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Influencing Human Affective Responses to Dynamic Virtual Environments

Abstract

Detecting and measuring emotional responses while interacting with virtual reality (VR), and assessing and interpreting their impacts on human engagement and "immersion," are both academically and technologically challenging. While many researchers have, in the past, focused on the affective evaluation of passive environments, such as listening to music or the observation of videos and imagery, virtual realities and related interactive environments have been used in only a small number of research studies as a mean of presenting emotional stimuli. This article reports the first stage (focusing on participants' subjective responses) of a range of experimental investigations supporting the evaluation of emotional responses within a virtual environment, according to a three-dimensional (*Valence*, *Arousal*, and *Dominance*) model of affects, developed in the 1970s and 1980s. To populate this three-dimensional model with participants' emotional responses, an "affective VR," capable of manipulating users' emotions, has been designed and subjectively evaluated. The VR takes the form of a dynamic "speedboat" simulation, elements (controllable VR parameters) of which were assessed and selected based on a 35-respondent online survey, coupled with the implementation of an affective power approximation algorithm. A further 68 participants took part in a series of trials, interacting with a number of VR variations, while subjectively rating their emotional responses. The experimental results provide an early level of confidence that this particular affective VR is capable of manipulating individuals' emotional experiences, through the control of its internal parameters. Moreover, the approximation technique proved to be fairly reliable in predicting users' potential emotional responses, in various affective VR settings, prior to actual experiences. Finally, the analysis suggested that the emotional response of the users, with different gender and gaming experiences, could vary, when presented with the same affective VR situation.

1 Introduction

Virtual reality (VR), and interactive 3D environments generally, have experienced a significant "comeback" of recent years, courtesy of developments in the gaming industry and the relentless demand for high-fidelity escapist experiences on the part of gamers and simulation users alike. Yet, despite many international initiatives involving the design and development of highly innovative and affordable human–computer interaction (HCI) technologies in the quest for the

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ultimate "immersive" experience,[1] some believe that true "immersion" may only ever be achieved through the use of advanced brain–computer interfaces (BCI) (Cairns, Cox, Berthouze, Dhoparee, & Jennett, 2006). However, until that day arrives, it is important to understand how it may be possible to measure and, indeed, influence human engagement and emotional connectivity with virtual worlds using psychophysiological techniques.

The term *immersion* has most often been used to describe the multisensory experience of *presence* by individuals, while performing a task in VR. However, different researchers have suggested different definitions for this term (Brown & Cairns, 2004). As an illustration, Cairns et al. suggested that immersion could be defined as a feeling of being deeply engaged when people enter a make-believe world and feel as if it is real (Cairns, Cox, Berthouze, Dhoparee, & Jennett, 2006). In 2004, Brown and Cairns suggested that immersion can be divided into three levels: engagement (during which the users invest time, effort, and most importantly attention), engrossment (the time that the user's emotions are directly affected by the environment), and total immersion (when the users are detached from reality and the virtual world is, for them, all that matters). They claim that engagement and engrossment could be achieved much easier than a total level of immersion, believing instead that it could be achieved by overcoming other barriers. Such barriers include *empathy* as a "growth of attachment" to the environment, and *atmosphere* as representing the VR's environmental realism. The authors also mentioned that "total immersion can be difficult to achieve: there are barriers to immersion from both the human and the system perspectives" (Brown & Cairns). Other researchers combine the immersive experience in virtual realities and 3D environments with the term *presence*, which is defined as "the extent to which a person's cognitive and perceptual systems are tricked into believing they are somewhere other than their physical location" (Patrick, Cosgrove, Slavkovie, Rode, Verratti, & Chiselko, 2000). Based on the variety of definitions of immersion evident in the literature, several discussions have been presented on the topic of how to evaluate immersive experiences. Many believe that true immersion might even be impossible to achieve with the present state of maturity in VR and gaming technologies. Others believe it could be achieved simply by defining the term more appropriately (Brown & Cairns).

To date, HCI systems designers have, in their attempts to increase the sense of end user immersion, introduced several multidimensional input/output devices, in order to provide user-friendly, intuitive techniques and styles of interaction with real-time 3D worlds. However, the area of HCI research that strives toward establishing direct communication between a computer system and the human brain has, until recently, been treated as science fiction.[2,3] In the HCI domain, BCI systems attempt to improve human–computer interaction and increase the sense of immersion by interfacing directly with the human brain and, thus, removing the artificial barriers to intuitive interaction afforded by conventional input-display techniques. This new interface channel has the potential to introduce a large number of new communication techniques in advanced HCI systems, and may be able to improve the interaction process considerably (e.g., translating imaginary movements to virtual actions, improving levels of concentration, affecting emotional states, etc.). So far the interaction process has been based mostly on conventional methods, in that computer users typically use physical interaction devices to see, hear, act, sense haptic or olfactory stimuli, and in some cases even talk to the system. The near-term goal of BCI systems, as an extension to these conventional systems (as opposed to a replacement, which is a longer-term aspiration), would be to translate human thoughts and emotions by direct connection to the human brain and use this information as a new modality channel for HCI systems (Nijholt, Plass-Oude, & Reuderink, 2009).

Turning briefly to the field of VR and the relevance of issues of affect, to date, researchers have studied the implementation of virtual realities in many different domains. As well as entertainment, virtual realities and

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[1] Witness, for example, the wide range of visual displays, data inputs, haptic, and other forms of devices available from "crowd-funding" platforms, such as Kickstarter and Indiegogo.

[2] https://en.wikipedia.org/wiki/The_Matrix

[3] https://en.wikipedia.org/wiki/Pacific_Rim_(film)

their so-called “serious games” counterparts have been used for training purposes (Ahlberg et al., 2007; Zyda, 2005; Seymour et al., 2002), pain distraction (Mahrer & Gold, 2009; Hoffman, Doctor, Patterson, Carrougher, & Furness, 2000; Hoffman et al., 2004), rehabilitation (Rizzo et al., 2002; Jack et al., 2001), and disorder therapy (Parsons & Rizzo, 2008; Difede et al., 2007; Rizzo et al., 2013; Kaganoff, Bordnick, & Carter, 2012). The focus of all of these studies has been to engage the human users in an interactive virtual environment, and to increase the sense of presence and immersion within them, thereby effectively delivering new skills, knowledge, or in some cases, acting as a form of clinical distraction. In 2006, Joels et al. suggested that changes in the excitement level (depending on pleasurable or displeasurable condition) affect the learning and memory process. They proposed that memory performance changes (either improvements or impairments) are highly dependent on the time and context of the emotional experience (Joels, Pu, Wiegert, Oitzl, & Krugers, 2006). Therefore, the recognition of the users’ emotions when exposed to virtual realities, and controlling their affective experiences within the virtual environments (regardless of their purpose) can be as important as the VR’s contextual outcome.

One of the subcategories of research into BCI systems is described as *affective computing*. During the process of affective computing, psychophysiological signals from the users are recorded to enable the BCI system to extract data of relevance to their emotional and cognitive states. This new input channel could provide several features for an advanced HCI system attempting to support the generation of believable immersive experiences. As an illustration, the system could use this information to adapt itself to the user’s emotions and, by doing so, increase his/her performance and immersion levels during the interaction process. Recently, new techniques in HCI-mediated emotional recognition have been developed using noninteractive or passive environments, such as listening to music, or the observation of videos and imagery (Koelstra et al., 2012; Frantzidis, Bratsas, Papadelis, Konstantinidis, Pappas, & Bamidis, 2010; Yazdani, Lee, & Ebrahimi, 2009; Rizon, Murugappan, Nagarajan, & Yaacob, 2008; Murugappan, Rizon, Nagarajan, Yaacob, Hazry, & Zunaidi, 2008; Katsis, Katertsidis, Ganiatsas, & Fotiadis, 2008; Takahashi & Tsukaguchi, 2003). Others are now beginning to focus on virtual realities and more interactive environments (e.g., Parnandi, Son, & Gutierrez-Osuna, 2013; Wu et al., 2010; Antje, Peter, Markert, Meer, & Voskamp, 2005).

To perform the affect recognition process in virtual realities, first the affective features of VR environments need to be carefully investigated. Second, a system has to be designed, trained, and validated with respect to a psychophysiological affective database, recorded from a large number of users exposed to a number of controlled and known affective stimuli (considering supervised learning algorithms; Mohri, Rostamizadeh, & Talwalkar, 2012). To construct such a database, a number of controlled emotional situations (evoking some specific affective states on the part of the users[4]), would need to be presented to participants in an experiment, while taking part in a physiological measurement paradigm. These recordings, tagged by the corresponding affective states, would then be analyzed for the design, training, and validation of the affect recognition system. Therefore, two distinct steps in the psychophysiological affective database construction can be considered: (a) evoking controlled emotional experiences and (b) the measurement of physiological parameters. It would be important to ensure the implementation of strict experimental designs in such a paradigm, in order to avoid the development of an inappropriate psychophysiological affective database, which would invalidate the recognition system’s training process. As an illustration, if the users’ emotional experiences were poorly controlled (e.g., it was not possible to state with confidence that anger had been experienced by the users during the corresponding session), then the classification techniques would be unable to train the affect recognition system properly and the accuracy of the system would be affected accordingly. To prevent such incidents, the emotional stimuli must be subjectively evaluated and categorized prior to the undertaking of physiological measurements, in order to validate their effectiveness in evoking the required emotional experiences on the part of all users.

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[4] Such as images that evoke fear and disgust in users—image number 3000 to 3266 in IAPS (Lang, Bradley, & Cuthbert, 2008).

To date, a number of evaluated affective stimuli databases using images (the International Affective Picture System—IAPS; Lang, Bradley, & Cuthbert, 2008), sounds (the International Affective Digital Sounds—IADS; Bradley & Lang, 1999), and video clips (Baveye, Bettinelli, Dellandrea, Chen, & Chamaret, 2013) have been presented in the literature. These established databases provide investigators with a variety of pre-evaluated affective stimuli, which (from a subjective outcome perspective) have been found to elicit specific (and quite strong) emotions in recipients. However, to the knowledge of the authors, no validated affective VR-based stimuli database has been presented as yet. The availability and reliability of such a database of stimuli in form of a virtual reality (VR) is crucial in the design and validation of an affective computing system, which can be used in VR-based systems.

In the present article, an *affective virtual reality* and the process by which it was conceptualized, designed, and subjected to an early validation study is discussed in detail. The affective VR is capable of eliciting multiple emotions within the users, and manipulating their affective experiences within a 3-dimensional affective space (described later), by controlling the VR's internal parameters. A number of "sub-games" (based on the selection of multiple unique VR parameters) have been selected using an affective power estimation process, and evaluated in a subjective experiment employing 68 participants. The work described in this article represents a number of early steps in research that is working toward a more comprehensive psychophysiological understanding of the future role of brain–computer interfaces in VR and so-called serious games. The affective VR described herein is supposed to be used in construction of an *affective physiological database*, to be used in the conceptualization, design, and validation of an affect recognition system.

