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How did you feel during the navigation? Influence of emotions on browsing time and interaction frequency in immersive virtual environments

Marco Mandolfo[a] *, Francesco Baisi[a], Lucio Lamberti[a]

[a] *Politecnico di Milano, Department of Management, Economics, and Industrial Engineering, Milan, Italy*

* Corresponding author

Correspondence: Marco Mandolfo, Politecnico di Milano, Department of Management, Economics, and Industrial Engineering, Via Lambruschini 4/B, Milan, 20156, Italy. Email: marco.mandolfo@polimi.it

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Abstract

Immersive virtual environments (IVEs) represent virtual settings that simulate the physical world. Users interacting in such virtual venues commonly display behaviours like the ones that would occur in the physical world. However, little is known about how the affective states experienced while browsing IVEs may in turn influence user's interactive behaviour. The present research investigates how affect in terms of arousal and valence generated by IVEs influences browsing time and interaction frequency. Three studies analyse various facets of affect in IVEs. Study 1 investigates the cognitive responses and shows that browsing time is positively affected by self-reported arousal. Study 2 analyses neurophysiological responses and demonstrates consistent results with Study 1. It further shows that physiological correlates of arousal and valence positively influence interaction frequency. Study 3 delves into personal interest, a recurring factor emerged in the two previous studies, and investigates its interaction with arousal. Findings show that in a high arousal IVE, highly interested users are more likely to browse longer than low-interested users. Overall, the results show that behavioural realism evoked in IVEs involves both users' actions and affective states. Implications in terms of design guidelines to foster positive affect in IVEs are drawn.

Keywords: Immersive reality; Virtual reality; Emotions; Affect; Interactive behaviour

1. Introduction

Recent technological developments have weakened the dividing line between physical and digital environments (Bolton et al., 2018). Current digital technologies allow generating virtual settings that simulate the physical world in terms of interaction possibilities. Among these technologies, immersive virtual environments (IVE) represent a notable example. These are intended as virtual environments "that organize sensory information in such a way as to create a psychological state in which the individual perceives himself or herself as existing within the virtual environment" (Blascovich, 2002, p.128). Examples of commercial IVEs range from pioneering virtual spaces such as Second Life to extant metaverses as Roblox, Fortnite, or Facebook Horizon Worlds, where users engage in social, cultural, and even economic activities (Park & Kim, 2022; Saunders et al., 2011). Evidence shows that interacting with such virtual spaces can convey a feeling of immersion towards the virtual environment (Blascovich et al., 2002; Nah et al., 2011). This absorption represents a key factor to evoke individual responses like the ones that would occur in the physical world. In other words, IVEs foster a form of behavioural realism (Freeman et al., 2000; Higuera-Trujillo et al., 2017). The use of IVEs has acquired a relevant role in the user experience field. From a business perspective, IVEs offer the possibility to create engaging experiences during the user journey (Lau & Lee, 2019). Immersion has been linked to a stronger focus and an extension of the time perception, which, in turn, may have a positive impact on overall satisfaction (Rudd et al., 2012). Engaging IVEs offer also new opportunities for establishing relationships with users through participation and co-creation (Cowan & Ketron, 2019; Mandolfo et al., 2020) or during learning experiences (Alhalabi, 2016; Jimeno-Morenilla et al., 2016). From a research perspective, IVEs allow simulating real environments under controlled conditions, thus offering the possibility to study the effects of a specific environment on the individual experience (Meißner et al., 2019). Along this line of thinking, Schnack et al. (2020) employed an immersive virtual convenience store to study the shopping experience in terms of purchase rates and shelf positioning. Moreover, evidence shows that IVE might help in analysing different facets of complex affective states such as gratification, awe, or anxiety (Rauschnabel, 2018; Riva et al., 2007).

A considerable amount of literature has been published on how IVEs affect the user experience (Marín-Morales et al., 2020; Rubio-Tamayo et al., 2017). These studies cover several responses, including affective states (Kim et al., 2014; Marín-Morales et al., 2018), spatial presence (Higuera-Trujillo et al., 2017; Kober et al., 2012), and choice (Meißner et al., 2020). So far, however, there has been little discussion about how affective states experienced during browsing of the IVEs may in turn influence the interactive behaviour. Previous experimental investigations tended to focus on IVEs as a means to generate affective states, overlooking how affect may alter the final user behaviour. Nevertheless, there is a large volume of studies describing how affective states generated by certain atmospheric qualities influence the user behaviour in physical venues as well as in online settings (Donovan & Rossiter, 1982; Eroglu et al., 2001). Specifically in online websites, affective states are repeatedly shown to impact the online user behaviour (Eroglu et al., 2003; Ha & Lennon, 2010). In this work we posit that a similar effect can be observed also in IVEs. Hence, we suggest that affect represents a central driver for an effective interactive experience in IVEs.

Based on this rationale, this study aims to investigate how affect generated by an IVE influences two aspects of the user experience: the length of the browsing experience and the characteristics of the interaction. We characterise affective states as a combination of arousal and valence, in line with a significant body of literature examining the role of affect in IVEs (for a review, see Marín-Morales et al., 2020). Consequently, we analyse how affective states influence the length of the browsing experience and the frequency of clicks on interactive elements. We carry out three sequential studies. First, we explore the relationship between cognitive affect and interactive behaviours through an online survey. Next, we replicate the investigation in a laboratory setting to assess the role of neurophysiological correlates of affect on interactive behaviours. Lastly, based on the observed experimental outcomes, a third laboratory investigation is conducted to evaluate the effect of arousal and personal interest on interactive behaviours.

