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Measuring presence: Hypothetical quantitative framework

Krzysztof Szczurowski

matt smith

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Hypothetical Quantitative Framework

Krzysztof Szczurowski, Matt Smith
Department of Informatics
Institute of Technology, Blanchardstown
Dublin, Ireland
krzysztof.szczurowski@student.itb.ie; matt.smith@itb.ie

I. Abstract

Virtual Reality Head - Mounted Display (HMD) manufacturers claim that consumer electronics can finally deliver a high degree of presence in virtual and remote environments. Certainly, current consumer-grade HMD systems offer rich and coherent mediated experiences of such environments. However, the very concept of presence is still a subject of debate, and researchers' investigation of the phenomenon of 'presence' is based primarily on qualitative (i.e. questionnaire-based) assessments.

Some researchers attempted to develop real-time, quantitative methods to facilitate more objective investigation of presence in mediated environments. Most such methodologies are derived from attempts to correlate presence with cardiovascular and electrodermal activity in response to stressful stimuli [1]**. Such methodologies often don't comply with the underlying logic, fundamental to this approach: a high degree of presence manifests itself through similar responses to the stimulus observed in a physical and Virtual Environment (VE). Therefore, the lack of deviation from baseline measurement observed in a physical environment should be a manifestation of a high level of presence.**

We have argued theoretical grounds for the development of quantitative methodologies for measuring presence in VE. However, our hypothesis can be applicable to other contexts, such as presence in physical but remote location, augmented reality, and even a physical environment. We argue that the concept of presence requires further research and development and that the definition of presence should be addressed first. Presence is discussed in the context of brain function theory [2]**.**

Three hypothetical experiments are proposed and described. The first experiment is designed to evaluate capacity of the medium for inducing presence. The second experiment evaluates factors loading on presence, through physiological deviations from baseline observed during controlled regression in quality of the VE properties. The third experiment is designed to evaluate brain function theory hypothesis in relation to Virtual Environments. Possible experiment results and their interpretation is discussed along benefits of adopting Open Science methodology in our research community.

II. Introduction

Currently, there is no consensus on the definition of presence [3]. Below we will briefly discuss some of the most popular definitions of presence and their limitations. Most of such definitions are derived from empirical observations of a subjective experience of presence, for example:

- "The extent to which a person fails to perceive or acknowledge the existence of a medium during a technologically mediated experience" [4, p. 181]
- "Presence is defined as the subjective experience of being in one place or environment, even when one is physically situated in another" [5, p. 225]
- "the perceptual illusion of nonmediation." [6]

Initially it may seem that such definitions fail to provide explanation to why such system exists in nature. Why would human evolution develop a system for assessing environment 'realness'? Observations of the processes occurring in a brain while its processing an environment, through brain imagining techniques, provide some grounds for justifying the existence of presence [2]. Brain function theory suggests that humans process the environment using a mental model of it [7]. Over the course of life more information about the environment is gathered empirically and encoded into that mental model. In consequence when an 'experienced' human sees an object in the environment, their brain can use information collected in the past applied to a current context, and evaluate the level of threat, or the affordances created by it, to generate appropriate response. Some researchers hypothesize that the function of presence is to evaluate accuracy of that model [7]. Presence provides us with a 'gut feeling' of how well we understand the environment we are in, and if we can predict the outcomes of our actions in it.

There seems to be evidence suggesting that presence can be achieved in an abstract environment, furthermore realism seems to have a small effect on presence [8]. Accuracy of a model constructed based on the information from the physical environment, should be extremely low in such scenario. This would suggest an existence of specialized models that are applicable for such abstract environments.

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In this view on presence, the subject of the experience might be cognitively aware of the artificial nature of the experience, but still respond to the VE as if it was real. Interactions with the environment should not be required to invoke presence. Failed interactions that wouldn't match the outcomes expected by the model are likely to have a negative impact on presence, while successful interaction should have a positive effect. However, we hypothesize that presence without interaction should also be possible. There is no evidence suggesting that presence diminish when the subject is not interacting with the environment, unless being in the environment is also classified as a form interaction.

