

# A virtual reality-based setting to investigate how environments and emotionally-laden stimuli interact and compete for accessing consciousness

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**Abstract.** Despite the clinical relevance of the interaction between emotionally-laden stimuli and their context, little is known about it. We used virtual reality (VR) to create an experimental setting capable to measure subjective, behavioral and psychophysiological correlates of the conscious access – and subsequent recognition – of phobic (spiders), generically-fearful (scorpions) and neutral (ants) stimuli located in positive, neutral and negative versions of the same virtual scenario. Behavioral data showed significant effects of scenario’s salience on recognition times, among low-spider fearful participants only. In addition, error rates were significantly higher as stimulus’ pleasantness increased, resulting in the lowest number of errors for spiders and in the highest for ants (scorpions placing in the middle of this ranking, coherently with their fearful but non phobic effect) in both high- and low-spiderfearful groups. Finally, stimulus’ content was found to significantly interact with error’s rate and level of fear for spiders, suggesting that a higher self-reported fear for a stimulus increases the likelihood of detecting it. Concluding, these results showed that valence of stimuli was more impactful than that of scenario; however, scenario’s salience (but not valence) was still capable to affect recognition times and error’s rates, though among low-spiderfearful participants only.

**Keywords:** Virtual Reality, Exposure Therapy, Spider Phobia, Conscious Access, Behavioral Data Analysis.

## 1 Introduction

Reality is continuously filtered by our perceptual systems based on the emotional salience of both stimuli and their context: while it is appropriate to fear a deadly-poisonous spider attacking us in the Amazon rainforest, the same fear elicited by a picture of the

spider appearing on the therapist's computer suggests a diagnosis of specific phobia [1]. Indeed, in the first context, the emotional reaction is considered rational and adaptive; in the second, it is considered disproportionate and irrational – in most cases, by the phobic patient himself [1].

The complex relationship between stimulus and context plays a role also in the effectiveness of the gold standard treatment used to reduce phobic fear, i.e., exposure therapies [2], [3]. On one side, the aversiveness for clearly-visible stimuli prevents the majority of phobic patients from undergoing treatment, even if the exposure is carried on in a safe (e.g., clinic) context [4]; on the other, exposure protocols are typically held in just one environment, which makes the desensitization hardly generalizable to everyday-life encounters with the phobic stimulus [5] and thus susceptible to relapses [6].

A growing interest in addressing these issues inspired two research lines, involving virtual reality (VR) and subliminal stimuli respectively:

- VR-based exposure therapies (VRET [7]) allow a confrontation with the phobic stimulus in multiple environments perceived by patients as safer than their real-life alternative (e.g., in vivo exposure);
- an efficacy comparable to that reached through the exposure to clearly visible (and, thus, undesirable) phobic stimuli can be reached through stimuli made more acceptable since delivered under the patient's perceptual (i.e., perceptually-subliminal [8]–[10]) or emotional (i.e., emotionally-subliminal [4]) threshold.

A synthesis of these research lines is represented by paradigms that manipulate the emergence of stimuli to consciousness, showing (1) that stimuli made salient by their emotional (e.g., phobic [11]) content emerge to consciousness faster than neutral controls, and (2) that this emergence can be predicted by psychophysiological correlates (e.g., fMRI [12]). Interestingly, the emergence of a picture to consciousness can be speeded up also by the simultaneous presentation of a stimulus emotionally coherent with it [13], suggesting an interaction with other information coming from the context. However, no study ever investigated how the emotional salience of stimuli and their environment interact and compete for conscious access. Filling this gap could increase both generalizability and acceptability of desensitization protocols, by (1) inducing habituation to phobic stimuli shown in scenarios varying for emotional salience, and (2) through a biofeedback-based system hiding stimuli just before they reach the exposure time that triggers an emotional reaction [4].

These perspectives motivated the building of a VR-based experimental setting allowing measuring subjective, behavioral and psychophysiological correlates of the emergence to consciousness and consequent recognition of phobic, generically-fearful or neutral stimuli appearing in positive, negative or neutral versions of a virtual scenario.