2. Conceptual Background

2.1 Affect elicitation in immersive virtual environments

Immersive experiences in IVEs are commonly characterised by two elements, namely the subjective sense of presence and the objective capacity to isolate the individual from the physical reality (Bowman & McMahan, 2007; Slater, 2018). The former embodies the perception of being in a specific environment (Cowan & Ketron, 2019; Slater & Wilbur, 1997), whereby a significant degree of presence generates the illusion of physicality and the impression of interaction with the physical world. On the other hand, isolation and dissociation from the physical surroundings are promoted by the sensory fidelity a system provides. Objective fidelity is commonly achieved by substituting real-world inputs with virtual sensations (Bowman & McMahan, 2007). This phenomenon can be induced by different IVEs with varying degrees of immersivity, including desktop PCs, cave automatic virtual environments or head-mounted displays (Flavián et al., 2019).

These characteristics have prompted previous research to assess significant parallelisms between the user behaviour observed in the real context and the one displayed in IVEs (Higuera-Trujillo et al., 2017). Among these parallel responses, affect elicitation is a common topic. IVEs can be used as a means to induce affect in several forms, including relaxation, anxiety, and complex emotions (Kim et al., 2014; Marín-Morales et al., 2018; Riva et al., 2007). Such affective states are commonly labelled through an established three-dimensional space consisting of valence, arousal, and dominance (Russell & Mehrabian, 1977). The first dimension, namely valence, measures the degree to which an instance is perceived as positive or negative. Arousal assesses affect in terms of activation on a continuum from low to high stimulation. Whereas dominance evaluates the perceived degree of control of specific feelings. The dominance dimension, however, has been often discounted due to its low influence on user behaviour (Eroglu et al., 2003; Marín-Morales et al., 2020).

Affect has been often observed to be a significant mediator explaining the relationship between environmental stimuli and user behaviour. In other words, an external stimulus (e.g., an atmospheric cue) was demonstrated to influence the individual affective state, which, in turn, influences the user behaviour (Donovan & Rossiter, 1982; Eroglu et al., 2001). Such a relationship has been stigmatised through the Stimulus-Organism-Response (S-O-R) framework, which has been tested both in online and offline contexts (Eroglu et al., 2003). Based on this framework and given the characteristics of the immersive experience, we posit that a comparable relationship between the context and experienced affect exists also in IVEs, where the IVE represents the Stimulus.

2.2 Influence of affect on interactive behaviours

According to the S-O-R framework, the Organism embodies the affective states. These are intended as psychophysiological responses that include several instances, which are often characterised in terms of arousal and valence, as previously discussed. Within these two core dimensions, specific emotions are theorised to be recognisable in terms of cognitive interpretations and in connection with neurophysiological activations (Posner et al., 2005, 2009). Cognitive interpretations are intended as the subjective appraisals of the affective experience. These include the individual interpretations and labelling of core affect and are commonly assessed through self-reports (Bradley & Lang, 1994). On the other hand, neurophysiological correlates of affect are intended as biological activations triggered in response to a stimulus. These are frequently conceived as two neurophysiological systems, one related to valence and the other to arousal so that emotions are theorised to stem as a linear combination of these two dimensions (Posner et al., 2005). Based on this rationale, a growing body of studies in affective neuroscience has confirmed the possibility to assess neurophysiological correlates of affect based on cortical and subcortical brain activations (Mauss & Robinson, 2009).

Cognitive and neurophysiological correlates of affect are conceived to influence individual responses. More specifically, with reference to the S-O-R framework, both facets are expected to impact the

Response element. Previous studies have shown that cognitive affect modulates multiple responses. For instance, Menon & Kahn (1995) found that the combination of positive valence and positive arousal leads to increased variety-seeking behaviour and more experimentation. In other words, positive affect is shown to enhance the desire to seek more stimulation in the environment. Comparable evidence was provided by Koo & Ju (2010), who showed that cognitive arousal and valence positively impact the intention to continue to use an online website. Taken these together, we posit that a specular phenomenon can be observed in IVEs. Specifically, we suppose that positive cognitive arousal and valence elicited from the interaction with the IVE will result in higher desire to explore and will then increase the total browsing time. Formally, we develop the following hypotheses:

H1a: Cognitive arousal positively influences the browsing time.

H1b: Cognitive valence positively influences the browsing time.

Parallel research in affective neuroscience and psychophysiology holds that analogous effects can be observed in terms of neurophysiological responses. For instance, Marín-Morales et al. (2018) monitored the cortical activations to assess valence and arousal while tracking the length of browsing time in an IVE shaped as a museum. Whereas Bender & Sung (2021) demonstrated that affective reactions of arousal and enjoyment experienced in IVEs can be observed through electrodermal responses. The use of neurophysiological measurement tools is also becoming an accepted practice in IVE research (Marín-Morales et al., 2020). Indeed, differently from self-reports, these tools offer the possibility to directly track individual responses in real-time without interrupting the interactive experience. The use of physiological metrics to assess affective states finds also theoretical support in the established mind-body relationship (Green et al., 1970), which holds that through the quantitative assessment of the physiological state of individuals, information about their psychological state can be extracted. Based on the present discussion, two more hypotheses centred on neurophysiological responses are advanced, namely:

H2a: Neurophysiological arousal positively influences the browsing time.

H2b: Neurophysiological valence positively influences the browsing time.