2 Model of Affects, Self-Assessment, and Affective Clusters

2.1 Model of Affects

One of the most important challenges in the study of emotions is the definition one adopts. Bradley, in 2006, stated that "part of the complexity in studying emotion is defining it: there are almost as many definitions as there are investigators" (Bradley & Lang, 2006). The common factor among all of these definitions is that of physiological effects, broadly reflecting the fact that, in emotional situations, the body reacts and performs accordingly. In high-tempo, high-pressure contexts, for example, the heart rate changes, sweating occurs, the muscles tense, facial expressions such as smiling and frowning appear, and many other less overt physiological changes take place (Bradley & Lang, 2006). The term *emotion* has been presented by some researchers in the form of either *quantitative* (*dimensional*) or *qualitative* (*categorical*) models, often referred to as affective space.

In *qualitative* models, the affective space is presented by using an emotion set (a number of emotional labels), such that the user can be "categorized" as experiencing either one or a mixture of these emotional labels. As an illustration, Ekman and Friesen (2003) used a qualitative presentation of emotions, categorizing them as surprise, fear, disgust, anger, happiness, and sadness. Researchers have introduced several emotion sets, although there are some common strong emotions that are present in most of them. These strong emotions include anger, fear, disgust, excitement, happiness, sadness, and boredom (Bradley & Lang, 2006).

In contrast to the work by Bradley and Lang, both Russell and Mehrabian presented two similar *quantitative* models in the 1980s and 1970s. These models define emotions based on two or three continuous independent parameters (dimensions or axes) (Mehrabian, 1970; Russell, 1980). Mehrabian introduced three independent quantities: *Valence*, defining pleasure and displeasure; *Arousal*, describing the excitation level; and *Dominance*, identifying the level of control within a given situation. Russell, on the other hand, ignored Dominance, and created a 2-dimensional *Circumplex of Affect*. Mehrabian and Russell believed that representation of verbal labels of emotions within either the 2D- or 3D-model would differ between people with different cultures, especially those with different languages (Mehrabian, 1970; Russell, 1980). In 1980, Russell represented some the most common English verbal labels, within his Circumplex of Affect (shown in Figure 1).

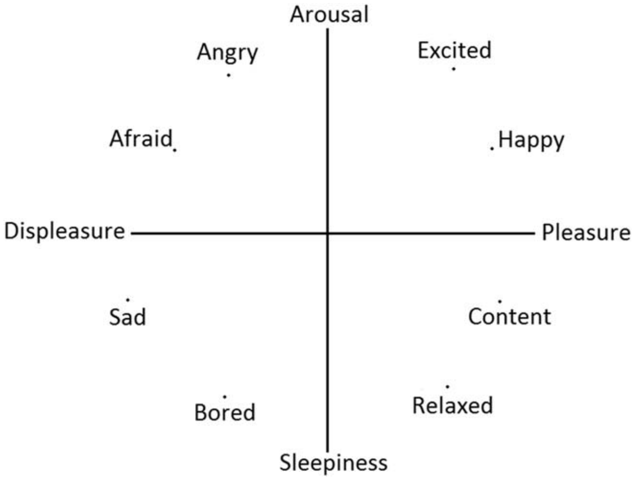

Figure 1. *Simplified Russell Circumplex of Affect for English verbal labels of emotions (Russell, 1980).*

2.2 Emotional Experience Assessment

In the affective psychophysiological database construction process, each session, in which participants are exposed to an affective stimulus, has to be tagged by an emotional experience state, within an affective space (qualitatively or quantitatively or both). This assessment has to be able to reliably categorize the participants' emotional experience.

So far, researchers have, in the main, employed either *self* or *expert* assessments. In expert assessments, a psychologist or human emotion expert would be instructed to evaluate the participant's affective state, and categorize it within an affective space (Katsis, Katertsidis, Ganiatsas, & Fotiadis, 2008). However, the majority of studies appear to employ *self-assessment* techniques to evaluate participants' emotional states within an affective space (Murugappan, Rizon, Nagarajan, Yaacob, Hazry, & Zunaidi, 2008; Rizon, Murugappan, Nagarajan, & Yaacob, 2008; Frantzidis, Bratsas, Papadelis, Konstantinidis, Pappas, & Bamidis, 2010). In this process the user is instructed to evaluate his/her affective state according to a particular model (either qualitatively or quantitatively). On the other hand, in some cases, a *pre-emotional hypothesis* was presented prior to the experiment. As an illustration, a certain physiological behavior is considered as a result of a specific emotional status (e.g., high heart rate tempo means high arousal status), and the emotional status of the users is evaluated accordingly (Takahashi & Tsukaguchi, 2003). Therefore, as self-assessment has been employed by the majority of research studies, and also due to the lack of availability of a psychologist or human emotion expert in the present study, it was decided to employ *self-assessment* techniques in the emotional evaluation process.

2.3 Self-Assessment

In the present study, both qualitative and quantitative affective spaces were employed within the experiments when performing participants' self-assessments. The participants were asked to evaluate their emotional experiences and self-report them in the 3-dimensional affective space (as conceived by Mehrabian—scaled arbitrarily from -3 to $+3$), while each axis was defined and presented to the participants as discussed next. To perform the emotional assessment in the 3D model of affect, an interactive version of Bradley and Lang's Self-Assessment Manikin (SAM) questionnaire (Bradley & Lang, 1994), was employed to enable participants to self-report their Valence, Arousal, and Dominance levels.

1. **Valence:** How pleasurable this gaming experience was. Higher positive values mean more pleasure (e.g., you enjoyed it), and higher negative values mean more displeasure (e.g., you did not enjoy it).
2. **Arousal:** How arousing this gaming experience was. Higher positive values mean more aroused (e.g., excited, alert, stressful, etc.), and higher negative values mean minimally aroused (e.g., relaxed, tired, bored, etc.).
3. **Dominance:** How much control you had in this gaming experience. Higher positive values mean higher control in the game (e.g., proper controller response, ability to perform required maneuvers, etc.), and higher negative values mean lower control during game-play (e.g., inability in performing required maneuvers, etc.).

The dimensional assessment was followed by a qualitative eight-label assessment (labels: Relaxed, Content, Happy, Excited, Angry, Afraid, Sad, and Bored). These

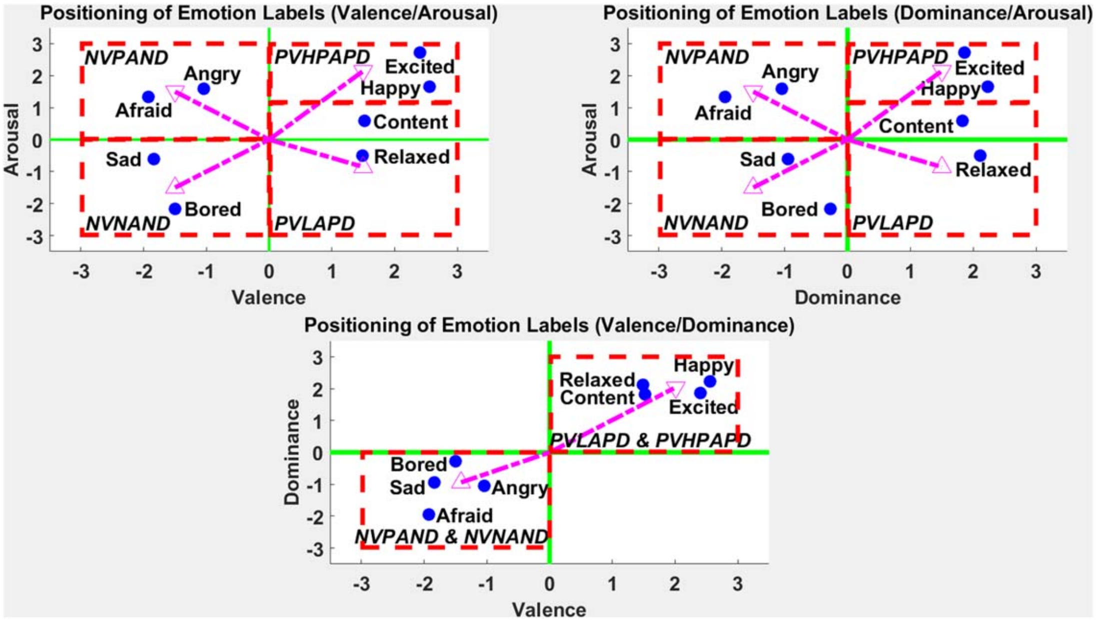

Figure 2. *Presentation of 8 English verbal labels of emotions within the 3D affective model. Dots present the location of each label within the 3D space. The dashed boxes present the affective clusters—the clusters' names (PVLAPD, PVHPAPD, NVPAND, and NVNAND) have been presented within the dashed boxes. The dashed vectors are the affective clusters' centroid vectors.*

eight labels were selected as they were assumed to be relevant to most VR experiences, and equally distributed along the multidimensional space (see Figure 1).

2.4 Affective Clusters—Subjective Experiment

2.4.1 Participants and Method. To subjectively evaluate the position of the selected eight labels within the Circumplex of Affect (see Figure 1), a questionnaire was designed and presented to all participants (103 in total, with a mean age of 23.23 years, and a distribution of 52% male and 46% gamers), who partook in all experiments (see Experiments 1 and 2 in Sections 4 and 5). The purpose behind this experiment was to assess the placement of the eight presented labels within the Russell's Circumplex of Affect, within the *gaming and VR experience context*.

The questionnaire contained eight questions, each of which required the participants to locate one of the emotional labels (Relaxed, Content, Happy, Excited, Angry, Afraid, Sad, and Bored) within the 3-dimensional space. The example given next presents one of the questions, assessing the Relaxed label. The participants were asked to choose one of the integer scalars, (arbitrarily) between −3 to +3, for each parameter.

> "*What value of these parameters (Valence, Arousal, and Dominance) would describe the experience of 'Being Relaxed' in virtual realities?*"

2.4.2 Results. Figure 2 presents the subjective arrangement of these labels within the 3D (Valence, Arousal, and Dominance) affective space. The mean ratings across participants, within each axis, have been used as the subjective position of the labels within the Circumplex. As can be seen in Figure 2, the labels follow the Russell's Circumplex order, while the position of Relaxed and Content are associated with higher arousal states than expected (compare Figure 1 and the "*Valence vs. Arousal*" plot in Figure 2). It can be considered that this reflects the fact that the ratings were undertaken in the context of the gaming and VR experience. It can be expected that relaxing while playing a game can be more arousing than simply relaxing on a sofa, for example.