It's worth noting that this view on presence is not mutually exclusive with most existing definitions of presence. Seeing presence through a prism of its function rather than its symptoms can yield a higher chance for identifying origins of presence in a human body, and aid in development of methodology that would objectively evaluate presence through physiology, rather than subjective, self-reported feelings.

Providing a new definition of presence is outside of the scope of this publication. Therefore, the argument above should be considered as an entry point to understanding the rationale behind the hypothesis put forward in the following paragraphs. However, we believe that the definition of presence should be redeveloped, based on the function of presence rather than its symptoms.

III. Taxonomy of Presence

The term presence is used in various contexts. Two taxonomies are often used in presence literature. One is based on the source of a stimulus. The other taxonomy is rooted in the function of presence in the experience.

In the context of teleoperation Marvin Minsky developed the concept of telepresence [9]. It refers to the operator feeling physically present in a remote physical location. Ellis proposed that issues related to telepresence can be expanded to presence in Virtual Environment (VE) since "users of virtual environment interface are in the same position with respect to simulated effectors in the virtual environment as that of human telerobotics controllers with respect to a remote robot" [10, p. 247]. By extension presence could also apply to Augmented Reality (AR) applications (i.e. [11]). 'All reality is Virtual Reality', as human experience of the physical world is always mediated by a perceptual process. Therefore, the notion of non-mediated experiences refers to the 'first order' mediation, which is the natural way humans perceive their physical environment [3]. Presence can also be used in the context of 'first order' mediation and be applied to a physical environment. We discuss presence in the context of VEs, but our hypothesis should apply to all the contexts listed above, as we are not familiar with any evidence that would suggest different function or symptoms of presence in such contexts.

Different taxonomies are also found in literature. The term Spatial Presence (SP) is associated with the conviction of being in a mediated environment. It is commonly known as a sensation of "being there" [12]. To incorporate existing theories of users' responses to media Writh and colleagues argue that SP is not limited to Virtual Reality and can also be invoked by "old media" such as books or television. In their view, SP is regarded as a two-dimensional concept that also include perceived possible actions afforded by the environment [12].

Lombard and Ditton identify six types of presence in related literature [6]:

- Presence as social richness, refers to the extent to which the medium is perceived as sociable, and intimate when it is used to interact with other users.
- Presence as realism, refers to the accuracy of a medium in representing objects, events, and people.
- Presence as transportation, refers to the sensation of being transported to the VE, and is further divided into three subcategories: "You are There", "It is Here" and "We are Together".
- Presence as immersion, is referring to the extent to which the senses are engaged by the medium.
- Presence as a social actor within medium, refers to the extent to which the user responds socially to a representation of a person in a mediated environment.
- Presence as medium as social actor, is referring to the extent the medium itself is perceived as a social actor.

There are other taxonomies such as embodied presence, or co-presence, positioned at the intersection of social and physical presence [4].

It seems that currently, there's also no consensus on the type of variable that presence is [4]. Is it Boolean, scalar or constant? Presence scores produced by qualitative metrics are all scalar. However, this is a property of the test, that might not necessarily reflect the nature of presence. Results of the experiment conducted by Jordan and Slater suggest that presence might be binary in nature, as they demonstrate a specific threshold point at which presence starts taking effect inducing responses as if in real life, rather than gradually increasing participants 'realness' of response to the stimulus [13].