Affective states are further expected to influence approach behaviours towards the contents of the IVEs. Indeed, it is widely established how valence and arousal induced by the context can enhance approach behaviours. Eroglu et al. (2003) showed that approach or avoidance behaviours are not directly affected by the atmospheric characteristics of the environment, but they are the result of the affective state experienced by the user. Ha & Lennon (2010) demonstrated in a similar vein that affective states play a mediating role between online task relevance and approach behaviours. Along this line of thinking and based on the mind-body relationship, we posit that such approach tendencies can be observed through neurophysiological responses occurring in IVEs. In particular, we suppose that positive neurophysiological affect will influence the frequency of interactive actions with the products displayed (e.g., clicks on product information and product price). In other words, we expect that positive neurophysiological affect will be an antecedent of potential interactive actions. Formally, we advance the following hypotheses:

H3a: Neurophysiological arousal positively influences the frequency of interaction with products displayed in the IVE.

H3b: Neurophysiological valence positively influences the frequency of interaction with products displayed in the IVE.

3. Method

Study 1 and Study 2 were first carried out. Study 3 was then conceived on the results of the previous studies. Study 1 was conducted through an online survey to test our H1a and H1b hypotheses. The independent variables in this study were cognitive responses related to affect, namely arousal and valence. Furthermore, we explored the influence of two possible modulators, namely personal interest and expertise, and their interaction effect with our independent variables. Study 2 replicated Study 1 in a laboratory setting to investigate H2a, H2b, H3a and H3b.

The two studies involved the same IVE, that is a virtual replica of an exhibition of a notorious auction house. This virtual environment was developed by Matterport and was openly accessible online. The IVE offered a first-person navigation perspective and included seven virtual rooms displaying musical instruments (for a representation see Figure A1 and Figure A2 in Appendix). Most of the virtual rooms had multiple entrances and no signage was displayed, therefore the IVE did not guide the user towards a specific navigation path. Furthermore, the user could choose to interact with the digital exhibition by clicking on the virtual musical instruments displayed. Clicking on the musical instrument provided information about the item (e.g., sound characteristics, design features) and its selling price. Every user started the navigation in the same location at the centre of the virtual exhibition (a room linked with other four rooms) to encourage heterogeneity of navigation direction from the first step. Users could independently move in the IVE using either the mouse or the keyboard. The choice of this IVE was motivated by the possibility of offering heterogeneous navigation patterns, a high variety of touchpoints, and a large space to explore.

3.1 Study 1

3.1.1 Participants

A sample of 149 university students took part in the study, of whom 133 completed the procedure (age range: 18-30, 49 females and 84 males). All the subjects were Italian.

3.1.2 Procedure

Self-reports about the browsing perception were gathered through an online survey. This was formed by two sections. In the first, respondents were presented a set of instructions about how to interact with IVE. They were then redirected through a weblink to the IVE, where they were asked to freely browse the virtual space. No specific task was provided in order not to guide the user. Once the navigation was completed, participants were asked to report the time displayed on their computer clock. This passage was instrumental to gather the browsing time. In the second section, ratings about the experience were gathered through closed-ended scales. All participants were asked to fill in the survey through a computer to prevent the use of smaller screen sizes (e.g., smartphones).

3.1.3 Measures

Browsing time was assessed as the time in minutes between the opening of the weblink and the time displayed on the user's clock after the navigation. To check for possible input inaccuracies, an additional query asked participants the length of their navigation on 6-point scale (e.g., "less than two minutes", "2 to 3 minutes", "3 to 5 minutes", "5 to 10 minutes"). Actual browsing time and self-reported browsing time proved to be strongly linearly correlated ($r(133) = .733$, $p < .001$), thus validating the time assessment.

Self-reports gathered after the navigation were adapted from previous literature and evaluated on 7-point Likert scales. These included two 6-item constructs respectively for Valence and Arousal in accordance with Mehrabian & Russell (1974), a 2-item covariate assessing the interest towards musical instruments ("How fond of music are you?", "How interested are you in the world of guitars?"), and a single item assessing the expertise in using IVEs ("How expert do you consider yourself in navigating 3D websites as Google Street View?"). Interest and expertise were investigated as potential modulating variables. All constructs reported satisfactory reliability scores, namely Arousal (α = .80), Valence (α = .89), and Interest (α = .76). All items were translated into Italian.

3.1.4 Results and discussion

Browsing times proved to be heterogeneous (M = 4.0 min; SD = 3.2 min), as expected. Table 1 presents the means, standard deviations, and correlations among our variables of interest. As expected, positive correlations were found between browsing time and self-reported affect and between browsing time and interest.

To test H1a and H1b, a hierarchical linear regression was run. To reduce multicollinearity, first, we mean-centred all the variables. Next, the linear relationship between the variables was confirmed by visual inspection of the scatterplots. The model was run with all main effects of self-reported valence and self-reported arousal first (Model 1), with interest and expertise added next (Model 2), and with interactions effects added later (Model 3). Residuals were independent, as assessed by a Durbin-Watson statistic of 1.864. There was no evidence of multicollinearity, as assessed by tolerance values greater than 0.6 and all VIFs <1.62. The results are presented in Table 2. Overall, self-reported arousal proved to positively influence the browsing time in all three models, thus confirming our H1a. On the other hand, no significant effect of self-reported valence emerged. Therefore, H1b was rejected.

As expected, interest appeared to have a positive influence, underscoring how the interest in the content of the IVE plays a central role, whereas no substantial role of expertise emerged. Unexpectedly, self-reported arousal and interest proved to have comparable effects in terms of influence on the browsing time. This finding, while preliminary, suggests that personal interest towards the content of the IVE might be as important as affective arousal to modulate the users' browsing time.