On the other hand, there is a high correlation between the Valence and Dominance ratings ($r(960) = 0.69$, $P < 0.001$—this correlation can be observed in all affective ratings in Experiments 1 and 2, described in Sections 4 and 5). This correlation makes the "*Valence vs. Arousal*" and "*Dominance vs. Arousal*" graphs almost identical (see Figure 2). Furthermore, it makes the "*Negative Valence, Positive Dominance, and Positive/Negative Arousal*" and "*Positive Valence, Negative Dominance, and Positive/Negative Arousal*" octants[5] (four octants out of eight) completely empty (containing no emotion label), while the other four contain all eight affective labels (see "*Valence vs. Dominance*" plot in Figure 2).

To the contrary, the cluster containing the Relaxed and Content emotional labels is occupying the entire "*Positive Valence, Negative Arousal, and Positive Dominance*" and part of the "*Positive Valence, Positive Arousal, and Positive Dominance*" octants. Thus, it can be concluded that the verbal labels are not separated with respect to the octants; however, the separation is based on four *affective clusters*, defined as follows:

1. **PVLAPD Cluster:** Positive Valence, Low Positive Arousal, Positive Dominance (PVPPAPD), and Positive Valence, Negative Arousal, Positive Dominance (PVNAPD). Therefore this cluster can be named: Positive Valence, Low Arousal, Positive Dominance ***PVLAPD***—Containing Relaxed and Content labels:
   1) $0 \leq \text{Valence} \leq 3$
   2) $-3 \leq \text{Arousal} \leq 1.16$
   3) $0 \leq \text{Dominance} \leq 3$
2. **PVHPAPD Cluster:** Positive Valence, High Positive Arousal, Positive Dominance ***(PVHPAPD)***—Containing Happy and Excited labels:
   1) $0 \leq \text{Valence} \leq 3$
   2) $1.16 \leq \text{Arousal} \leq 3$
   3) $0 \leq \text{Dominance} \leq 3$
3. **NVPAND Cluster:** Negative Valence, Positive Arousal, Negative Dominance ***(NVPAND)***—Containing Afraid and Angry labels:
   1) $-3 \leq \text{Valence} \leq 0$
   2) $0 \leq \text{Arousal} \leq 3$
   3) $-3 \leq \text{Dominance} \leq 0$
4. **NVNAND Cluster:** Negative Valence, Negative Arousal, Negative Dominance ***(NVNAND)***—Containing Sad and Bored labels:
   1) $-3 \leq \text{Valence} \leq 0$
   2) $-3 \leq \text{Arousal} \leq 0$
   3) $-3 \leq \text{Dominance} \leq 0$

2.4.3 Discussion. To be able to design the affect recognition system, an affective VR, capable of manipulating the users' emotions within the *entire* emotional space, needs to be designed. Considering the previous discussions, it can be concluded that an *affective virtual reality* needs to be capable of manipulating users' emotions such that they gravitate toward all four affective clusters.

3 Affective Virtual Reality

Emotional stimuli play a vital role in the design and performance evaluation of any affective computing system. To date, the majority of the researchers have used images (Frantzidis, Bratsas, Papadelis, Konstantinidis, Pappas, & Bamidis, 2010), video clips (Rizon, Murugappan, Nagarajan, & Yaacob, 2008; Murugappan, Rizon, Nagarajan, Yaacob, Hazry, & Zunaidi, 2008; Yazdani, Lee, & Ebrahimi, 2009), music (Takahashi & Tsukaguchi, 2003; Koelstra, et al., 2012) and, occasionally, real-life scenarios (Katsis, Katertsidis, Ganiatsas, & Fotiadis, 2008) to evoke emotional experiences on the subjects. However, virtual realities, as a potentially powerful affective medium, have been used only in a small number of research studies as a means of presenting emotional stimuli (Parnandi, Son, & Gutierrez-Osuna, 2013). The focus of this study was to design and subjectively evaluate an affective VR, capable of evoking multiple emotional experiences within the user population.

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[5] An octant is one of the eight divisions of a Euclidean three-dimensional coordinate system, defined based on the signs of the coordinates.

3.1 Affective VR Design

Two different approaches are possible for designing an affective virtual reality, capable of evoking certain emotions:

1. **Multiple VRs**: A number of *entirely different* VRs can be designed to evoke different emotions. The first advantage of this approach is that every VR can be designed in a way that would have the maximum impact on the users, in order to evoke a particular emotion. The disadvantage of this method is the variability between the environments. Different environments may well result in different VR experiences, which may in turn lead to too much variability between the recorded data. This would leave no ground truth for any comparison between the independent situations. Also, each VR would take the form of a new environment for the participants and could create an element of surprise in every attempt. This issue may decrease or even change the expected emotional experience on the part of the participants.
2. **Single VR**: A single but well-constructed virtual reality can be designed that is capable of evoking different emotions by changing the simulated environment's internal properties. The first advantage of this approach is the minimum variability between the emotional experiences, as the background environment or scenario (or so-called *Neutral Scenario* of *VR*—the overall theme, environment, and rules of the VR) for all experiences would be the same, and changes in the parameters of the VR and incidents could elicit different emotions. Another advantage would be the minimum element of surprise on the participants (compared to the multiple-VRs approach). The overall VR environment, interaction algorithm, and other aspects related to the background scenario would stay the same and allow participants to concentrate on the affective parameters rather than the changes. The disadvantage of this approach is that the effectiveness of emotional experiences may be less influential than the first method. The reason for this is that, in a multiple VR approach, one scenario can be designed to evoke boredom and another to elicit excitement, each in a very powerful way; while in this approach there is only one VR scenario, which should be capable of evoking all emotions in an effective manner.

In human-centered experimentation, minimum variability between VR experiences is an extremely important matter, as any acceptable analysis dealing with either affects or physiological databases has to be based on changes in emotional experiences, due to *different environments* (between games), rather than different *personal experiences* (between participants). Multiple VRs may create different experiences among participants, rather than a single VR with an overriding context, due to variability between environments. Therefore, in the present project, the *Single VR* approach has been adopted as the design approach for the virtual affective medium.

A Speedboat Simulation[6] game (see Figure 3) was designed for use as the background scenario of the affective VR. As the experimental cohort was anticipated to comprise both gamers and nongamers, it was decided to use a driving-based simulation with a simple directional interface style (a speedboat scenario in this case), to reduce the amount of prior gaming experience required for participation (i.e., when compared to the skills and experiences typically manifested by players of first-person combat and strategic games). Also, the creation of an environment with a very basic contextual setting in terms of graphical elements drove the choice of a speedboat simulation (as opposed to automobile driving, which typically consists of complex urban representations). Moreover, the dynamics of the environment would, it was felt, provide a wide range of possible parameters and variables that could be implemented and controlled in the environment (described in more detail in Section 3.2).

In the *neutral* speedboat simulation environment, the user is able to navigate a small boat, freely, within a coastal virtual environment originally created for VR healthcare research (Stone & Hannigan, 2014). By

[6] This simulation can be viewed at: https://www.youtube.com/watch?v=pqn-X1Z5AoM.

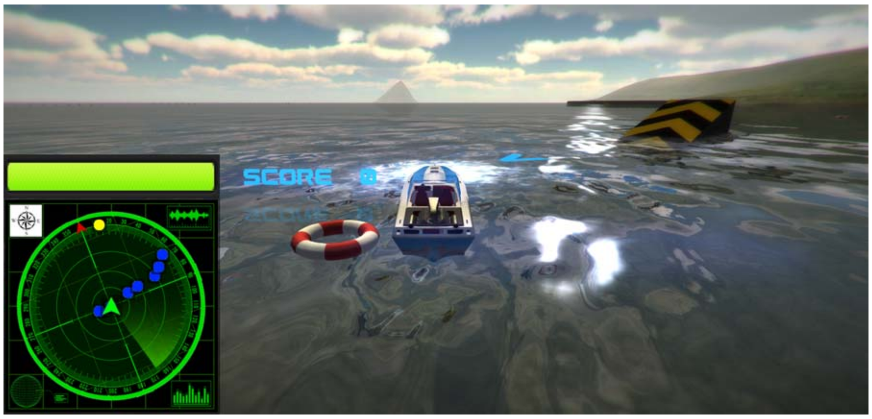


Figure 3. *Speedboat simulation environment.*

manipulating the VR parameters (described in more detail in Section 3.2), a number of different variations of the *neutral* environment were created. In this study, these variations have been called *sub-games.*

In the majority of sub-games, there are a number of floating “ring buoys” on the water that the users can collect to gain higher scores. In all sub-games, the users can either finish the game by passing the finish line at a distance (from where the game is started), or continue exploring for as long as they require (only in the sub-games, which do not have any time limitations). Regardless of the time settings for each VR variation, no sub-game is allowed to continue beyond 5 minutes. If the participant spends longer than 5 minutes in a particular sub-game, it terminates automatically. Depending on the VR settings (Section 3.2), participants can interact with the virtual environment using either a mouse or a force-feedback joystick. The joystick is capable of displaying vibration effects according to simulated “water turbulence” and, in addition, left/right forces on the grip, simulating simple “water resistance” effects, created when the boat is turning. A Samsung 32-inch flat LCD screen was used to present the VR scenes, together with a Sennheiser RS-170 wireless headphone to play the environmental sound effects.