IV. Importance of Presence and Its Metric

Evolution of media technologies move us ever so closer to achieving full presence in VEs. Current development of consumer grade Head Mounted Displays (HMD) represent a significant leap forward in that direction. An explanation to why HMDs offer such a high degree of immersion over other forms of media, might lay in their capacity to obstruct real environment, eliminating sensory conflicting arising from processing information from two environments simultaneously. Similarly, Cave Automatic Virtual Environment (CAVE) systems also seems to have a high capacity for inducing presence, most likely for the same reason. Some researchers argue that eliminating sensory conflict is crucial for delivering high degree of presence [14]. Developing Augmented Reality technology, might reveal a slightly different picture, where the two environments (virtual and physical) correctly blended together might still deliver a high degree of presence in that mixed (augmented) environment. This wouldn't necessarily mean that sensory conflicts do not degrade the experience of presence, but that the two environments can be synthesized into a coherent environment, that doesn't result in a sensory conflict. Sensory conflict theory can therefore be used to support the notion, that presence is a result of synchronization between the expected and observed properties and behaviors of the environment.

With a high degree of presence, it should be possible to observe similar responses to a stimulus in a Virtual Environment (VE), as those observed in a physical environment [14]. This in turn creates affordances for a range of possible applications for Virtual Reality (VR) technology. For example, delivering training and instruction in scenarios that would create a significant risk on a trainee and/or third parties, or impose a high cost on the facilitator, but require a high degree of realism, and cannot be easily substituted with traditional media. Familiarizing oneself with the scenario in VR might accommodate higher transfer of learning, and allow for habituation of the skill, including formation of motor memory [15]. In consequence, such training should enable the pilot to carry out the procedure in real life with smaller error rate. Teleoperation systems provide examples of higher experienced presence leading to higher level of operators' performance [16] & [9]. HMD's are also finding an application in more leisure-based activities. In teleoperation of radio controlled (RC) drones and planes, pilots can use a streamed image from the camera mounted on the vehicle to remotely control it from first person's perspective. Examples of utilizing presence can be found in psychology, where exposure therapies in VR offer patients a safe environment to confront their fears and become more comfortable in presence of the stressful stimuli. Meta-analysis of several studies investigating the effect of Virtual Reality Exposure Therapy (VRET) on the patient shows that "there was a small effect size favoring VRET over in-vivo conditions" [17, p. 561], this could be due to degree of safety afforded by the virtual nature of the therapy, which could have had a positive effect on dissociating stimulus from stressful response.

A VR environment that generates a high degree of presence, and in consequence life-like responses to a stimulus should provide an inexpensive, safe, repeatable and fully controllable environment that can be used in behavioral research, or any other research that requires a human response to a stimulus. Such an environment could provide a 'laboratory' for machine learning algorithms used for assessing neural activation patterns in a human brain. One advantage of a VE in the context of such research, is that every detail of the environment is known in advance. Algorithms can then monitor the brain activity of human participants interacting with that VE, while tracking additional information, such as the focus of visual attention through eye tracking to precisely evaluate the target, currently processed by the participants brain. This may support the development of machine learning algorithms capable of identifying neural activation patterns in a human brain, in respect to perception of the environment and processing different entities in it.

It seems plausible that presence enables these life-like responses. However, to be able to assess how much of it can be attributed to presence, hardware properties or content and interactions, quantitative methods for measuring presence are needed. Without such metric, it is hard to prove any correlation, or influence that presence might have on knowledge transfer and/or retention, habituation of a stimulus, or invoking emotions. Quantitative metric of presence can also reveal what type of variable presence is, and provide more clarity on the taxonomy of presence.

V. Measuring presence

Currently available methods are mainly qualitative. Some researchers have argued that due to the subjective nature of the experience of presence this might be the only possible method [16], others, including some of the authors of such questionnaires [18] & [19], criticize this approach [10]. Most qualitative methods are post-experience measures. Therefore, they rely on participants' memory of the experience which impose a limitation on the use of such methods to evaluate changes in temporal domain. There are also within the subject factors that can influence qualitative measurements of presence, susceptibility to suspend belief, might allow some users to forget about the mediation effortlessly while others will actively resists departing from their physical environment. With questionnaires, it's also difficult to avoid giving grounds to a response bias, and the fact that a questionnaire is asking about presence (directly or indirectly) is likely to load the answers that otherwise wouldn't have reach participants consciousness. This is particularly evident in continuous methods, that are relying on a participant operating a mechanical device (usually a slider) to indicate their level of presence in real time [20].