Table 1. *Means, Standard Deviations, and Correlations among the measures employed in Study 1 (N = 133)*

Variable	***Mean***	***Std. Dev.***	**1. Browsing time**	**2. Self-reported Arousal**	**3. Self-reported Valence**	**4. Interest**
1. Browsing time	4.00	3.24	-			
2. Self-reported Arousal	3.57	1.04	.33**	-		
3. Self-reported Valence	4.76	1.03	.28**	.53**	-	
4. Interest	3.88	1.59	.24**	.22*	.09	-
5. Expertise	4.23	1.74	.04	.22*	.17*	.08

* p < .05; ** p < .01

Table 2. *Summary of results from hierarchical regression analyses (Dependent variable: Browsing time)*

	Model 1			***Model 2***			***Model 3***		
	B	SE B	β	B	SE B	β	B	SE B	β
Intercept	4.00	.27		4.00	.26		3.84	.26	
Self-reported Arousal	.80	.31	.25*	.69	.32	.21*	.66	.31	.20*
Self-reported Valence	.48	.31	.15	.51	.31	.15	.53	.30	.16
Interest				.59	.27	.18*	.73	.26	.22**
Expertise				-.15	.27	-.05	-.00	.26	.00
Self-reported Arousal × Interest							.09	.32	.03
Self-reported Valence × Interest							.59	.25	.21*
Self-reported Arousal × Expertise							-.31	.28	-.11
Self-reported Valence × Expertise							.88	.27	.32*
Overall model statistics	Adj R^2 = .11 F(2, 130) = 8.984***			Adj R^2 = .13 F(4, 128) = 5.85***			Adj R^2 = .23 F(8, 124) = 5.89***		

* p < .05; ** p < .01; *** p < .001

3.2 Study 2

3.2.1 Participants

20 right-handed university students (age range: 18-30, 9 females and 11 males) took part in the experimental procedure. The recruitment phase granted the exclusion of subjects with pacemakers or

those diagnosed with cardiac or diabetic pathologies, on therapy with hypertension drugs, with a history of epilepsy, acute visual problems, or frequent migraines.

3.2.2 Procedure

Neurophysiological responses to the browsing experience were gathered in a controlled laboratory setting. Each experimental session involved five sequential phases. First, a laboratory assistant briefed participants about the objective of the study and written consent was obtained. Subsequently, the measurement instrumentation was set up and each subject was invited to sit in front of a 24” computer monitor used for stimuli delivery. Next, each subject went through a resting phase. Subjects were first exposed to a grey static image for one minute and, subsequently, they were asked to close their eyes for another minute. These steps were employed to acquire physiological baselines. Participants were then presented a set of instructions about how to interact with IVE. Next, the IVE was displayed in full-screen mode and participants were asked to freely navigate the environment either through the computer mouse or keyboard. No time limit was set for the navigation nor indication about the passing of time was provided (e.g., the experimental room had no clocks and participants were asked to leave their watches and smartphones outside the room in order not to interfere with the measuring devices). Subjects could end the browsing by pressing a button reporting “end navigation session”, which was displayed on the right-hand side of their screen. After the navigation experience, a closing online survey was presented. The procedure was developed in line with the principles of the Helsinki Declaration.

3.2.3 Instrumentation

Electrodes mounted in a 64-channels pre-cabled cap were used to record EEG activity. Cortical signals were recorded from 25 Ag/AgCl surface electrodes placed according to the 10-10

International System with channels which explore the frontal (Fp1, Fp2, Fpz, AF3, AF4, AF7, AF8, F1, F2, F3, F4, F5, F6, F7, F8, Fz), temporal (T7, T8), central (C3, C4, Cz), parietal (P7, P8), and occipital (O1, O2) regions. All impedances were kept below 5 kΩ and data were acquired at a sampling rate of 256 Hz. During the data collection, 1 Hz high-pass and 200 Hz low-pass filters were used; a 50 Hz notch filter was also employed.

An eye-tracking bar (SMI REDm) was attached to the computer monitor to gather ocular data. The recording was performed at a sampling rate of 30 Hz during the whole navigation. Each subject underwent initial calibration and validation phases with respectively 13 and 4 gaze points. To assure the validity of the signal acquisition, each subject was required to stay in a range of 60-80 cm from the stimulus monitor.

3.2.4 Measures

EEG data were pre-processed using Matlab EEGLAB toolbox and custom scripts were employed for offline processing. First, data were bandpass filtered (high pass = 1 Hz; low pass = 45 Hz) through a finite impulse response filter of order 1000. Next, muscular and ocular artefacts were detected and removed through independent component analysis. Data from one subject was removed due to significant noise related to movement artefacts. Third, the original EEG signal was referred to a specific electrode placed on the pre-cabled cap, between CPz and Pz and the signal was transformed through Common Average Reference. Individual Alpha Frequency was then computed for each subject and signals were bandpass filtered to isolate the standard frequency bands (Klimesch, 1999). Hemispheric frontal asymmetry was assessed by computing Global Field Power and then considering a specific subset of frontal and pre-frontal electrodes, namely F3, AF3, F4, AF4 in accordance with Vecchiato et al. (2012). Hemispheric frontal asymmetry was employed as the measure of neurophysiological valence, as suggested by a large body of literature (Ohme et al., 2010; Ravaja et al., 2013; Vecchiato et al., 2011; Venkatraman et al., 2015). Cortical activations in the beta and alpha frequency bands were further employed as the measure of neurophysiological arousal. Specifically, the ratio between the power spectrum in the beta and alpha band was computed on the F3, F4, F7, F8 electrodes in accordance with Coelli et al. (2018) to measure neurophysiological arousal. Both indicators of arousal and valence were standardised in reference to the physiological baseline.