3.2 Affective Parameters (“Incidents”)

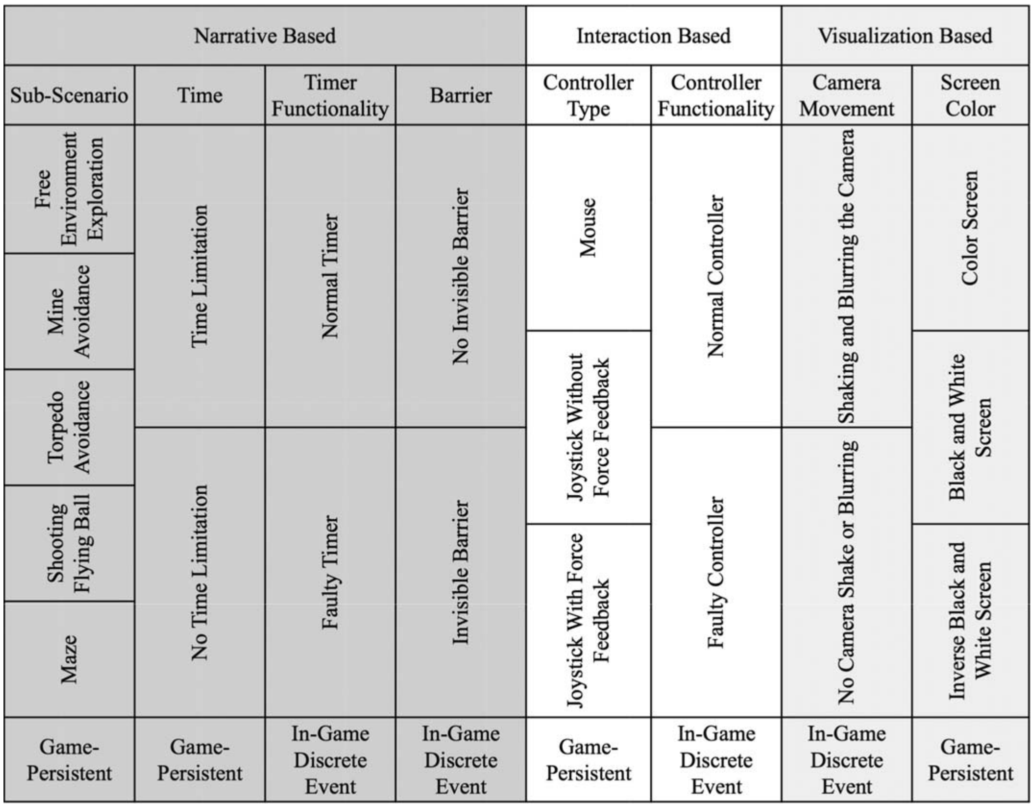
In order to evoke multiple emotions in the participants, a number of controllable affective parameters need to be identified and implemented within the VR. Manipulation of these parameters would (it was hypothesized) evoke different emotions within the participants. The general nature of these parameters or “incidents” needs to be studied prior to any identification or implementation within the environment.

3.2.1 Categorization of Incidents.

I. VR Aspects: For the purposes of this study, the parameters or incidents presented in the speedboat simulation were categorized into four major aspects:

1. **Visualization:** Any aspect of the game related to visual stimulation, including lighting, textures, fidelity, scale of the objects, realism of any action (such as avatar animation), and physical behaviors.
2. **Auditory:** All features of the game that are related to the auditory sense of the users, including the background music, sounds of objects, voices of avatars, and so on.
3. **Interaction:** Keyboard, mouse, joysticks, voice recognition systems, gestural translators, and so on, all fall within the interaction category.
4. **Narrative:** Any aspect of the game (visual, auditory, and interaction) that is presented to the users in a meaningful or contextually relevant way through a narrative or background scenario. This aspect can influence the user’s perception and change his or her experience quite dramatically. As an illustration, even a game created using extraor-

Table 1. *Twenty-One Incidents Categorization According to VR and Timing Aspect*



Narrative Based				Interaction Based		Visualization Based	
Sub-Scenario	Time	Timer Functionality	Barrier	Controller Type	Controller Functionality	Camera Movement	Screen Color
Free Environment Exploration	Time Limitation	Normal Timer	No Invisible Barrier	Mouse	Normal Controller	Shaking and Blurring the Camera	Color Screen
Mine Avoidance	No Time Limitation	Faulty Timer	Invisible Barrier	Joystick Without Force Feedback	Faulty Controller	No Camera Shake or Blurring	Black and White Screen
Torpedo Avoidance				Joystick With Force Feedback			Inverse Black and White Screen
Shooting Flying Ball							
Maze							
Game-Persistent	Game-Persistent	In-Game Discrete Event	In-Game Discrete Event	Game-Persistent	In-Game Discrete Event	In-Game Discrete Event	Game-Persistent

dinary visualizations, auditory, and interaction factors can have different influences on users simply by the way the game's narrative has been presented. If the background presents a science fiction scenario, for example, the user may expect to experience extreme levels of action, a high tempo, even fear. Yet, the same game presented with a real-life scenario as its background narrative, perhaps one that depicts a desert island or peaceful countryside setting, can create a completely different set of expectations and perceptions on the part of the user.

II. Timing Aspects: Each incident in the game can be presented to the users either as a single event in the game (In-Game Discrete Event, such as a sudden sound, a short aggressive attack, a short screen vibration, etc.), or throughout the whole duration of a game (Game-Persistence, such as a time limitation, a change in the input device control law, etc.).

3.2.2 Incidents Identification and Assessment. According to the speedboat simulation's environmental capabilities, 21 possible incidents were identified for implementation within the affective VR. These incidents were categorized based on their presentation timing, together with the VR aspects. Table 1 shows these incidents, clustered with respect to the VR aspect and timing classifications.

Different combinations of these incidents could create different sub-games. Combination of elements within the columns can create 1444 different sub-game combi-

Figure 4. *Incidents presentation examples within the Affective VR. A) Start line flag for time limitation scenarios. B) Ramps in the virtual environment. C) Mine avoidance. D) Jumping over ships. E) Driving freely outside the ring buoys lane. F) Finding hidden ring buoys inside the bushes, by using the radar. G) Torpedo avoidance. H) Splashing water to the flying ball. I) Inverse black and white screen in the torpedo avoidance sub-scenario. J) Black and white screen in maze sub-scenario. K) Finish line flag to terminate the game on demand. L) Score calculation at the game termination.*

nations (C_i means i^{th}column – $5(C_1) \times 2(C_2) \times 2(C_3) \times 2(C_4) \times 3(C_5) \times 2(C_6) \times 2(C_7) \times 2(C_8) = 1444$). As some of these combinations are not possible (e.g., no time limitation while the timer is faulty, etc.), the total number of possible combinations is, as a consequence, reduced to 792 different sub-games.

3.3 Affective Virtual Reality

The speedboat VR is capable of generating all required combinations of incidents (described in Section 3.2.2). Figure 4 presents some examples of possible sub-game combinations. Each sub-game was allocated an

8-digit code. Each code represented the index number within each column of Table 1. As an illustration, code “21223111” would set up a sub-game environment with the following settings:

$$\begin{gathered}\text{Mine Avoidance} + \text{Time Limitation} + \\ \text{Faulty Timer} + \text{Invisible Barrier} + \\ \text{Joystick with Force Feedback} + \\ \text{Normal Controller} + \\ \text{Shaking and Blurring the Camera} + \text{Color Screen}\end{gathered}$$

The experimenter generates a list of these codes for the VR, in order to create an automated sequential (randomized) experiment. In addition, an interactive SAM (Bradley & Lang, 1994) questionnaire (scaled between -3 to $+3$ in all axes), followed by the eight-emotions list described earlier, was automatically presented to the user, at the end of each sub-game (Section 2.3). The rating results, followed by the sub-game information, were saved in a text file during the run-time of the experiment, and could be simply extracted after the experiment.

4 Pre-Experiment Survey (Experiment 1)

4.1 Sub-Games Affective Power Approximation

As explained in Section 3.2.2, 792 different sub-games can be constructed using the 21 *incidents.* Two different approaches were available to test the emotional effect of each sub-game:

1. **Subjective Assessment:** In this approach, all sub-games need to be played at least once by one of the participants. It is impossible to allow each participant to play all 792 sub-games, as no one individual would be able to play all of them without experiencing extreme fatigue (even in multiple sessions, over different days). Therefore, all 792 sub-games can be divided into “m” subsets, each of which contains a number of sub-games. Then each subset can be played (I) either by “n” participants, or (II) by only one participant. To be able to perform a meaningful affective analysis, the affective power of sub-games cannot be assessed by subjective assessment of a single participant (approach I). Therefore, a high number of participants need to be recruited, to enable each game to be played by “n” participants (approach II).
2. **Subjective Approximation:** In this method, the emotional effect of each incident, rather than each sub-game, would be evaluated, using an approximation technique. This means that each participant would estimate the possible emotional effect of each *incident* (all 21 *incidents* considered), described verbally (Section 4.2). Then, by employing the approximated emotional effects of all *incidents*, and an estimation technique (Section 4.3), the overall affective power of each single sub-game, containing a number of incidents, can be approximated.

Due to the high number of possible sub-game combinations, to reduce this number to include those affective combinations which would be most likely to manipulate the participants’ emotional status toward all four affective clusters (described in Section 2), the *Subjective Approximation* approach was employed in this study.

4.2 Participants and Method

Subsequently, a subjective survey was designed and presented online to 35 respondents (with a mean age of 24.72 years, and a distribution of 57% males and 66% nongamers). The study was reviewed and approved by the University of Birmingham’s Ethical Review Committee (Ethical Reference Number: ERN_13-1157). To distinguish gamers from nongamers, the following description was presented to the respondents as part of the online survey to enable them to self-assess appropriately:

> “*If you follow games in the market regularly and have a lot of experience playing games on PC and consoles, you are a gamer.*”

Within the survey, a brief overarching explanation of the VR, followed by a short video of the environment (as referenced earlier under footnote 6), was presented to the respondents. Then, each incident was described in text form, such as: “imagine that you need to drive the boat through mines scattered on the water,” or

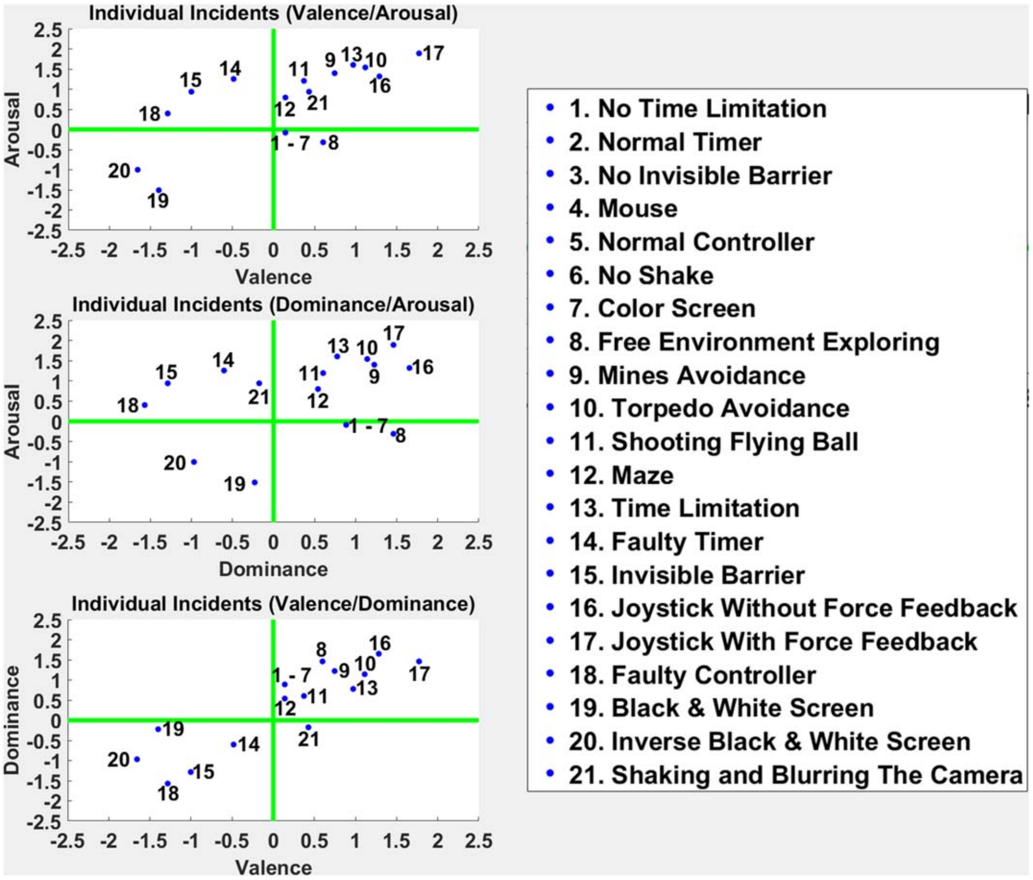


Figure 5. *Presentation of incidents within the 3D affective space.*

"imagine that the controller used to control the boat is faulty and is not responding to your actions." The respondents were then required to estimate their Valence, Arousal, and Dominance levels, and to choose one of the eight emotion labels (as presented in Section 2), for each incident, by considering themselves within the described affective situation.