If presence exists outside of the subjective feeling domain, it's unlikely to be a conscious process. No one must remind themselves about staying present in the real world. It's also unlikely that it is possible to force oneself into feeling present in a VE. It's reasonable to assume that the nature of presence is subconscious. Therefore, investigating presence through questionnaires might give us some overview of presence but the granularity and accuracy of such measure is most likely poor. Presence literature also suggests that some questionnaires fail to successfully differentiate between real world and VE [19].

A range of proposed quantitative methods for measuring presence can be found in related literature, and can be divided into two groups. Biometric measures including: Skin Conductance Level (SCL) [1], Heart Rate (HR) and its derivatives in time and frequency domain (Heart Rate Variability - HRV) [21], Blood Pressure (BP), and eye scanpath entropy [13]. Empirical methods, involve observation of behaviors exhibited in response to presence. For example, Reaction Time (RT) or involuntary reflexes.

Hypothetically any physiological response that can reflect the activity of an autonomic nervous system can be used for this purpose. Each method has its own limitations, either in granularity of the measure, complexity of the procedure used for data collection, or the number of external factors that can impact on results. Brain imaging techniques such as Electroencephalography (EEG) can be used to evaluate brain activity in response to degrading presence. With functional Magnetic Resonance Imaging (fMRI) or Low-Resolution Brain

Electromagnetic Tomography (LORETA) it should be possible to observe regions in the brain where activity is altered in response to fluctuation in presence, and identify the origin of presence in the brain.

Most studies exploring quantitative methods for measuring presence in VE are grounded in a rationale that if one is present in a VE then physiological response to stimuli observable in that VE should match responses to the same stimuli observable in the real world, under assumption that presence in a physical environment without any stimulus flowing from another environment that would create a sensory conflict, is a given [14]. Most are focused on the match between physiological responses to stressful stimuli in physical and virtual environment (i.e. virtual precipice experiment [1]).

Such approach raises questions about specificity of results, because presence is measured indirectly through an independent variable that is likely to be influenced by other factors (for example physiological response to a precipice, is much stronger for a participant who suffers from acrophobia), and are often within themselves a subject to change with consecutive exposures. Such approach provides useful insights into the nature of presence, but its application is limited to emotion-inducing (i.e. fear) environments. An example of how such approach can lead to false conclusions, can be seen, in Meehan's investigation of the effect of multiple exposures on the sense of presence in a Virtual Environment (VE). Physiological response to a stressful stimulus decreased with multiple exposures, leading to a conclusion that presence has also decreased [1]. It is possible that presence decline with multiple exposures, but reduced response to a stimulus with repeated exposure is a known phenomenon called the Orienting Effect [22]. Multiple exposures to stressful stimulus combined with lack of danger that would normally accompany it, lead to re-association of the stimulus and overrides phobic reaction. For example, if a person experiences a threatening situation in the real world (such as standing at the edge of a precipice), given all environmental variables remaining constant, the same person will experience a lower level of fear (manifested through a weaker physiological response) on a consecutive attempt. This doesn't mean that they are less present in their environment but that they have habituated the stimulus. Whether presence decreases or increases with multiple exposures is still an open question, but it cannot be answered through a variable that within itself is a subject to change with multiple exposures. Meehan was aware of this issue pointing to Abelson and Curtis [22] for an explanation to why physiological reaction decreased [1]. But he also points to Heether who suggests that presence might decrease with multiple exposures as the novelty of the experience wears off [23].

Jordan and Slater reported a correlation between eye scanpath entropy and presence. The experiment where the environment was building progressively, results demonstrate a correlation between the amount of geometry in the environment (progressively increasing), the eye scanpath entropy (negative correlation) and an onset of physiological responses to stressful stimulus (positive correlation). Results suggest an existence of a threshold amount of cues in the geometry that is required before an environment is recognized and classified as a space that participant responds to as if it was real. Furthermore, the onset of responses to stressful stimuli in an intervention group (standing on a virtual pillar) occurred simultaneously with a rapid decrease in eye scanpath entropy [13].