Browsing time was assessed as the duration in seconds of the total navigation in the IVE. The eye-tracking signal was processed through a dedicated software designated software (SMI BeGaze, version 3.7) to detect ocular responses related to the interaction frequency. Specifically, subjects could activate interactive information by clicking on specific products in the IVE. Each time the subject opened one interactive window, we tallied one interaction in case the participant showed an ocular dwell time on the interactive content greater than 2 seconds. This time window was chosen to be certain that the subject purposely displayed an interactive behaviour. Lastly, the same self-reported items for assessing interest employed in Study 1 were investigated ($\alpha = .81$). Individual expertise was not investigated since it did not show significant influence in Study 1.

3.2.5 Results

In line with Study 1, navigation times resulted heterogeneous (M = 433.6 s; SD = 210.2 s). Overall descriptive statistics are reported in Table 3. To test H2 and H3, we employed two hierarchical linear regressions following the same methodology adopted in Study 1. First, a two-step model was used with browsing time as the dependent variable. The model was run with neurophysiological valence and arousal as independent variables first (Model 1), with interest added next (Model 2). Next, a parallel two-step model was used with interaction frequency as the dependent variable. The results of both regressions are presented in Table 4.

Concerning browsing time, results showed a significant positive influence of neurophysiological arousal in both steps of the regression. Therefore, this finding supports H2a. On the contrary, no evidence of a significant influence of neurophysiological valence was observed; hence we reject H2b.

We further underscore a positive influence of personal interest, whereby adding this variable in the model leads to a significant increase in R^2 ($\Delta R^2 = 0.18$, $\Delta F(3, 15) = 1.81$, $p < .05$). This outcome proves to be consistent with Study 1, advancing evidence of a significant role of personal interest to affect browsing time. Moreover, consistently with Study 1, we found no significant effect of valence. Second, concerning the interaction frequency with the IVE, both affective factors resulted influential. On the one hand, with neurophysiological valence and interest as further independent variables (Model 2), neurophysiological arousal proved to have a significant positive influence on interaction frequency. However, when we considered only the influence of valence as a further independent variable (Model 1), arousal showed only a marginal influence ($\beta = .31$, $p = .09$). Accordingly, H3a was partially supported. On the other hand, neurophysiological valence resulted to be significant in both models, providing a positive influence on the number of interactions with the IVE. Therefore, full support was evidenced for H3b. Personal interest appeared to have a positive influence as well. Interestingly, our findings show that arousal and interest proved to have comparable effects in terms of influence on the interaction frequency. This result, which is aligned with the observation concerning the outcome of Study 1, underscores the centrality of personal interest.

Table 3. *Means, Standard Deviations, and Correlations among the measures employed in Study 2 (N = 19)*

Variable	***Mean***	***Std. Dev.***	**1. Browsing time**	**2. Interaction frequency**	**3. Neurophys. Arousal**	**4. Neurophys. Valence**
1. Browsing time	433.6	210.2	-			
2. Interaction frequency	20.0	23.4	.81**	-		
3. Neurophysiological Arousal	.056	.249	.54*	.53*	-	
4. Neurophysiological Valence	.499	1.448	.33	.70**	.37	-
5. Interest	4.11	1.72	.31	.46*	-.29	.30

* p < .05; ** p < .01

Table 4. *Summary of results from hierarchical regression analyses employed in Study 2*

	Dependent variable: Browsing time						**Dependent variable: Interaction frequency**					
	Model 1			***Model 2***			***Model 1***			***Model 2***		
	B	SE B	β	B	SE B	β	B	SE B	β	B	SE B	β
Intercept	440.8	43.9		426.2	39.4		23.3	3.8		21.8	3.2	
Neurophysiologic. Arousal	98.7	45.7	.48*	138.0	43.8	.67**	7.1	3.9	.31	11.2	3.5	.49**
Neurophysiologic. Valence	47.6	68.2	.16	-19.4	66.8	-.06	20.1	5.9	.59**	13.1	5.4	.39*
Interest				100.6	43.1	.48*				10.5	3.5	.45**
Overall model statistics	Adj R^2 = .23 F(2, 16) = 3.630*			Adj R^2 = .39 F(3, 15) = 4.905*			Adj R^2 = .53 F(2, 16) = 11.016***			Adj R^2 = .69 F(3, 15) = 14.153***		

* $p < .05$; ** $p < .01$; *** $p < .001$

3.2.6 Discussion

This study examined participants' neurophysiological responses related to valence and arousal to an IVE. The results were consistent with findings obtained through self-reports in Study 1. Browsing time appeared to be affected only by the arousal experienced during the navigation. No evidence of an influencing role of valence emerged, whereas personal interest proved to have a significant positive effect. The specular results obtained in Study 1 and Study 2 corroborate the findings of a great deal of previous work in affective psychology and neuroscience. Namely, congruent findings might be observed through the neurophysiological activations and self-reports assessing cognitive evaluations (Posner et al., 2005). This finding is consistent with the body-mind theory that suggests the existence of a connection between psychological and neurobiological models.

Under a psychological perspective, these results suggest that users have different, yet consistent responses to IVE. Browsing activity appears to be driven by the arousal component. The significance of positive arousal can be interpreted in relation to the desire to seek novelty and exploration. Indeed, variety seeking can stimulate individuals and enhance their exploratory behaviours. On the other hand, the interaction with the product displayed in the IVE proves to be driven by a combination of positive arousal and valence. It is possible to hypothesise that this interaction is prompted not only by excitement but also by a positively valenced desire. In other words, the enjoyment evoked by the IVE embodies an influencing factor to drive interaction with the products displayed.