## 2 Methods

### 2.1 Experimental sample

Participants were recruited via advertisements shared on social media and screened for exclusion criteria: they were asked to fill out the 90-item Symptoms Check List (SCL-

90-R [14]) and the Fear survey schedule [15] to discard candidates with psychopathologies or fears other than arachnophobia, as these could represent confounding factors. The participants were then screened for their fear of spiders through the Spider Phobia Questionnaire (SPQ [16]). The results obtained in this scale, ranging from 0 to 30, allowed the assignation of participants to a low- (LS group, SPQ score = 0–15) or a high- (HS group, SPQ score = 15–30) spiderfearful group with comparable numerosity, age and sex of participants. Based on the results coming from these questionnaires, 20 volunteers (age:  $25 \pm 3$ y, 13 females and 7 males) were enrolled and split into two groups. Finally, a State Trait Anxiety Inventory (STAI [17]) was administered to measure trait- and state-anxiety of participants.

## 2.2 Experimental setting

An Oculus Quest 2 – a HMD manufactured by Meta with two 1832x1920 pixels LCD displays and a supported maximum refresh rate of 90 Hz – was linked through a 5 Gbps 5 meters cable to a laptop (MSI Stealth 15MA11UEK, Intel Core (TM) i7-11375H, @ 3.30 GHz, 16 GB RAM, dedicated video card NVIDIA GeForce RTX 3060). Blender and Unity were respectively exploited to design or modify 3D assets and to run 2 virtual experiences described in paragraph 2.3.

This hardware setting has been integrated with devices for the acquisition of psychophysiological signals. Electrodermal activity (EDA) has been recorded with Shimmer3 GSR+ (sampling frequency: 250.4 Hz) Unit using Ag/Cl electrodes placed on the distal part of index and middle fingers of the non-dominant hand. With the same system, the photoplethysmographic signal (PPG) has been acquired by using a Shimmer Optical Pulse Sensing Probe. The three standard electrocardiographic (ECG) derivations (LA-RA, LL-LA, LL-RA) have been registered using a Shimmer3 ECG Unit (sampling frequency: 250.4 Hz) with four Ag/Cl electrodes properly placed on the subjects' torso. Finally, participants' electroencephalogram (EEG) has been acquired through a Geodesic EEG System 300 with a 128-channels flexible EEG net. The EEG signal and the VR flow were appropriately synchronized.

## 2.3 Virtual scenarios

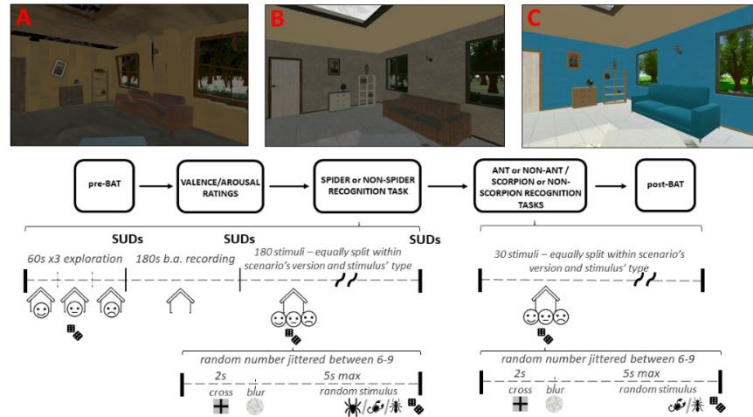
A behavioral assessment test held in virtual reality (VR-BAT) has been designed as a neutral corridor furnished with doors and a window by which a neutral, natural environment could be seen. Altogether, plain, not-arousing colors and wider building dimensions (11.97x1.80x3.00 m) have been exploited to avoid possible biases (e.g., for claustrophobic sensations).

