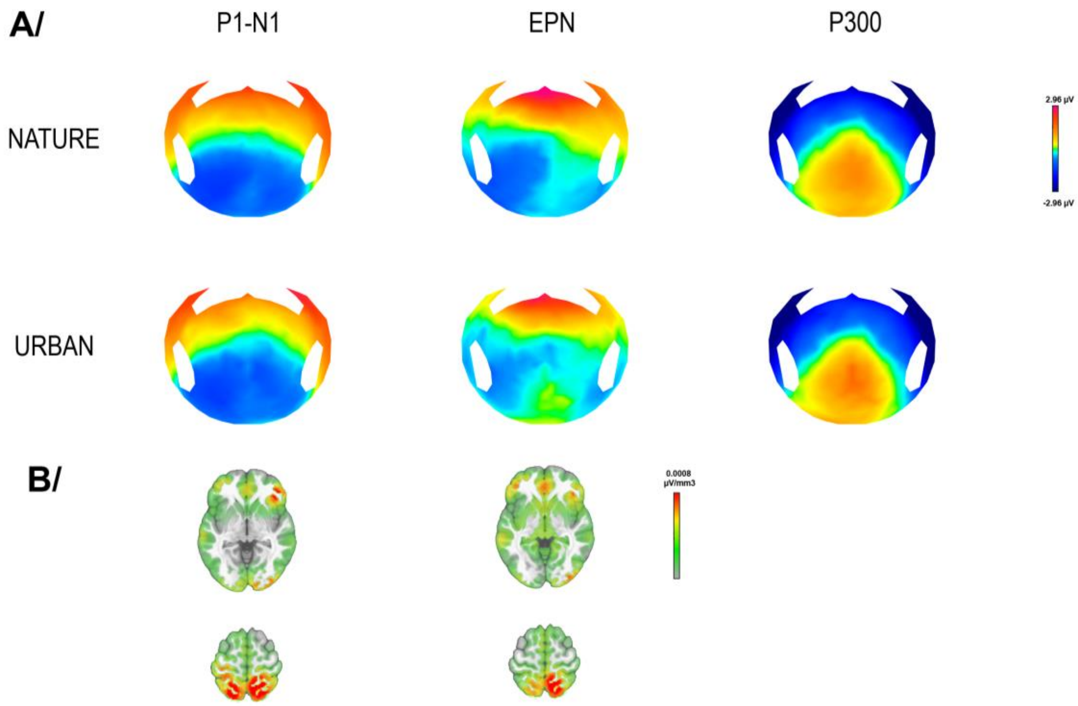

Figure 3: (A) Surface topography representing the global cerebral response of the P1-N1 complex, the EPN, and the P300 wave after a correct response in a natural and an urban environment. (B) Source localization of the brain regions at the origin of the differences between natural and urban environments for the P1-N1 complex (left) and EPN wave (right).

3.2. Comparison between Nature experience and the application of a cosmetic product

As a control, we first compared neurophysiological differences to nature and urban videos. No significant differences in psychophysiology parameters were found. Comparing brain activity during the viewing of nature and urban videos, significantly stronger alpha activity was observed at the O2 electrode for urban compared to nature videos (p = 0.01).

Neurophysiological measurements were compared during the viewing of nature and urban videos, as well as during the application of a cosmetic product. The application of the cosmetic product led to a general increase in brain activity (electrode O2), a significant decrease in electrodermal response (SCR/min), and a reduction in RR interval. Interestingly, the repeated measures ANOVA showed a significant effect of the experimental condition for the number of SCRs per minute ($F(2,62) = 4.194$; $p = 0.020$) and the LF/HF ratio ($F(2,62) = 3.719$; $p = 0.030$). Post-hoc tests revealed that the application of a cosmetic product only differed from the urban condition ($p=0.016$ for SCR frequencies; $p=0.042$ for the LH/HF ratio) but not from the nature condition (Figure 4).

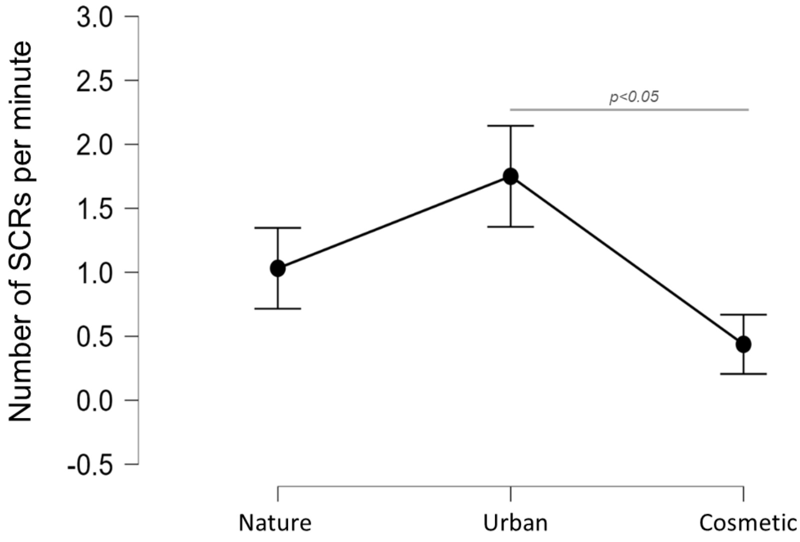

Figure 4: SCR frequencies as a function of the experimental conditions (nature video, urban video, application of the cosmetic product). Error bars represent the standard error.