A further recurring factor in our findings is represented by personal interest. Both studies highlight a positive influence of interest on all dependent variables, thus pointing out that individual preferences may influence the interactive behaviour as strongly as the experienced affective states. We hence deemed relevant to determine how the effects of interest and arousal impact user behaviour in IVEs. On the one hand, the two factors represent two characteristics shared by the concept of flow (Csikszentmihalyi, 1990; Hunter & Csikszentmihalyi, 2003). In line with the theory of flow, the combination of an arousing environment with a positive disposition towards the environment is expected to foster absorption. Total engrossment further promotes the distortion of the temporal experience, whereby the user experiences a sense that the time has passed faster than normal (Csikszentmihalyi, 1990). The possibility of eliciting flow states in IVEs has also been previously theorised and tested in relationship to several components of the immersive reality, including affect, interactivity, and involvement (Cheng et al., 2014).

On the other hand, the interaction effect between interest and arousal is established in early affective theories (Tomkins, 1962). These theories posit the existence of a strong relationship between the two constructs, treating this interaction as a form of primary affect defined as interest-excitement. Interest-excitement is intended as a motivational driver of action. Indeed, it motivates exploration and learning and fosters individual engagement in the environment (Izard, 1977; Tomkins, 1962). Based on these premises and considering our results, we posit that the interaction between arousal and interest will lead to longer browsing times. More formally, we offer the following hypothesis:

> **H4.** In a high arousal IVE, highly interested users will be more likely to browse longer than low-interested users.

To examine the proposed hypothesis, a third study was carried out. The independent variables in this study were induced-arousal (high vs low) and personal interest (high vs low), whereas the browsing time represented our dependent variable. The same IVE employed in Study 1 and Study 2 was tested.

3.3 Study 3

3.3.1 Participants

The third study involved 31 university students (age range: 18-30, 14 females and 17 males). The recruitment phase was conducted in the same fashion as Study 2 and the overall sample showed the same characteristics of the sample previously chosen.

3.3.2 Stimuli selection

Two music stimuli differing on the arousal dimension but comparable in terms of valence were employed to manipulate induced-arousal. The stimuli were chosen based on the established relationship between experienced arousal and music tempo, whereby fast tempo music is commonly related to higher arousal than slow tempo music (Brown, 1979; Milliman, 1982). Highly arousing music is defined as loud, erratic, and difficult to predict, while low arousing music is commonly soft, monotonous, and predictable. Accordingly, we selected two songs characterised respectively by 168 BPM (Beats per Minute) and 59 BPM. The first music stimulus ("Motivation" by Sum 41) belonged to the rock genre, while the second piece ("Older" by Sasha Sloan) belonged to the ambient genre. We selected the instrumentals versions of both songs to narrow down any complexity related to vocals and lyrics.

We conducted an online survey on a convenience sample of 96 respondents (44 men and 52 women; Mean Age = 25.6, SD = 8.31) to assess the validity of our stimuli. Each subject listened to four randomised songs, among which our two target stimuli. After each stimulus, the self-reported valence and arousal were investigated on 7-points Likert scale in accordance with Mehrabian & Russell (1974). As expected, the two musical stimuli were different on the arousal dimension ($t(95) = 18.830$, $p < .001$), while no difference was reported in terms of valence ($t(95) = 0.87$, $p > .05$). Therefore, the stimuli were deemed appropriate.

3.3.3 Procedure

We employed the same experimental facility and procedural steps used in Study 2. During the browsing experience, the music stimuli were played in loop mode with fading effects at the beginning and end in order not to introduce pauses in the experience. To isolate from the external context and experience the musical stimulus, each participant wore a pair of headphones. During the recruitment, personal interest was assessed through the same self-reported items for measuring interest in Study 1 and Study 2. We divided the participants into two groups based on median scores (high vs low interests). Participants were then randomly assigned to the music treatment (high vs low arousal). Participants received the same instructions provided in Study 2. After the navigation experience, self-reports investigated the constructs of arousal and valence.

3.3.4 Measures

Browsing time was assessed as the duration in seconds of the browsing experience, as in Study 2. The same self-reported items for assessing self-reported valence, self-reported arousal, and interest employed in Study 1 were investigated. All constructs showed satisfactory reliability scores, namely Arousal ($\alpha = .87$), Valence ($\alpha = .83$), and Interest ($\alpha = .74$).

3.3.5 Manipulation check

Elicited arousal confirmed that participants in the high arousal condition (M = 5.10, SD = 1.00) experienced stronger arousal during the browsing than did participants in the low arousal condition (M = 3.70, SD = 1.19), $t(29) = 3.442$, $p < .01$. Furthermore, as expected, no difference emerged in terms of valence ($t(29) = 0.965$, $p > .05$).

3.3.6 Results and discussion

The results showed that the overall browsing time proved to be heterogeneous (M = 263.9 s; SD = 128.2 s), in line with Study 1 and Study 2. With regards to Study 2, browsing time appeared to be lower (U = 149, z = -2.908, $p < .01$), thus indicating that the presence of music background significantly reduced the exploration time. This phenomenon was previously observed in retailing contexts (Milliman, 1982). Overall descriptive statistics are reported in Table 5 and Table 6 for the low and high induced-arousal treatments, respectively.