VI. Dissemination

The field of presence research is still maturing, sharing knowledge and increasing critical mass of the research community is urgently needed to accelerate this process. Therefore, an Open Science model for reporting experiments results and sharing as much data and designs as it's legally possible is suggested. To promote collaboration and exchange of information "open access" and "open data" principles should be used. To ensure that experiments can be easily repeated and evaluated by independent sources of inquiry, "open source" and "open reproducible research" principles should be implemented, as such a detail description of procedures and experiment set-up should be provided [24].

VII. Brain as an I/O machine

Human brain is a complex processing device that takes inputs from the environment, process it, and generate outputs. An artificial system that would apply the same processing method to same set of inputs should generate the same set of outputs (assuming no random parameters present in the system). A similar logic can be used for understanding the physiology of presence. Most research dedicated to development of quantitative metrics for assessing presence operates on the underlying assumption that a high degree of presence will result in a high correlation between outputs (i.e. physiological responses) observed in a real world, and these observed in a VE. For example, Meehan demonstrated similar, life-like responses to stressful stimulus in a VE, increasing with the 'realness' of the environment [1]. It is important to note that Meehan never claimed to prove a correlation between presence itself and physiological responses observed in the virtual precipice experiment. The observed changes in physiology were attributed to a stronger onset of the stressor, associated with higher fidelity of the VE. Changes in Heart Rate, Skin Conductance and body temperature were not a direct response to an increase in presence, but to an increase in 'realness' of the stimulus itself, that increased alongside environment 'realness'.

Based on the assumption that similar inputs should produce similar outputs (in the context of a hypothetical medium capable of producing inputs indistinguishable from real world stimuli), different outputs (including physiological response) between the real world and a VE would violate this underlying assumption, fundamental to this methodology. Therefore, while investigating physiological responses to presence, it seems logical to interpret deviations from physical environment baseline responses, as a manifestation of a decline in presence, or if it is possible, an increase above the level of presence observed in the real world. This rationale might have a profound implication on the methods used for analyzing results from previously completed studies. The nature of statistical tests is that certain assumptions must be made over what constitutes a success. Therefore, searching for a physiological response that would yield statistically significant results between responses to a high presence and low presence scenarios (i.e. H1 = mean high presence response – mean low presence response > 0), is unlikely to produce statistically significant results. However, the same data set analyzed with an alternative hypothesis set as a difference in physiological response between high presence and low presence scenario going in the other direction, chances of success should be much higher, particularly in one tailed tests. Similarly searching for a positive correlation between a deviation in physiological response and results obtained by qualitative means, in the context of a rationale presented above, suffers from a very similar issue. If any, such correlation should be negative: as self-reported presence increase, deviation from baseline physiology observed in real world should decrease. This result would support the notion that desynchronization between the model and the environment will likely result in an update of the model, such update will require energy, and in consequence manifest itself through a change in physiological state of the participant. Most likely observable through increased activity of the sympathetic nervous system.

Results of several studies that were investigating physiological responses to presence in VE can be used to support brain function theory approach to the concept of presence. Wiederhold and colleagues indicate an unexpected result in the direction of change in participants' Heart Rate (HR). Based on Meehan's work [1] authors were expecting an elevated HR being positively correlated with higher scores on self-reported presence questionnaire, however the opposite was true, participants who haven't marked the environment high on realism, demonstrated elevated HR [25]. This could be explained through an increased cognitive load imposed on the system when it attempted to associate sensory information with a model that had to be created for this environment. Different study reported lower HR in the experiment scenario, compared to the training scenario. Authors attempt to explain this result with the fact that participants were encouraged to move around the environment during the training phase and/or because participants were more comfortable in the experiment (bar) scenario compared to training scenario (unknown). An increase in Low Frequency (LF) and a decrease in High Frequency (HF) component of the Heart Rate Variability (HRV) was also reported [21]. These results might suggest a greater activation of the sympathetic system indicated by increase in LF observed in training phase. We hypothesize that such physiological response can be explained by the process of internalization of the new environment and a higher cognitive load associated with either updating an existing model or generating a new one.