4. Discussion

The present study's goal was to evaluate how the sensory richness of natural and urban environments could affect neurophysiological responses and how these responses could be similar to those resulting from the application of cosmetic products. We first confirmed the beneficial effect of nature by showing that the perception of natural scenes under stressful situations reduced cortisol levels, and these differences were reflected by differences in both behavioral and neurophysiological responses relative to emotions and attention.

Neurophysiological markers that are indicative of the restorative role of nature
Go/No task showed that participants' behavior was facilitated in the natural environment compared to the urban environment. Impaired performance in the urban environment could be due to the induction of mild stress in the participants, which is corroborated by the lower SCR frequency for nature-related stimuli since SCR frequency is related to sympathetic system activity [10]. Regarding the attention-related neurophysiological responses, we focused on the P1-N1 complex since it is associated with early attentional processes [6]. We observed a large difference between the two environments, with a larger response for the urban environment. These results suggest that a larger attentional load in processing images of an urban environment is necessary compared to the natural environment. Source localization showed that this difference mainly emerged both from the occipital regions and from the right inferior frontal area. This would reflect a top-down modulation of discriminative processing in areas of ventral visual flow. To evaluate the neural processes related to emotions, we focused on the EPN, that is associated with early selective processing of the emotional content of sensory stimuli [11]. Our results indicate that the natural environment induced greater occipital negativity than the urban environment. Source analysis revealed that the generator of the EPN was located in the right occipital region, a specific area for the emotional processing of natural environments. All these results are coherent with attention restoration theory [12]. The natural environment contributes

to the restoration of attention and cognitive capacities in general. In contrast, the urban environment captures involuntary attention in a more sustained way, leaving less room for the restoration of attentional capacities.

Impact of sensory richness on behavioral and neurophysiological responses to nature.
There is evidence that other senses are involved when walking in nature. For example, hearing nature sounds benefits people and reduces their stress level, which can be reflected by increased recovery of skin conductance level [8]. Perceived pleasure is increased when nature pictures and sounds are combined, suggesting that sounds seemingly enhance our presence in the environment [13]. Odor can also have profound effects on our emotions and attention. There is ample evidence that natural odors can improve mood and reduce stress. Exposure to flowers' perfume is also known to enhance vigilance performance [14]. It can consequently be suspected that the combination of all sensory elements is at the basis of nature's restorative effect.
We showed that the number of correct responses in the Go/No Go task varied according to the sensory stimuli used, with the combination of images with odors inducing more errors in both environments compared to the presentation of images alone, or images with a background sound. The combined use of three sensory stimuli (visual, auditory, and olfactory) also reduced performance, but to a lesser extent than olfactory stimulation alone. This could be explained by the fact that during audiovisual stimulation, the presence of a congruent odor could induce a super-additive effect on sensory neural processing by enhancing neuronal activity. Thus, attention could have been impaired by the presence of odors, reducing performance during the task.
Moreover, SCR frequency seems to be potentiated by the fact that all sensory modalities are presented simultaneously, suggesting that participants need an experience as close as possible to real-life conditions to feel the effects of nature. The frequency of SCRs appears to be specifically related to high-arousal situations and, more specifically, can be considered an indicator of background arousal [15]. This suggests that urban stimuli may have induced slightly higher background arousal than nature stimuli.

Comparison of urban and nature responses to the application of a cosmetic product.
In a second step, we compared the neurophysiological responses from nature and urban videos to the responses recorded the application of a cosmetic product. We chose to present videos instead of pictures in order to increase the participants' immersion in the natural environment. In EEG, we based our analysis of videos on the source localization resulting from the ERP measures because the analysis of neural responses to nature in higher degrees of immersion than the presentation of pictures is difficult, especially regarding the regions of interest and their interpretation [6]. We consequently chose to analyze one electrode of interest during the video viewing of natural and urban scenes: Electrode O2 is located above the right occipital area and may be a biomarker of emotional processes.
Our results show very large differences across all neurophysiological parameters between video viewing and the application of a cosmetic product, which was expected given the behavioral differences between passive viewing and active application. However, quite interestingly, we found that the application of a cosmetic product decreases both the LF/HF ratio and SCR frequency compared to viewing an urban video, but not compared to a nature video. This suggests that applying a product, much like exposure to nature, promotes a state of relaxation by reducing sympathetic activity or increasing parasympathetic activity. This shared soothing effect deserves to be further explored in future studies under more controlled conditions.

5. Conclusion

This study highlights the neurophysiological benefits of multisensory exposure to natural environments and shows that a nature-inspired cosmetic product can elicit similar effects. Natural settings enhanced attention and emotional regulation, as evidenced by behavioral performance and neurophysiological markers. Remarkably, the application of a cosmetic product led to a reduction in SCR frequencies, suggesting a shift toward parasympathetic dominance—indicative of a relaxation response comparable to that induced by nature exposure. These findings suggest that cosmetics designed to evoke nature may contribute not only to sensorial pleasure but also to emotional well-being. Future research should explore these effects further, reinforcing the potential of neurocosmetics in stress modulation and holistic care.

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