A two-way ANOVA was conducted to examine the effects of induced-arousal and interest level on browsing time. There was a statistically significant interaction between induced-arousal and interest, $F(1, 27) = 4.298$, $p < .05$, partial $\eta^2 = .137$. Contrast tests revealed that in the high arousal condition, highly interested users browsed longer (M= 365.6, SD = 162.3) than low-interested users (M= 180.7, SD = 58.9), $F(1,27) = 10.594$, $p < .01$. On the other hand, no evidence was observed of a difference between interest levels in browsing time in the low arousal condition ($F(1,27) = 0.076$, $p > 0.05$). Figure 1 shows the described interaction effect. Together these results provide support for H4.

The interaction effect between arousal and interest, which is observed only in the high arousal treatment, is consistent with previous literature. Excited individuals who are also interested in the content of the IVE proved to browse longer. Hence, it could conceivably be hypothesised that the arousal component plays a reinforcing role to sustain attention and create engagement towards the IVE. This also accords with theories of flow, whereby the congruency of excitement and interest may promote a greater focus and immersion in the IVE. On the contrary, a lack of congruency between high arousal and interest proves to elicit the opposite effect. Users with low interest exposed to fast-tempo music tended to browse for a shorter time. It may be the case that high arousal elicited annoyance, which promoted avoidance behaviours in disinterested users. Interestingly, we also observed a lack of differences in browsing times in the low arousal condition. This finding is interpreted in line with early theories of affect, which posit the motivating effect of interest-excitement (Izard, 1977; Tomkins, 1962). This outcome underscores that the interaction effect between arousal and interest occurs only in high-arousal conditions.

Table 5. *Means, Standard Deviations, and Correlations among the measures employed in Study 3 – Low arousal treatment (N = 15)*

Variable	***Mean***	***Std. Dev.***	**1. Browsing time**	**2. Self-reported Arousal**	**3. Self-reported Valence**
1. Browsing time	241.6	89.6	-		
2. Self-reported Arousal	3.70	1.19	-.34	-	
3. Self-reported Valence	5.37	0.76	.28	.00	-
4. Interest	3.53	1.14	.23	-.14	-.31

Table 6. *Means, Standard Deviations, and Correlations among the measures employed in Study 3 – High arousal treatment (N = 16)*

Variable	***Mean***	***Std. Dev.***	**1. Browsing time**	**2. Self-reported Arousal**	**3. Self-reported Valence**
1. Browsing time	284.7	156.2	-		
2. Self-reported Arousal	5.10	1.00	.53*	-	
3. Self-reported Valence	5.62	0.73	.42	.43	-
4. Interest	3.78	1.35	.47	.45	.37

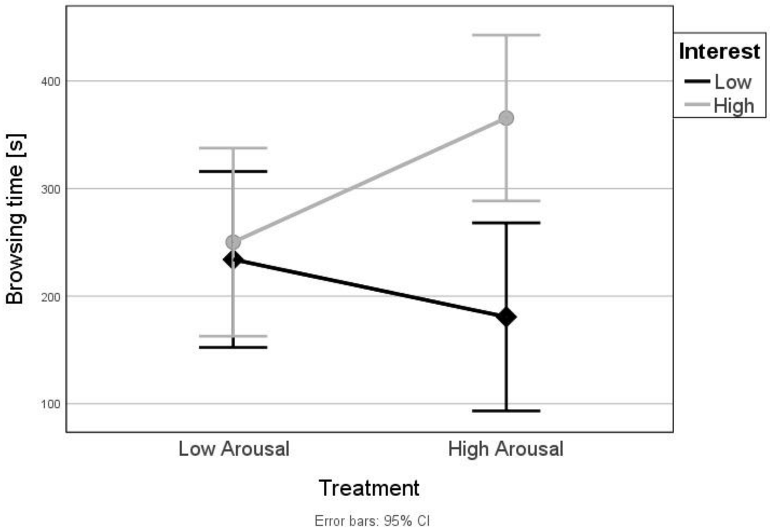

Figure 1. Two-way interaction between induced-arousal and interest levels on browsing time

4. General Discussion

Across three studies, the current research established a significant role of affect in influencing two aspects of the user behaviour in IVEs, namely the length of the browsing experience and the characteristics of the interaction. Study 1 was conducted through an online survey and analysed the cognitive appraisals influencing browsing time. Results highlighted that cognitive arousal positively impacted on the overall browsing time, while a significant role of personal interest was observed. Study 2 replicated Study 1 in a laboratory setting and investigated the neurophysiological correlates of affect influencing browsing time and interaction frequencies with products displayed. Results were consistent with Study 1 concerning the role of arousal in impacting on browsing time. Furthermore, interaction frequency proved to be positively affected both by neurophysiological correlates of arousal and valence. The findings of Study 2 further underscored the importance of personal interest. Therefore, Study 3 was carried out to delve into the interaction between arousal and personal interest. Results showed that in a high arousal IVE, highly interested users were more likely to browse longer than low-interested users, thus validating the hypothesis of the motivating effect of interest-excitement. A summary of the hypotheses tested across the three studies is reported in Table 7.