A virtual room was created setting its architectural features as follows: 5.00x6.50x2.80 m room, with two 1.65x1.55 m windows on a wall, a 2.10x1.40 m window on the plain roof, two 2.00x0.80 m closed doors. Importantly, the same room template was customized to convey different emotional valences: each of the three resulting scenarios (positive, neutral, negative) was provided with the same furnishings slightly altered in parameters such as colors, lightness, shapes, natural elements and spatial configuration. These

parameters were customized to induce the valence of interest accordingly with the scientific literature [18] summarized below:

- **colors** influence mood, reasonably affecting the pleasantness associated with the environment [19];
- **lightness** intensity positively correlates with mood (a well-lit environment is more likely to induce a positive mood and *vice versa* [19]);
- **shapes** influence the environment's pleasantness perception since associated with dangerous (e.g., sharp knives) or harmless (e.g., rounded ball) objects [20];
- **natural elements** are reported to reduce stress, positively influencing participant's mood [21];
- **spatial configuration** of roof, walls, furniture and objects in a room influences its overall pleasantness, with open – rather than enclosed – spaces increasing the perceived visual permeability (i.e., the perceived ability to see through space but not necessarily pass through) and thus the perceived safety [22].

Of note, the three room's scenarios – supposed to have a negative, neutral, or positive valence – were validated in a pilot study involving 48 participants recruited in the general population: for each version, a 40s-long video showed a visual exploration of the room from a position matching that of participants during the experimental protocol. After the exposure to each video (the order of which was randomized between the participants), volunteers were asked to rate it in terms of valence and arousal. This pilot experiment confirmed that each scenario's version induced the supposed valence.



**Figure 1:** experimental setting and procedure. The top panel shows the three scenario's versions rated as negative (A), neutral (B) and positive (C). The bottom panel schematizes the experimental procedure: specifically, a behavioral avoidance test (BAT) was held in virtual reality before and after the whole experimental session, that consisted of a main recognition task (spider/non-spider) followed by either an ant/non-ant or by a scorpion/non-scorpion recognition task. The spider/non-spider recognition task consisted of an exploration of each scenario's versions (represented in A, B, and C), followed by a baseline in a blank scenario; then, the task began, showing 180 random stimuli (equally split between spiders, ants or scorpions) emerging from a blurred mask in the various scenario's versions. The following secondary (ant/non-ant, or scorpion/non-scorpion) task had a comparable organization, but a lower number and variety of stimuli. Subjective Units of Distress scale (SUDs) was conducted before and after the blank scenario, as well as at the end of the spider recognition task.

## 2.4 Experimental procedure

The procedure represented in Figure 1 started with (1) a virtual BAT, (2) a 1-minute exploration of each scenario (panels A, B and C), and (3) a 3-minutes baseline in a blank scenario.

After these initial steps, the spider VS non-spider recognition task (Fig. 1) began, consisting of 180 virtual stimuli gradually appearing on a virtual coffee-table within the three different scenarios. Based on an emotion recognition paradigm previously used with human faces [23], each stimulus was initially pixel-blurred to make it not immediately recognizable; within 5 seconds, the mask was progressively losing its masking effectiveness to make the stimulus clearly recognizable. Importantly, stimuli were equally distributed to be neutral (ant), generically-fearful (scorpion) or phobic-fearful (spider). Each participant was instructed to click a mouse button as soon as the stimulus was recognized as a spider or a non-spider with above-chance accuracy: mouse buttons indicating each answer were paired among participants and between control and experimental group. The presentation order was random for stimuli and pseudo-random for scenario's versions (after consecutive stimuli jittered between 6 and 9 within the same virtual environment, this switched randomly to a different one to avoid a mere exposure effect [24] of the scenario's version).

Once the spider VS non-spider recognition task was completed, one of two comparable tasks was conducted, asking participants to indicate the recognition of a new target (i.e., a scorpion or an ant) in two 30-trial sessions each. Of note, the sequence of experimental tasks following the spider VS non-spider one was paired among participants and between groups.