4.3 Results

Using the mean ratings (across participants) of the respondents for each incident, the affective power of all VR parameters have been approximated within the 3-dimensional affective space and are shown in Figure 5.

To analyze and estimate the total emotional power of each *sub-game*, an estimation algorithm was designed based on the following two hypotheses.

1. **Interacting and Additive Effect:** Each individual incident can have an effect on another incident if they are both presented within the same sub-game. This means that incidents can have additive effects from each other. It also means that, if several incidents are presented in a sub-game, the overall emotional effect of that combination can be considered as the summation of Circumplex values of all individual incidents.
2. **Background Game as the Neutral:** The background scenario can be considered as neutral, with (0, 0, 0) as its 3D emotional effect. This means that all possible combinations would be evaluated with respect to the background VR scenario.

Accepting these hypotheses, then, the affective power of all 792 sub-games can be estimated by adding the approximated 3D affective values of all incidents within

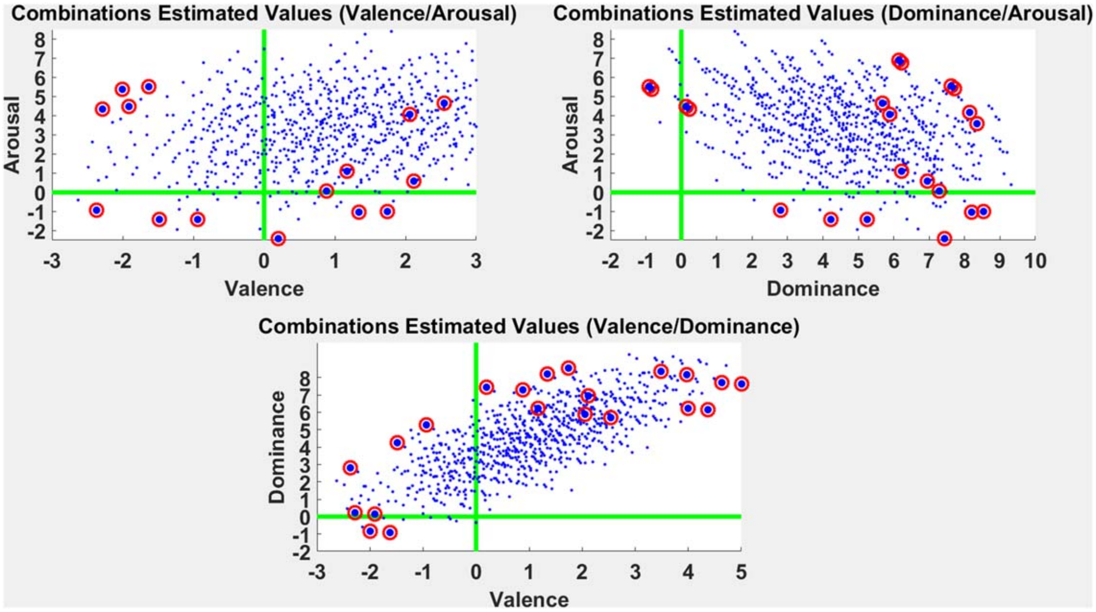


Figure 6. *Presentation of sub-games within the 3D affective space. Dots represent the sub-games. Circled dots represent the 22 selected sub-games.*

each combination. Figure 6 presents the positioning of all 792 sub-games within the 3-dimensional affective space. Furthermore, to estimate the *Occurrence Probability* (*OP*) of each categorical label for each game in the future subjective experiment, Equation 1 was employed in the analysis. By using this equation, the probability in which a particular label can be selected in a specific sub-game is approximated.

Equation 1. Categorical Label Occurrence Probability Estimation Formula

$$OP = \frac{\sum(\text{Occurence Frequency of all incidents in a subgame})}{(\text{Number of Incidences within the subgame}) \times (\text{Number of Participants in the experiment})}$$

5 Preliminary Subjective Experiment (Experiment 2)

5.1 Sub-Games Selection for Preliminary Experiment

After performing the affective power estimation process on the sub-games, the postexposure subjective affective response of the participants to a number of them can be assessed. This subjective affective evaluation can, first, assess the accuracy of the approximation process and second, identify the subjective emotional power of a number of sub-games (rather than their estimated values), for future affective experiments. Therefore, a number of sub-games need to be selected to be presented to a number of participants, for subjective affective evaluation.

For this experiment, it was decided to adopt an overall *Experiment Duration* (ED) of less than 2 hours (in order to minimize participant fatigue). Considering the maximum duration of each sub-game as 5 minutes (no sub-game was permitted to take longer than 5 minutes, as described in Section 3.1, although they usually lasted less than this), and the training session (Section 0) duration of between 5 and 15 minutes (average 10 minutes), the maximum number of sub-games for the experiment (not to exceed 2 hours experiment duration), was calculated as 22 (Equation 2). Therefore the 22 most affective sub-games (those which are most likely to evoke emotional experience within the four affective clusters) have to be identified (using their approximated values) to be presented in the experiment.

Table 2. *Seven-Dimensional Presentation of Games' and Clusters' Ideal Vectors*

Valence	Arousal	Dominance	PVLAPD Occurrence Percentage	PVHPAPD Occurrence Percentage	NVPAND Occurrence Percentage	NVNAND Occurrence Percentage
Valence Mean Value Across All Participants	Arousal Mean Value Across All Participants	Dominance Mean Value Across All Participants	Fraction of Participants Who Chose Either Relaxed or Content	Fraction of Participants Who Chose Either Happy or Excited	Fraction of Participants Who Chose Either Angry or Afraid	Fraction of Participants Who Chose Either Sad or Bored

Table 3. *Clusters' Ideal Vectors*

Cluster	Valence	Arousal	Dominance	PVLAPD Occurrence Percentage	PVHPAPD Occurrence Percentage	NVPAND Occurrence Percentage	NVNAND Occurrence Percentage
PVLAPD	1.5	−0.85	1.5	100%	0%	0%	0%
PVHPAPD	1.5	2.14	1.5	0%	100%	0%	0%
NVPAND	−1.5	1.5	−1.5	0%	0%	100%	0%
NVNAND	−1.5	−1.5	−1.5	0%	0%	0%	100%

Equation 2. Calculation of Maximum Required Number of Sub-Games

$$ED = n \times 5(\text{minutes}) + 10(\text{minutes}) \leq 2(\text{hours})$$

$$n = number\ of\ subgames$$

$$n \leq 22$$

5.2 Most Affective Sub-Games Selection

In order to select the most affective combinations, each sub-game was presented as a vector, in a 7-dimensional space, presented in Table 2. The Valence, Arousal, and Dominance values were calculated through the sub-game affective power estimation algorithm (Section 4.3). In addition, the approximated *Occurrence Probability* (OP) for each sub-game was used to create the sub-games' affective vectors (Section 4.3).

In an ideal situation, the *most affective game* within each cluster would feature that cluster's central values for Valence, Arousal, and Dominance (ideally, in the dimensional model—Section 2—the clusters' *centroids*); while all participants have chosen one of the two verbal labels within that cluster (i.e., the probability of selecting either of the cluster's labels is 100%—ideally in the categorical model). Therefore the clusters' ideal vectors could be presented as shown in Table 3.

To select the most affective sub-games, the Cosine Similarity algorithm (Pang-Ning Tan, 2005) was employed to find the 4 most similar sub-game affective vectors to the clusters' ideal vectors in each affective cluster. Therefore, in each cluster the 4 most powerful combinations were selected to consider the 16 most affective sub-games, which can cover the entire 3D affects space effectively. Furthermore, 5 additional test combinations (added manually—those which have the maximum standard deviation and minimum level of agreement among participants), followed by the *neutral scenario* (the sub-game with background scenario settings—"12111121" combination) were added to create the 22-game experiment. Figure 6 presents the 22 selected sub-games among 792 combinations, highlighted with circles. Table 4 presents the arrangement of the incidents within the 22 selected sub-games.

Table 4. *The 22 Selected Sub-Games' Settings*

	Narrative				Interactive		Visualization	
#	Main Scenario	Time Limitation	Timer	Invisible Barrier	Controller Type	Faulty Controller	Camera	Screen Color
1	Free Environment Exploring	No Time Limitation	Normal Timer	No Invisible Barrier	Mouse	Normal Controller	No Shake or Blurring	Color Screen
2	Free Environment Exploring	No Time Limitation	Normal Timer	No Invisible Barrier	Mouse	Normal Controller	No Shake or Blurring	Black & white
3	Free Environment Exploring	No Time Limitation	Normal Timer	No Invisible Barrier	Mouse	Faulty Controller	No Shake or Blurring	Black & white
4	Free Environment Exploring	No Time Limitation	Normal Timer	No Invisible Barrier	Mouse	Faulty Controller	No Shake or Blurring	Inverse Black & white
5	Free Environment Exploring	No Time Limitation	Normal Timer	No Invisible Barrier	Joystick Without Force Feedback	Normal Controller	No Shake or Blurring	Black & white
6	Free Environment Exploring	No Time Limitation	Normal Timer	No Invisible Barrier	Joystick With Force Feedback	Normal Controller	No Shake or Blurring	Black & white
7	Free Environment Exploring	No Time Limitation	Normal Timer	Invisible Barrier	Mouse	Normal Controller	No Shake or Blurring	Black & white
8	Free Environment Exploring	No Time Limitation	Normal Timer	Invisible Barrier	Mouse	Faulty Controller	No Shake or Blurring	Black & white
9	Mine Avoidance	Time Limitation	Normal Timer	No Invisible Barrier	Joystick With Force Feedback	Normal Controller	Shaking and Blurring the Camera	Color Screen
10	Mine Avoidance	Time Limitation	Faulty Timer	No Invisible Barrier	Joystick With Force Feedback	Normal Controller	Shaking and Blurring the Camera	Color Screen