Table 7. *Summary of the hypotheses tested and empirical evidence*

Hypothesis	Study	Formulation	Empirical evidence
H1a	1	Cognitive arousal positively influences the browsing time.	Supported
H1b	1	Cognitive valence positively influences the browsing time.	Rejected
H2a	2	Neurophysiological arousal positively influences the browsing time.	Supported
H2b	2	Neurophysiological valence positively influences the browsing time.	Rejected
H3a	2	Neurophysiological arousal positively influences the frequency of interaction with products displayed in the IVE.	Partially supported
H3b	2	Neurophysiological valence positively influences the frequency of interaction with products displayed in the IVE.	Supported
H4	3	In a high arousal IVE, highly interested users will be more likely to browse longer than low-interested users.	Supported

4.1 Theoretical Contributions

The present work proposes two theoretical contributions. First, the major conclusion from this research is that affective states experienced during the interaction with an IVE influence user's browsing time and interactive patterns. This result, which reflects previous observations carried out in brick-and-mortar realities and online websites (Donovan & Rossiter, 1982; Eroglu et al., 2001, 2003; Ha & Lennon, 2010), represents an initial application of the S-O-R framework in IVEs. Notable similarities are found in the theorisation of the antecedents of approach-avoidance behaviours, which appear to be driven both by valence and arousal. We claim that this outcome can be associated with the intrinsic characteristics of IVEs. Indeed, IVEs may convey a feeling of immersion, which triggers conative and emotional responses comparable to those of the physical world. In other words, the behavioural realism evoked in IVEs does not involve only users' actions, but also their affective states. This observation further expands the concept of behavioural realism (Freeman et al., 2000; Higuera-Trujillo et al., 2017). In particular, it suggests that IVEs elicit also affective responses that are comparable to the ones that occur in the physical world. These findings raise intriguing questions regarding the nature and extent of the feeling of immersivity. It could conceivably be hypothesised that complex user behaviours can be investigated through IVEs, thanks to the substantial affinity to the physical world. In particular, IVEs might be employed to study multifaceted behaviours which involve an affective component, such as impulse buying, affective brand commitment, or loyalty relationships. All these behaviours can be difficult to be gauged through self-reports, therefore designing IVEs to trigger such behaviours can pave the way to realistic observations of both users' behaviour as well as their affective reactions in controlled laboratory settings. That is, increasing the external validity of the experimental outcomes.

Second, our results confirm the association between cognitive affect and its neurophysiological externalisations. The specular outcomes obtained with regards to browsing time in Study 1 and Study 2 represent a validation of the mind-body relationship (Green et al., 1970) and provide one of the first assessments of the mind-body dualism in IVEs. This finding has important implications for understanding the psychophysiology of affective states. We expect that through the quantitative evaluation of the users' physiological state in IVEs researchers can gather insights about the users' psychological state. This raises the possibility of delving into specific affective constructs (e.g., arousal, valence) through their neurophysiological correlates rather than their cognitive rationalisations. This approach will also offer the researcher the possibility of analysing possible discordances between cognitive self-reports and physiological measurements. Indeed, the discordance between the two factors may shelter personal inner conflicts between individual visceral reactions (or desires to react) and cognitive responses (or willingness to restrain an action).

4.2 Managerial Implications

The findings of this study also provide information that could be useful to designing IVEs. Particular attention shall be paid to mechanisms to sustain high arousal and positive valenced affective states. To sustain arousal, designers might employ auditory cues. In particular, the present study showed that high tempo music embodies an arousing factor during the browsing of the IVE. Indeed, music can modulate the affective state coherently with the nature of the IVE and keep the users in a condition that facilitates their immersive exploration. On the other hand, positive valenced affective states can be induced through narratives and feedbacks. Narratives can effectively stimulate imagination that, in turn, elicits affect. Alternatively, moods can be influenced by anticipating positively valenced situations, which can be formally expressed through feedbacks. In these terms, retailers may leverage on the generation of affective expectation to prime the user before or during the navigation.

The present study also highlighted the significant role of interest and its positive influence on browsing time when paired with high arousal. Along this line of thinking, designers shall leverage mechanisms to sustain interest. A possible way to engage users is to incorporate a surprising, personal, and contagious trigger to generate a wow effect in the first browsing moments. Wow factors could be related to a personalised welcome message, the possibility of personalising the environment, or the use of a narrative trigger. Also, personalised costumes and items can be introduced as a medium to create customised experiences where users can express their individuality. Alternatively, setting objectives may embody a useful method to engage the users in IVEs. For instance, setting the objective of finding a hidden element in the IVE with the possibility of attaining a reward could be a potential trigger for engaging the user at the start of the browsing experience. Finally, it is important to consider that also the characteristics of the IVE can rapidly engage the users: high-quality immersive interfaces, representational vividness, and the perception of control over the experience can embody engaging elements per se.

5 Limitations and Directions for Future Research

Despite the contributions of this research, its limitations need to be acknowledged. First, we applied the S-O-R framework including only the affective components in the Organism factor. However, we acknowledge that individual tendencies might have affected our observations. For instance, individual tendencies to seek diversity during the exploration of the IVE might have influenced the total browsing time. Additional uncontrolled factors were personality traits. Individual traits such as conscientiousness or openness to experience might have influenced the proneness of an individual to explore thoroughly every virtual room, thus affecting our dependent variables. Along this line of thinking, future research might consider including an evaluation of personal dispositions either through self-reports or through prior evaluation of browsing patterns in testing IVEs.

Second, our studies were carried out on a desktop-based IVE. Existing evidence points out that individual behaviours differ across the typology of IVE used. For instance, Meißner et al. (2020) showed that devices with a different degree of immersivity such as head-mounted displays influence the variety of interactions and individual choice. Accordingly, our results are expected to be generalisable only on 3D desktop-based IVEs. Further empirical work will have to be conducted to determine the generalisability of our findings to a wider range of IVEs.

In addition, we chose an IVE characterised by a high variety of touchpoints, a large space to explore, and centred on musical instruments. We acknowledge, however, that the significant possibility of interactions without a predefined navigation pattern might have deterred the user with low interest towards the IVE. Further research is advised to establish the generalisability of the findings of the current study across different themes and sizes of the virtual space.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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