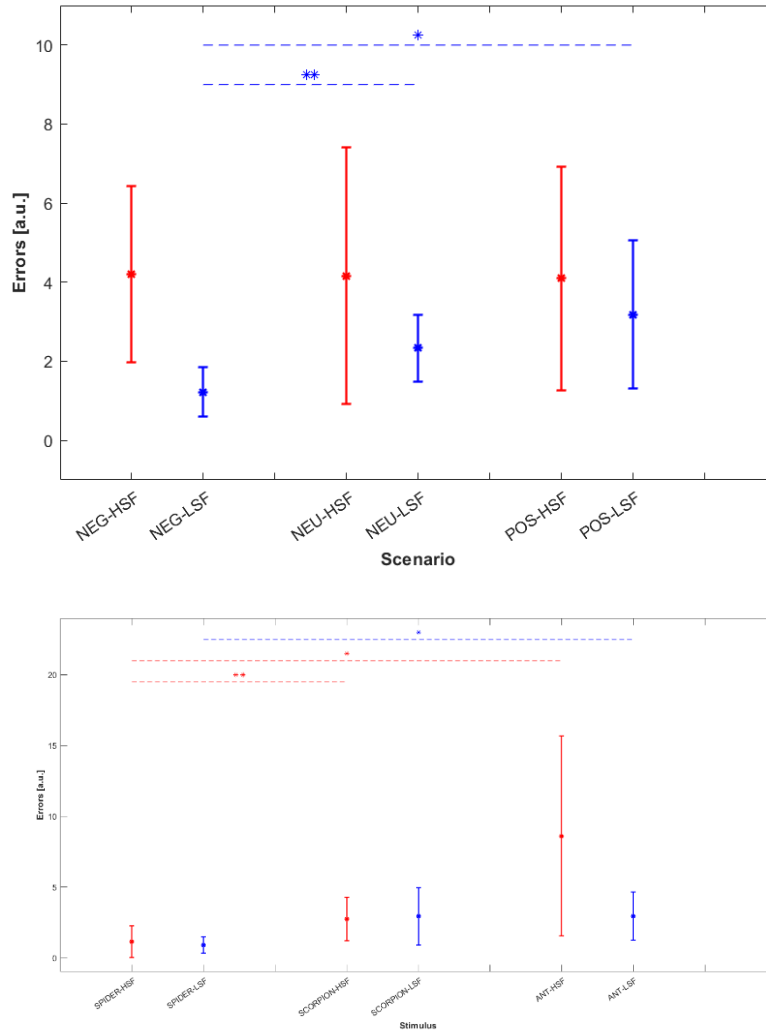
## 2.5 Data analysis

The present experimental setting allowed the recording of subjective, behavioral, and psychophysiological data.

Subjective data consisted of self-reported questionnaires measuring the level of psychopathological symptoms (SCL-90-R), fear (SUDs), state-/trait-anxiety (STAI), fear for spiders (SPQ) and for other stimuli or situations (Fear survey schedule). The results coming from SCL-90-R and from the Fear survey schedule were used to check that participants met inclusion criteria; the SPQ score was used to split the sample between a low- and a high-spiderfearful group, comparing their behavioral and psychophysiological correlates; finally, the results coming from SUDs and STAI were used to perform a pre-post comparison of experimental tasks' steps exploiting non-parametric statistical tests.

Behavioral data consisted of target stimulus recognition times and hit/error rates during the three experimental tasks. Recognition time has been defined as the amount of time between the stimulus' appearance on the virtual coffee-table and the mouse click corresponding to the participant spotting the stimulus as target or non-target with above-chance accuracy. Coherently with the standards of signal detection theory, each click was marked as a hit when the stimulus was correctly recognized as a target or a non-target, and as an error otherwise: hit/error rates have been defined as the number of correct answers (i.e., true positive or true negatives) or mistakes (i.e., false positives or false negatives) respectively made by participants within the overall stimuli recognition tasks.

For each of these metrics, 3x2 mixed-ANOVA design models have been exploited to detect statistical differences in the accuracy of recognition, exploring within effects on stimuli or scenario's versions and between effect on phobic groups.



**Figure 2:** error bars of errors' rate with respect to A) scenario's version and B) stimuli, in high- and low-spiderfearful groups (HSF and LSF respectively). Significant differences are marked with one ( $p < 0.05$ ) or two ( $p < 0.01$ ) asterisk(s).

### 3 Results

One female non-phobic participant was discarded because of an unexpected visual impairment reported during the experiment.

For what concerns the task with spiders as targets, recognition times were significantly influenced by scenario's version ( $p = 1.07e-04$ ). Post-hoc analysis found that average

recognition time among low-spiderfearful participants was higher within negative and positive scenario's versions than within the neutral one.