Brain function theory approach can also be used to evaluate other types of presence. Uncanny valley theory suggests that interactions with non-human entities closely resembling humans can result in a strong sensation of distress, resulting from the system (the working brain) struggling to evaluate if it is interacting with a live human being or a machine. Therefore, it should be possible to observe similar processes as these occurring when the environment desynchronizes with the model. In consequence if the source of spatial presence differs from the source of social presence, social presence should be classified as a separate construct that is governed by a different set of rules than spatial presence, or it can be confirm that they all belong to a greater superset of presence if their origins and function are similar.

VIII. Knowledge exchange

The field of presence research is still maturing, sharing knowledge and increasing critical mass of the research community is urgently needed to accelerate this process. Therefore, an Open Science model for reporting experiments results and sharing as much data and designs as it's legally possible is suggested. To promote collaboration and exchange of information "open access" and "open data" principles should be used. To ensure that experiments can be easily repeated and evaluated by independent sources of inquiry, "open source" and "open reproducible research" principles should be implemented, as such a detail description of procedures and experiment set-up should be provided [24]. Such approach to reporting advancements in the field should promote exchange of knowledge between researchers from different disciplines.

IX. Interdisciplinary nature of presence

Research on presence is not contained within the field of Computer Science. It requires inputs from Psychology, Neurology, Physiology, Media studies and other disciplines that focus on human perception. Particularly an input from Neurology researchers is highly desirable. For more in-depth cover of the overlap between presence research and Neuroscience refer to Sanchez-Vives and Slater [26].

X. Neurology of presence

Whether presence is a subjective phenomenon solely associated with subjective experience or a brain function, its source is almost certainly contained within the human brain. Therefore, brain imagining techniques may provide the data obtained closest to the source of this phenomena.

Baumgartner and colleagues carried out two experiments, where participants experienced a noninteractive, arousing Virtual Environments (roller coaster ride) while their brain activity was monitored through Electroencephalography (EEG) [27] and functional Magnetic Resonance Imagining (fMRI) [28]. Results from the EEG based experiment suggest that a strong spatial presence might be associated with an increased activity in parietal/occipital areas of the brain. Furthermore, an activation in brain areas, associated with somatic nervous system activity, and areas responsible for visceral representation of processing emotions, was reported [27]. The occipital lobe is responsible for processing visual information, therefore its greater activation during high-presence experiment scenario might be related to the dynamic nature of fast-changing visual stimulus in high-presence scenario, compared to more static nature of the visual stimulus in baseline condition. Increased activation in the parietal lobe, an area of the brain responsible for integration of sensory inputs (specifically posterior parietal cortex area), can be used to support hypothesis of the sensory conflict imposed on a system when stimulus from multiple environments compete against each other. A 17-inch monitor was used in the EEG version of the experiment, which can explain a source of the sensory conflict and a consequent increase in the activity of the parietal lobe. Results from the fMRI version of the experiment, suggest that presence is likely to be associated with activity in dorsal and ventral visual stream, parietal cortex, premotor cortex, mesial temporal areas, brainstem and thalamus. Dorsolateral prefrontal cortex (DLPFC) was reported as the key node of the associated with the level of qualitatively assessed presence. The experiment revealed a significantly lower role of DLPFC on the network in children, and both experiments demonstrated a different activation patterns in children and adolescents. This result can be explained with prefrontal cortex not being fully matured in children [27] & [28].

Jäncke and his colleagues also report that qualitative measures of presence obtained through questionnaires, can be influenced by applying transcranial Direct Current Stimulation (tDCS) to dorsolateral prefrontal cortex (DLPFC). They hypothesize that similar effect can also be achieved by Transcranial Magnetic Stimulation (TMS) [29].