Table 4. *(Continued)*

	Narrative				Interactive		Visualization	
#	Main Scenario	Time Limitation	Timer	Invisible Barrier	Controller Type	Faulty Controller	Camera	Screen Color
11	Mine Avoidance	Time Limitation	Faulty Timer	Invisible Barrier	Mouse	Faulty Controller	No Shake or Blurring	Inverse Black & white
12	Mine Avoidance	Time Limitation	Faulty Timer	Invisible Barrier	Mouse	Faulty Controller	Shaking and Blurring the Camera	Inverse Black & white
13	Torpedo Avoidance	Time Limitation	Normal Timer	No Invisible Barrier	Joystick With Force Feedback	Normal Controller	Shaking and Blurring the Camera	Color Screen
14	Torpedo Avoidance	Time Limitation	Faulty Timer	No Invisible Barrier	Joystick With Force Feedback	Normal Controller	Shaking and Blurring the Camera	Color Screen
15	Torpedo Avoidance	Time Limitation	Faulty Timer	Invisible Barrier	Mouse	Faulty Controller	No Shake or Blurring	Inverse Black & white
16	Torpedo Avoidance	Time Limitation	Faulty Timer	Invisible Barrier	Mouse	Faulty Controller	Shaking and Blurring the Camera	Inverse Black & white
17	Shooting a Flying Ball	Time Limitation	Normal Timer	No Invisible Barrier	Joystick Without Force Feedback	Normal Controller	No Shake or Blurring	Color Screen
18	Shooting a Flying Ball	Time Limitation	Normal Timer	No Invisible Barrier	Joystick Without Force Feedback	Faulty Controller	No Shake or Blurring	Color Screen
19	Shooting a Flying Ball	Time Limitation	Normal Timer	No Invisible Barrier	Joystick With Force Feedback	Normal Controller	No Shake or Blurring	Color Screen
20	Shooting a Flying Ball	Time Limitation	Normal Timer	No Invisible Barrier	Joystick With Force Feedback	Faulty Controller	No Shake or Blurring	Color Screen

Table 4. *(Continued)*

	Narrative				Interactive		Visualization	
#	Main Scenario	Time Limitation	Timer	Invisible Barrier	Controller Type	Faulty Controller	Camera	Screen Color
21	Maze	No Time Limitation	Normal Timer	No Invisible Barrier	Joystick Without Force Feedback	Normal Controller	No Shake or Blurring	Black & white
22	Maze	No Time Limitation	Normal Timer	No Invisible Barrier	Joystick Without Force Feedback	Normal Controller	Shaking and Blurring the Camera	Black & white

5.3 Participants and Method

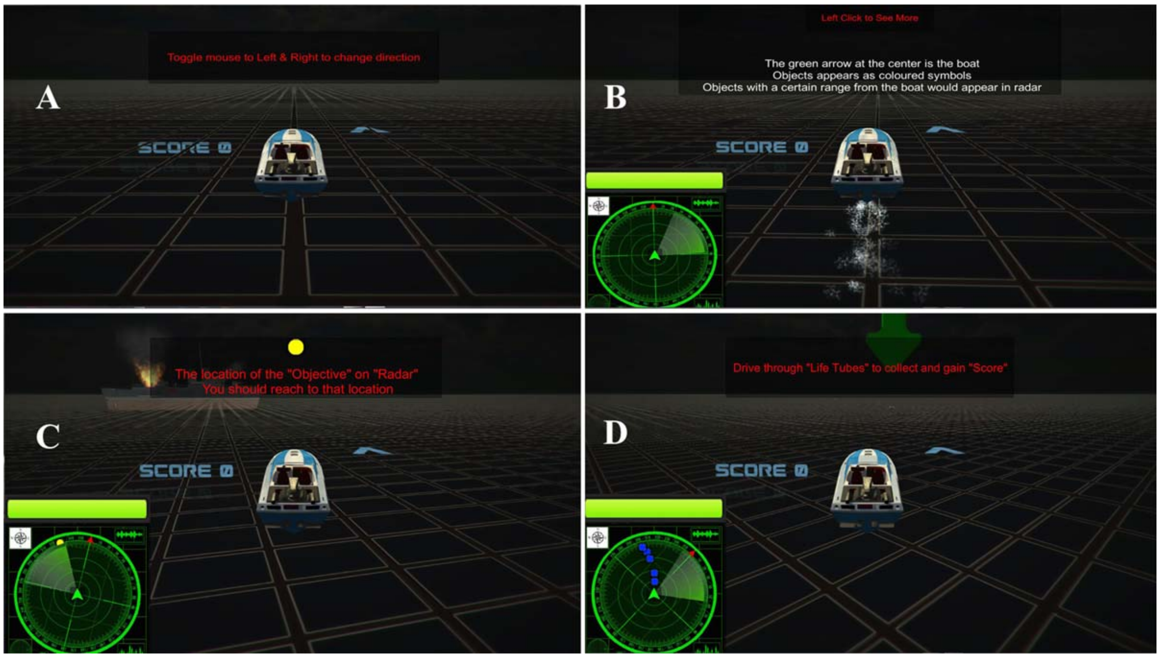
An experiment was conducted in which the 22 selected sub-games were presented to 68 participants (with a mean age of 24.12 years). The study was reviewed and approved by the University of Birmingham Ethical Review Committee (Ethical Reference Number: ERN_13-1157). The participants consisted of four different groups: male gamers, female gamers, male nongamers, and female nongamers (17 participants for each group—the gaming experience was subjectively assessed by the participants, according to the description presented in Section 4.2). Each experiment commenced with a training session (see Figure 7) to prepare the participants for every possible incident within the games. The training introduced the game environment to the participants and served to reduce any element of surprise in the games.

The sessions were performed in a quiet room. All participants were provided with a 32-inch Samsung LCD display, a Microsoft Wireless Mouse 5000, a Logitech Wingman 3D force feedback joystick, and a Sennheiser RS-170 wireless headphone. On average, participants spent 58 minutes playing the games, and 1 hour, 46 minutes to complete the entire experiment. Therefore, on average, participants spent 48 minutes of the experiment to complete the questionnaire, or to rest between the sub-game sessions.

5.4 Results

5.4.1 Raw Results. Table 6 presents the estimated (through Experiment 1) and subjectively reported (through Experiment 2) Valence, Arousal, and Dominance levels for each sub-game. The estimated values are calculated by adding the incident's (VR parameter) affective values (according to "Interactive and Additive Effect" presented in Section 4.3); therefore, the scaling is different from the sub-games' measured ratings, which are scaled between -3 and $+3$. Table 5 presents the estimated and reported OP of each categorical label in each sub-game.

5.4.2 Estimated Versus Reported Correlation. Figure 8 shows the scatter plot of the estimated Valence, Arousal, and Dominance levels in the Pre-Experiment (Experiment 1), versus the subjectively reported levels in the Preliminary Experiment (Experiment 2). A comparison of the estimated values shows a high correlation factor (Pearson technique) with the reported values across Valence, Arousal, and Dominance axes (see Table 7). From this, one can conclude that not only were the participants able to accurately estimate their emotions for each incident, before the real experience (using the dimensional affective space), but also that the estimation algorithm (presented in Section 4) was suffi-



Toggle mouse to Left & Right to change direction

Left Click to See More

The green arrow at the center is the boat
Objects appears as coloured symbols
Objects with a certain range from the boat would appear in radar

The location of the "Objective" on "Radar"
You should reach to that location

Drive through "Life Tubes" to collect and gain "Score"

Figure 7. *Affective VR training session. A) Practicing the maneuvering procedures. B) Explaining the radar. C) Describing the dot colors in radar and their definitions. D) Presenting the "ring buoys" and the scoring procedure.*

Table 5. *Estimated Versus Subjectively Reported Categorical Levels for the 22 Selected Sub-Games*

#		Relaxed	Content	Happy	Excited	Angry	Afraid	Sad	Bored
1	Estimated Percentage	18.41%	14.60%	10.79%	17.46%	5.08%	2.54%	0.00%	31.11%
	Reported Percentage	23.53%	36.76%	17.65%	14.71%	0.00%	1.47%	0.00%	5.88%
2	Estimated Percentage	17.14%	13.65%	9.52%	15.56%	5.71%	2.22%	2.22%	33.97%
	Reported Percentage	27.94%	20.59%	27.94%	1.47%	2.94%	0.00%	0.00%	16.18%
3	Estimated Percentage	13.97%	11.43%	6.98%	12.70%	20.63%	2.86%	3.17%	28.25%
	Reported Percentage	7.35%	13.24%	10.29%	5.88%	27.94%	1.47%	4.41%	27.94%
4	Estimated Percentage	15.24%	12.38%	9.21%	13.97%	14.92%	3.49%	1.90%	28.89%
	Reported Percentage	10.29%	7.35%	2.94%	7.35%	26.47%	1.47%	8.82%	35.29%
5	Estimated Percentage	15.87%	13.65%	12.38%	16.51%	5.71%	1.90%	2.22%	31.75%
	Reported Percentage	23.53%	23.53%	19.12%	5.88%	0.00%	0.00%	0.00%	25.00%
6	Estimated Percentage	13.97%	11.43%	8.57%	22.54%	9.52%	3.17%	2.54%	28.25%
	Reported Percentage	11.76%	16.18%	27.94%	20.59%	2.94%	1.47%	1.47%	16.18%
7	Estimated Percentage	15.24%	12.38%	8.25%	14.29%	13.33%	2.86%	2.86%	30.79%
	Reported Percentage	10.29%	17.65%	13.24%	8.82%	19.12%	2.94%	4.41%	20.59%
8	Estimated Percentage	13.97%	11.43%	6.98%	12.70%	20.63%	2.86%	3.17%	28.25%
	Reported Percentage	0.00%	7.35%	8.82%	2.94%	39.71%	1.47%	5.88%	32.35%
9	Estimated Percentage	10.16%	10.48%	9.84%	32.38%	9.84%	6.03%	0.32%	20.95%
	Reported Percentage	1.47%	13.24%	25.00%	45.59%	4.41%	2.94%	1.47%	1.47%