Errors' rate was significantly influenced by scenario's version ( $p=0.04$ ) as well as by stimulus ( $p=1.8017e-04$ ), while the relation with level of fear for spiders tended to significance ( $p=0.06$ ). Significant interactions were also found between (1) scenario's version and the level of fear for spiders ( $p=0.02$ ), and (2) stimulus and level of fear for spiders ( $p=0.01$ ). Post-hoc analysis represented in Fig. 2 revealed that error's rate among low-spiderfearful participants (A) was significantly lower in the negative scenario's version than in the neutral ( $p=0.0094$ ) or in the positive one ( $p=0.0116$ ), and (B) it was significantly lower for the spider than for the ant ( $p=0.0352$ ). Among high-spiderfearful participants, error's rate was significantly lower for the spider than for the scorpion ( $p=0.0098$ ) or for the ant ( $p=0.0265$ ).

For what concerns the tasks with ants and scorpions as targets, error's rates were not significantly different between ant and scorpion when the first was the target ( $p=0.2836$ ), while it was found a significantly higher error's rate for the scorpion than for the ant when the scorpion was the target ( $p=0.0223$ ).

The  $d'$  parameter (a sensitivity index that represents the overall accuracy in detecting signals) in the spider recognition task resulted not-significantly different between the two groups ( $p=0.8322$ ).

Subjective Units of Distress (SUD) resulted significantly higher among high-spiderfearful than among low-spiderfearful participants, both before ( $p=0.0207$ ) and after ( $p=0.0048$ ) the spider recognition task; within high-spiderfearful participants, SUD were significantly higher after the spider recognition task ( $p=0.0313$ ).

## 4 Discussion

The interaction between stimuli and context, as well as their competition for conscious access, was found to induce significant effects in behavioral measures recorded during the recognition tasks.

Within the low-spiderfearful group, the recognition time for target stimuli increased with arousal but not with valence of environments: the emotion conveyed by the scenario – regardless of it being positive or negative – represented a distractor for the experimental task. Within high-spiderfearful group, the distress induced by the spider recognition task – significantly higher than in low-spiderfearful participants – sets aside the effect of scenario on stimuli's recognition time.

Contrary to recognition times, error's rates were sensitive to stimulus' and, partially, to environment's valence. The effect of scenario's version was significant among low-spiderfearful participants only: within this group, the negative scenario's version induced an error's rate significantly lower than the other two. On the other hand, stimuli influenced errors' rates in both groups: error's rate decreased as it increased the distress induced by stimuli, with the most significant differences being observed within high-spiderfearful group. Observing the error's bar related to ants in Fig. 2, we could speculate that high-spiderfearful group was biased to misinterpret neutral stimuli as spiders: however, signal detection theory did not reveal any significant difference in the



accuracy of participants. Of note, error's rate related to spiders was significantly lower than that related to ants within the low-spiderfearful group too; this supports the debated hypothesis that spiders are recognized more easily than other animals due to the specificity of their perceptual features (i.e., 8-legged animals with a unique crawling pattern) [8], [25]–[27]. Importantly, the analysis of secondary tasks (ant or non-ant, scorpion or non-scorpion) showed that stimulus-related differences in errors' rate were not significantly lower for the target, suggesting that these results are driven by stimulus' valence rather than by each task's attentional focus.

Finally, the interaction among error's rate, stimulus, scenario's version, and level of fear for spiders was significant: even if this significance is mainly pulled by scenario's version, level of spider-fear approached significance (which makes it reasonable to test it on a bigger sample), suggesting that a higher self-reported fear for a target stimulus increases the likelihood of detecting it .

These results, taken as a whole, suggest that stimulus' valence overcame that of the surrounding scenario. Error's rate is the measure mostly differentiating between neutral, fearful and phobic stimuli (in all participants), and between neutral and emotionally-shaded scenarios (within low-spiderfearful group only); recognition times too are affected by scenario's valence, but this effect is probably overridden by distress for spiders in the high-spiderfearful group.

In conclusion, these behavioral data described the relevance of stimuli and environments for participants with varying levels of fear for spiders: integrating their psychophysiological correlates in this analysis could reveal the predictors of stimulus' emergence to awareness. Beyond the theoretical advances in the understanding of the complex relationship between emotional stimuli and their environments, this integrated information could be used to set a biofeedback-based system hiding the phobic stimulus just before its conscious recognition, thus making exposure therapies more acceptable.

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