High presence and low presence scenarios, were used in the fMRI based experiment, where the low presence scenario used a horizontal planar version of the track used in a high presence scenario. It is hard to estimate to what extent the differences between high presence and low presence condition have loaded on the results of the experiment. EEG version of the experiment suffer from similar limitations flowing from discrepancies between baseline and experiment condition. Lack of isolation of presence from other variables, is impairing the specificity of results (as explained by the authors). Such approach can be used to focus our investigations on the areas of the brain that are taking part in the process of modulating presence, but are unlikely going to produce conclusive answers.

XI. Isolating presence

It is argued that lack of isolation of presence, as an independent variable, is the main reason why the construct of presence is proving so difficult to capture through quantitative means. For instance, in a study on the effect of frame rate on physiological response to presence, a significant outlier was present in 10 Frames Per Second (FPS) scenario, as the heart rate measure was greater at 10FPS than in 15FPS scenario [1]. Considering how taxing for participants' proprioceptive system low FPS environment might be, it is easy to see how it might have compound with the stressful stimulus arising from the original task of balancing on the ledge of a pit room. In this example, lower frame rate, which is almost certainly reducing presence [8] has most likely contributed to higher magnitude of the physiological response to the stressful stimulus.

In 1995, Schloerb proposed a simple comparison test (within-subjects design) for evaluating presence based on an argument that if a person cannot correctly identify whether the environment they are experiencing is real or virtual, then they must be present in that environment [30]. Data from qualitative assessments seems to suggest that achieving some degree of presence does not require such realism [8]. This might be explained by the capacity of the brain for filling-in the missing details. Since a system capable of such degree of 'realism' doesn't exist until today, some researchers have suggested adding perceptual noise to the physical environment to minimize discrepancies between virtual and physical environment [31]. If the Virtual Environment (VE) used in the experiment is the same as the physical environment where the experiment is taking place, we can treat the Virtual Reality as an augmented (mixed) one. This way some sensory stimulus from the physical environment can be used to subsidize missing olfactory, auditory and haptic sensory information, maintaining consistency between environments. For example, participants can experience lab room temperature, airflow and ambient noise of a physical lab room, while experiencing a virtual lab room. This way we can reduce variability between sensory inputs, and be able to evaluate presence in response to visual stimulus separately. Some could argue that regardless of how well the VE will mimic the real world, presence of the medium will still expose the artificial nature of the experience. However, if the nature of presence is subconscious, the fact that the participant is aware of the device is unlikely going to affect their presence on a subconscious level. This would be an important factor if the test would rely on the participants' verbal report and their capacity to recognize artificial environment from physical one as it was originally proposed by Schloerb, but since participants have little to no control over there physiology, such awareness shouldn't impact on their presence recorded through biofeedback. An impact of the device itself can also be measured separately and subtracted from the model by comparing participants' physiology in conditions with and without HMD. If participants eyes remain closed through both measurements the observed physiological difference should be associated with the effect of wearing HMD on biofeedback, and can be consequently subtracted from results. This way responses associated with the visual stimulus can be isolated, and its impact on presence should be clearly observable.

XII. Methodology

Experiment 1: evaluate the difference in physiology between maximum presence capacity (MPC) of the medium and investigate deviations from baseline recorded in the physical environment. The virtual environment (VE1) used in the experiment should replicate the physical environment (PE1) where the experiment is taking place. Participants baseline physiology should be recorded in PE1. Once this process is completed, participant will put on the HMD and 'move' to the VE1, where contrast physiological measurement can be obtained. Physiology during adaptation phase in VE1, should also be recorded and analyzed as the internalization phase is likely going to begin immediately after VE1 is perceived.

Experiment 2: investigate physiological response to declining presence. As in experiment 1, VE1 must replicate the physical environment (PE1) in which the experiment is taking place. First, baseline biofeedback must be recorded in VE1, at MPC level (see experiment 1 procedure). Range of properties of the VE1 (i.e. shadows, textures, dynamic lightning quality, fidelity of geometry, presence or absence of participants' body, refresh rate, etc.) can then be gradually degraded in separate experiments, while participants physiology is being recorded.