Table 5. *(Continued)*

#		Relaxed	Content	Happy	Excited	Angry	Afraid	Sad	Bored
10	Estimated Percentage	8.25%	9.52%	9.21%	32.70%	15.87%	6.03%	0.32%	18.10%
	Reported Percentage	5.88%	11.76%	14.71%	29.41%	22.06%	2.94%	2.94%	4.41%
11	Estimated Percentage	6.35%	8.25%	7.30%	20.95%	29.52%	6.67%	2.54%	18.41%
	Reported Percentage	5.88%	7.35%	8.82%	7.35%	41.18%	5.88%	7.35%	14.71%
12	Estimated Percentage	4.76%	6.67%	6.03%	23.17%	33.65%	7.62%	2.86%	15.24%
	Reported Percentage	1.47%	4.41%	4.41%	4.41%	60.29%	5.88%	5.88%	11.76%
13	Estimated Percentage	10.16%	10.48%	10.16%	31.43%	10.48%	6.67%	0.32%	20.32%
	Reported Percentage	0.00%	4.41%	14.71%	69.12%	1.47%	1.47%	4.41%	0.00%
14	Estimated Percentage	8.25%	9.52%	9.52%	31.75%	16.51%	6.67%	0.32%	17.46%
	Reported Percentage	0.00%	14.71%	10.29%	44.12%	19.12%	1.47%	2.94%	4.41%
15	Estimated Percentage	6.35%	8.25%	7.62%	20.00%	30.16%	7.30%	2.54%	17.78%
	Reported Percentage	0.00%	7.35%	2.94%	8.82%	64.71%	2.94%	2.94%	8.82%
16	Estimated Percentage	4.76%	6.67%	6.35%	22.22%	34.29%	8.25%	2.86%	14.60%
	Reported Percentage	1.47%	2.94%	1.47%	14.71%	52.94%	5.88%	8.82%	8.82%
17	Estimated Percentage	12.38%	12.06%	14.92%	23.81%	6.98%	5.40%	0.32%	24.13%
	Reported Percentage	2.94%	25.00%	35.29%	19.12%	5.88%	0.00%	2.94%	7.35%
18	Estimated Percentage	11.11%	11.11%	13.65%	22.22%	14.29%	5.40%	0.63%	21.59%
	Reported Percentage	0.00%	10.29%	10.29%	16.18%	42.65%	1.47%	5.88%	10.29%
19	Estimated Percentage	12.06%	11.43%	12.38%	27.62%	6.67%	5.71%	0.32%	23.81%
	Reported Percentage	5.88%	13.24%	32.35%	33.82%	8.82%	0.00%	1.47%	4.41%
20	Estimated Percentage	10.79%	10.48%	11.11%	26.03%	13.97%	5.71%	0.63%	21.27%
	Reported Percentage	0.00%	11.76%	7.35%	22.06%	44.12%	1.47%	5.88%	5.88%
21	Estimated Percentage	13.97%	12.38%	11.75%	16.83%	8.57%	2.54%	2.54%	31.43%
	Reported Percentage	4.41%	8.82%	11.76%	4.41%	20.59%	2.94%	11.76%	32.35%
22	Estimated Percentage	12.38%	10.79%	10.48%	19.05%	12.70%	3.49%	2.86%	28.25%
	Reported Percentage	4.41%	7.35%	2.94%	2.94%	27.94%	1.47%	4.41%	45.59%

Table 6. *Estimated Versus Subjectively Reported Dimensional Levels for the 22 Selected Sub-Games (SE Is the Standard Error)*

	Valence		Arousal		Dominance	
Num	Estimated	Subjectively Rated	Estimated	Subjectively Rated	Estimated	Subjectively Rated
1	1.74	1.53	−1	0.04	8.54	2.09
	$(SE = 0.26)$	$(SE = 0.12)$	$(SE = 0.26)$	$(SE = 0.19)$	$(SE = 0.22)$	$(SE = 0.12)$
2	0.2	1.23	−2.43	−0.26	7.43	2.64
	$(SE = 0.26)$	$(SE = 0.15)$	$(SE = 0.26)$	$(SE = 0.21)$	$(SE = 0.23)$	$(SE = 0.09)$
3	−2.37	−0.57	−0.91	−0.01	2.8	−0.39
	$(SE = 0.26)$	$(SE = 0.18)$	$(SE = 0.26)$	$(SE = 0.19)$	$(SE = 0.24)$	$(SE = 0.19)$

Table 6. *(Continued)*

	Valence		Arousal		Dominance	
Num	Estimated	Subjectively Rated	Estimated	Subjectively Rated	Estimated	Subjectively Rated
4	−1.49	−0.6	−1.43	−0.15	4.23	−0.54
	($SE = 0.26$)	($SE = 0.16$)	($SE = 0.26$)	($SE = 0.19$)	($SE = 0.23$)	($SE = 0.2$)
5	1.34	0.91	−1.03	−0.24	8.2	2.36
	($SE = 0.26$)	($SE = 0.17$)	($SE = 0.26$)	($SE = 0.22$)	($SE = 0.22$)	($SE = 0.12$)
6	2.11	1.1	0.57	0.76	6.94	1.61
	($SE = 0.25$)	($SE = 0.16$)	($SE = 0.25$)	($SE = 0.2$)	($SE = 0.23$)	($SE = 0.16$)
7	−0.94	0.23	−1.4	0.23	5.26	1.79
	($SE = 0.26$)	($SE = 0.18$)	($SE = 0.26$)	($SE = 0.19$)	($SE = 0.23$)	($SE = 0.18$)
8	−2.37	−0.76	−0.91	0.22	2.8	−0.67
	($SE = 0.26$)	($SE = 0.18$)	($SE = 0.26$)	($SE = 0.19$)	($SE = 0.24$)	($SE = 0.2$)
9	4.63	1.43	5.4	1.77	7.71	1.42
	($SE = 0.24$)	($SE = 0.16$)	($SE = 0.24$)	($SE = 0.11$)	($SE = 0.23$)	($SE = 0.16$)
10	4	0.61	6.74	1.47	6.23	0.7
	($SE = 0.25$)	($SE = 0.2$)	($SE = 0.25$)	($SE = 0.14$)	($SE = 0.24$)	($SE = 0.21$)
11	−2.29	−1.15	4.34	0.6	0.23	−1.12
	($SE = 0.26$)	($SE = 0.18$)	($SE = 0.26$)	($SE = 0.2$)	($SE = 0.25$)	($SE = 0.2$)
12	−2	−1.07	5.37	0.88	−0.83	−0.96
	($SE = 0.27$)	($SE = 0.18$)	($SE = 0.21$)	($SE = 0.17$)	($SE = 0.25$)	($SE = 0.18$)
13	5	1.85	5.54	2.31	7.63	1.35
	($SE = 0.24$)	($SE = 0.15$)	($SE = 0.24$)	($SE = 0.1$)	($SE = 0.23$)	($SE = 0.17$)
14	4.37	0.8	6.89	1.76	6.14	1.09
	($SE = 0.25$)	($SE = 0.19$)	($SE = 0.25$)	($SE = 0.14$)	($SE = 0.24$)	($SE = 0.18$)
15	−1.91	−1.28	4.49	1.03	0.14	−1.55
	($SE = 0.26$)	($SE = 0.2$)	($SE = 0.26$)	($SE = 0.16$)	($SE = 0.25$)	($SE = 0.19$)
16	−1.63	−1.14	5.51	1.39	−0.91	−1.53
	($SE = 0.27$)	($SE = 0.19$)	($SE = 0.27$)	($SE = 0.16$)	($SE = 0.26$)	($SE = 0.17$)
17	3.49	1.31	3.6	1.24	8.34	1.81
	($SE = 0.25$)	($SE = 0.15$)	($SE = 0.25$)	($SE = 0.14$)	($SE = 0.22$)	($SE = 0.16$)
18	2.06	−0.45	4.09	1.08	5.89	−1.14
	($SE = 0.25$)	($SE = 0.21$)	($SE = 0.25$)	($SE = 0.19$)	($SE = 0.23$)	($SE = 0.19$)
19	3.97	1.54	4.17	1.69	8.14	1.53
	($SE = 0.24$)	($SE = 0.16$)	($SE = 0.24$)	($SE = 0.13$)	($SE = 0.23$)	($SE = 0.15$)
20	2.54	−0.18	4.66	1.39	5.69	−1.04
	($SE = 0.24$)	($SE = 0.23$)	($SE = 0.24$)	($SE = 0.15$)	($SE = 0.23$)	($SE = 0.18$)
21	0.89	−0.53	0.09	−0.33	7.29	1.7
	($SE = 0.26$)	($SE = 0.23$)	($SE = 0.26$)	($SE = 0.23$)	($SE = 0.23$)	($SE = 0.17$)
22	1.17	−1.11	1.11	−0.48	6.23	1.27
	($SE = 0.26$)	($SE = 0.22$)	($SE = 0.26$)	($SE = 0.23$)	($SE = 0.23$)	($SE = 0.22$)

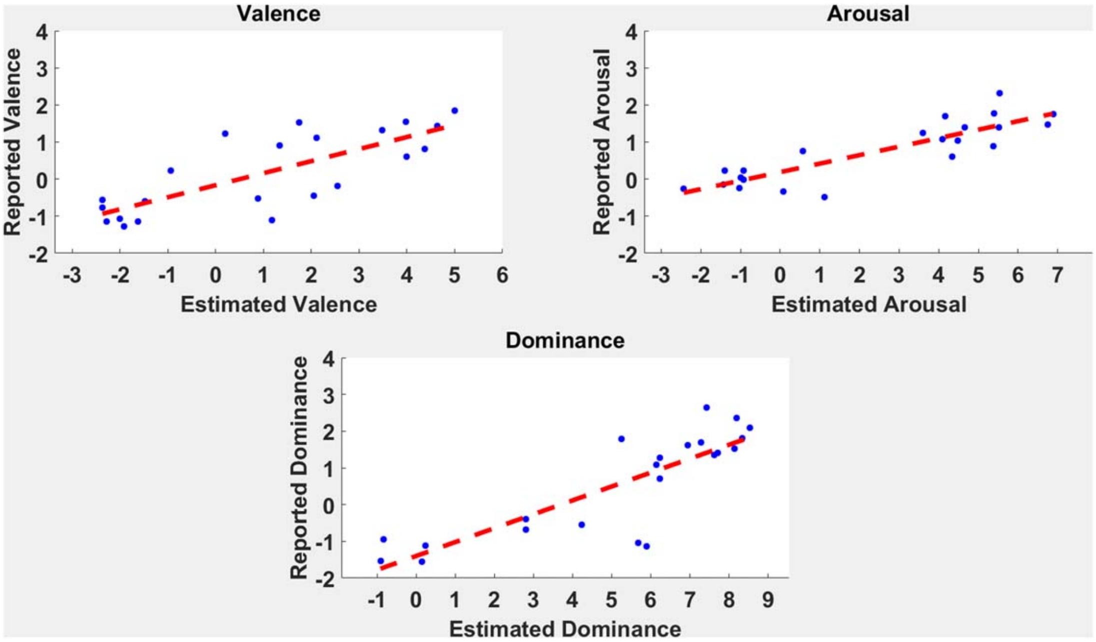


Figure 8. *Estimation vs. reported dimensional correlation.*

Table 7. *Axis and Emotion Labels Correlation Report*

Label	Correlation	Axis	Correlation
Relaxed	$r(22) = 0.702, P = 0.0003$	Valence	$r(22) = 0.774, P < 0.0001$
Content	$r(22) = 0.724, P = 0.0001$		
Happy	$r(22) = 0.536, P = 0.0100$	Arousal	$r(22) = 0.867, P < 0.0001$
Excited	$r(22) = 0.838, P < 0.0001$		
Angry	$r(22) = 0.878, P < 0.0001$		
Afraid	$r(22) = 0.566, P = 0.0060$	Dominance	$r(22) = 0.837, P < 0.0001$
Sad	$r(22) = 0.371, P = 0.0892$		
Bored	$r(22) = 0.595, P = 0.0034$		

ciently accurate to accumulate the overall affective power of each sub-game (using the dimensional affective space). Thus, it can be concluded that the presented dimensional affective power estimation algorithm appears to be capable of predicting the sub-games' affective power prior to the participants' actual subjective experience.