Experiment 3: evaluate usability of brain function theory, in the context of presence. Participants will first be exposed to a physical environment (PE1 - i.e. the room in which the experiment is taking place), and randomly assigned to either VE1 (VE replicating PE1) first, and VE2 (abstract VE) second, or reversed order scenario. Participants will then be exposed to two progressively building VEs. Complexity of the VE will be randomly progressively increased (from 0% to 100% geometry). The point where participants eye scanpath entropy decrease rapidly will be recorded as a threshold of minimum cues (as in [13]) calculated by dividing the number of polygons displayed at the threshold point by the total number of polygons in the VE. Same procedure has to be repeated for the other environment. To ensure that collected data can be easily compared between VE1 and VE2, the amount of geometry (total polygon count) in the abstract environment, should match the amount of geometry in the environment emulating familiar physical location. Both environments should build progressively at the same pace and polygons should be added at random order.

XIII. Analysis

In experiment 1, any deviation from baseline biofeedback recorded in the RE1 occurring when the participant is experiencing VE1 might be a manifestation of a cognitive load imposed on the participant as a result of desynchronization between the model and sensory information acquired from the environment. Consequent update of the model should be clearly observable in sympathetic nervous system activity. Participants' physiology observed in VE1 can be then associated with the maximum capacity of that set-up to invoke presence.

After the maximum capacity is established, results from experiment 2 can be analyzed. Deviations from participants physiology (recorded at maximum capacity), observed in response to degrading properties of the VE1, can be interpreted as a physiological response associated with decrease in presence. To confirm our hypothesis such response should be strongly correlated with the magnitude of degradation of the property. Each degraded property should be analyzed separately, regression analysis against qualitative results should reflect the impact on subjective presence associated with that property. Lack of a strong correlation between quantitative and qualitative results would suggest that one, or both (qualitative and quantitative) methods are invalid. Gradual decline in presence along gradual degradation of VE1 properties would indicate a scalar nature of presence, while a rapid change in participants physiology at some threshold point would indicate that presence is a boolean variable. No physiological response observed in result of this process might suggest constant nature of presence. Using the Low-resolution brain electromagnetic tomography (LORETA) it should be possible to locate areas of the brain that have altered activity in response to degradation of the environments properties.

Experiment 3 should be analyzed primarily through the entropy of eye scanpath movement. To confirm the hypothesis of retrievable mental models of the environment, and brains capacity to use previously developed models in new interactions, decrease in entropy should occur at the lower threshold (less geometry) for VE1 (familiar environment) compared to VE2 (abstract environment).

XIV. Future work

To increase mobility and reproducibility of these experiments a mobile lab that can be moved to a different data collection location, without the need for developing a new virtual environment that would correspond with the new location is required. It should increase research capacity to collect samples and allow global collaboration from any convenient location.

Quantitative results of previously completed studies, could be analyzed and discussed in the context of brain function theory. If the hypothesis of deviation from baseline, being a manifestation of desynchronization of the system (and consequent reduced presence) is correct, it should be possible to find statistical significance in some experiments that approached physiological responses to presence differently.

We believe the research community needs to continue refining the definition of presence. It was argued in previous paragraphs that a definition is needed, that will explain the function of presence and its nature along with its symptoms.

XV. Summary

We have discussed issues related to current definitions and the lack of consensus of presence. We argued the benefits for defining presence through its function rather than symptoms. We believe the research community is moving towards reliable quantitative methods for measuring presence. We have proposed a progression of three experiments (and how their results would be analyzed and interpreted) that will help clarify the understanding of presence, through quantitative metrics.
Modern day consumer-grade devices can deliver high-quality Virtual Environments with unprecedented levels of presence experienced by the users. To be able to progress from basic to applied research, we need to be able to investigate Virtual Environments equipped with tools that allow us to support our empirical observations with quantitative data.

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