A comparison of the estimated versus reported categorical emotional labels (occurrence probability) is presented in Figure 9. As can be seen in the graphs, not only were the correlation coefficients smaller (see Table 7) compared to the dimensional model, but also they were slightly less significant (see Table 7). One can conclude that the dimensional affective power estimation process was more accurate than the categorical approximation.

5.4.3 Affective VR Effectiveness. A multivariate analysis of variance (MANOVA) showed that the different *VR-combinations* were an extremely important factor ($P_{VR\text{-}Combinations} < 0.001$,[7] Valence, Arousal, and Domi-

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[7] Calculated using Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root algorithms.

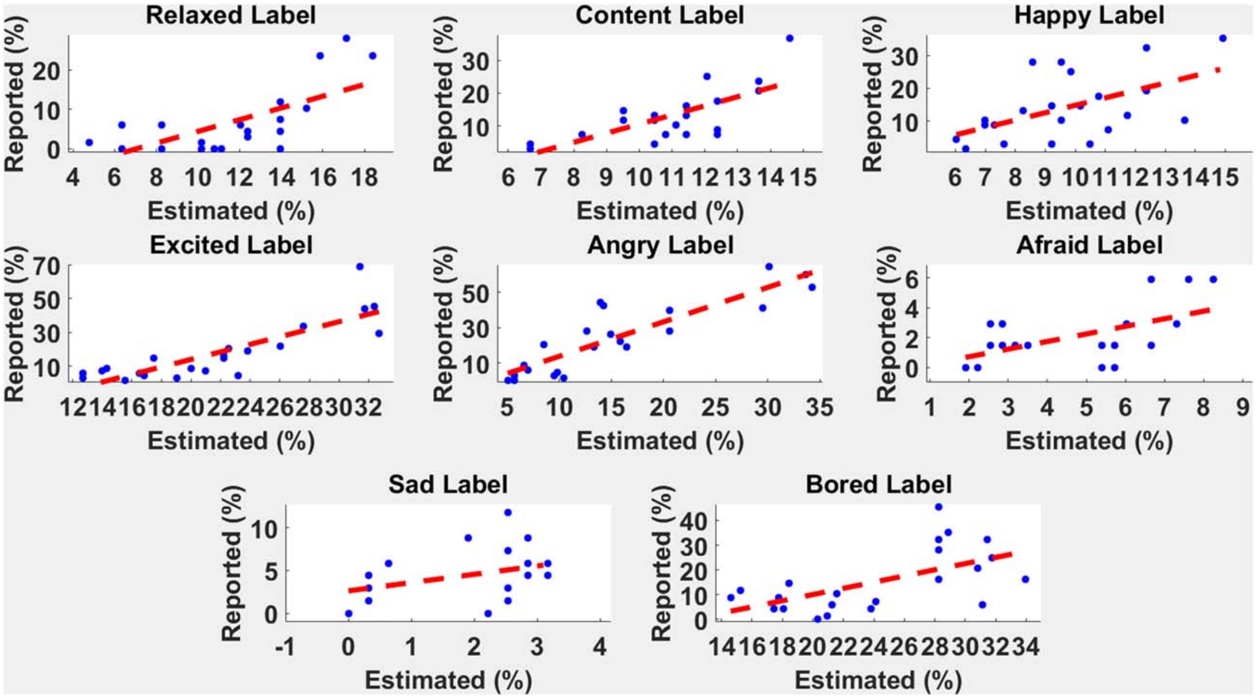

Figure 9. *Estimation vs. reported categorical correlation.*

nance are considered as dependent variables and different sub-games as independent parameter) in creating different emotional experiences (i.e., significantly different Valence, Arousal, and Dominance levels). From this one can conclude that the single controllable affective environment designed for this study has been able to manipulate the participants' emotions significantly, by controlling the VR parameters.

5.4.4 Groups Comparison. Further to the previous discussion, the same (MANOVA) test supported the conclusion that both *Gender* (male vs. female) and *Gaming Experience* (gamer vs. nongamer) are extremely important factors in the participants' emotional experiences ($P_{Gender} < 0.001$, $P_{Gaming\text{-}Experience} < 0.001$[7]—Valence, Arousal, and Dominance are considered as dependent variables and gender and gaming-experience as independent parameters). Thus it can be concluded that the emotional experiences of each group (male-gamer, male-nongamer, female-gamer, and female-nongamer) are significantly different from each other.

One of the most important challenges of designing any affective psychophysiological database is the minimization of variability between participants (in each individual sub-game), while maximizing the variability between sub-games' experiences. This is due to the fact that, in any human-centered experiment, minimum variability between participants' experiences in a single VR session is an extremely important issue. Any acceptable analysis, dealing with either affects or physiological databases, should, intuitively, be based on changes in emotional experiences, due to *different environments*, rather than different *personal experiences*.

Therefore, to reveal the similarity level between all 4 participant groups (male-gamer, male-nongamer, female-gamer, and female-nongamer), the Cosine Similarity Algorithm (Pang-Ning Tan, 2005) was once again employed. Table 8 presents the mean similarity comparison levels, across games, for the four groups, in order of the similarity level. As can be seen, the male gamers, male nongamers, and female gamers are the most similar groups, compared to the female nongamers (according

Table 8. *Groups Similarity Comparison Table*

Group Comparison	Mean Similarity Level Across Games
Male Gamer Vs. Male Non-Gamer	94.23% (±1.27%)
Male Gamer Vs. Female Gamer	93% (±1.54%)
Male Non-Gamer Vs. Female Gamer	90.98% (±2.07%)
Female Gamer Vs. Female Non-Gamer	78.48% (±8.88%)
Male Non-Gamer Vs. Female Non-Gamer	77.22% (±9.29%)
Male Gamer Vs. Female Non-Gamer	74.47% (±10.82%)

to higher average and lower standard deviation in similarity levels, across the games). This means that in an affective VR situation, the emotional experience of male gamers, male nongamers, and female gamers are very similar, particularly when compared to the female nongamers.

6 Discussion

The analysis presented in this study shows a number of early evaluation results based on an affective virtual reality scenario. The affective VR, based on a speedboat simulation, is capable of evoking multiple controllable emotional experiences within the users, through changes of its internal parameters. The analysis has highlighted the ability of this affective VR to manipulate the users' emotional experiences effectively, within the affective space (examined on both dimensional and categorical models), by combining a variety of affective incidents (VR parameters) within a number of sub-games. Moreover, the results suggest that the affective power approximation algorithm (also presented in this study) has been able to evaluate the emotional effect of each sub-game, fairly accurately, prior to the real experience of the users. The analysis concluded that the approximation algorithm has been able to estimate the emotional experience of the users more accurately in the dimensional affective space when compared to the categorical model. In addition, the analysis highlighted the fact that gender and gaming experience are significant factors in experiencing different emotional experience on the part of the users. This means that the male-gamers, male-nongamers, female-gamers, and female-nongamers would have significantly different emotional experiences (compared to each other), if exposed to a similar affective stimulus. However, despite the different emotional experiences, the similarity level comparison revealed that male gamers, male nongamers, and female gamers have a higher similarity level in their affective responses, with least variability, when compared to the female nongamers.

7 Conclusions

The human–computer interface has become one of the most important research topics in computer science since the introduction of the first "computers" (calculators) in the 17th century. Today, highly complex real-time computer-based systems and their interfaces with human operators are undergoing an evolution on a hitherto unheard-of scale, in what has become a quest to ensure that they become synergistic, even symbiotic with their human users—transparent, usable, intuitive, sensitive, and reactive. As a key part of this evolution, psychophysiological interfaces generally, and Brain–Computer Interaction (BCI) techniques specifically have introduced new dimensions to the human interaction process, by the introduction of direct human-to-computer connections. Enhancing this symbiosis is, today, both technically and ethically possible. From a VR perspective, affective computing, as one the subclasses of BCI research endeavors, could be exploited in an attempt to measure users' emotions and affective experiences, and, by incorporating them within advanced VR systems, support endeavors to enhance participants' sense of "immersion" and engagement.

This article has focused on the conceptualization, design, and early validation of an affective virtual reality, based on a dynamic VR environment, capable of evoking multiple emotional experiences on the part of end users. The literature reviewed demonstrated that much attention has, in the recent past, focused on affective computing motivated by passive human attention to music, static image or video-based stimuli, with less apparent interest being shown in the pursuit of similar interests in interactive, dynamic virtual environments. Moreover, it was also discovered that the construction of any affective computing and recognition system requires an affective psychophysiological database, recorded using *reliable emotional stimuli* when interacting with particular types of affective media. By focusing on affect recognition in virtual realities and artificial environments, a highly controllable affective VR-based simulation has been designed and evaluated through two early experiments, to be further used in the construction of such a database. Indeed, the aspiration of this ongoing project is to construct a reliable affective psychophysiological database to generate techniques that will ultimately support the design of *adaptive virtual environments*, not only by measuring human emotions stimulated by virtual environments through physiological parameters, but also by adapting the game's contents and events accordingly, with the ultimate aim of increasing the "immersion factor," possibly even tailored to the needs and responses of each individual user.

Elements of the research described in this article are currently being considered for application in other domains, such as the role of emotions in the exploitation of VR or serious games within healthcare contexts—for example, during cognitive restoration therapies (e.g., Stone, Small, Knight, Qian, & Shingari, 2014), or in rehabilitation and distraction therapies (e.g., Small, Stone, Pilsbury, Bowden, & Bion, 2015). In particular, these healthcare projects are generating early findings, based on issues with poor sustained participation on the part of certain patients, suggesting that the methods described herein may well be significant in future techniques of early "affective screening" during recruitment.

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