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Agrewal, Sarvesh ; Simon, Adèle Maryse Danièle; Bech, Søren; Bærentsen, Klaus B.; Forchammer, Søren

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Defining Immersion: Literature Review and Implications for Research on Audiovisual Experiences*

SARVESH AGRAWAL[1,2], *AES Student Member*, **ADÈLE SIMON**[1,3], **SØREN BECH**[1,3], *AES Fellow*,
(sraj@bang-olufsen.dk) (adsi@bang-olufsen.dk) (sbe@bang-olufsen.dk)
KLAUS BÆRENTSEN[4], **AND SØREN FORCHHAMMER**[2]
(klaus@psy.au.dk) (sofo@fotonik.dtu.dk)

[1]*Bang & Olufsen a/s, 7600 Struer, Denmark*
[2]*Technical University of Denmark, Department of Photonics Engineering, 2800 Lyngby, Denmark*
[3]*Aalborg University, Department of Electronic Systems, 9220 Aalborg, Denmark*
[4]*Aarhus University, Department of Psychology, 8000 Aarhus C, Denmark*

The use of the term *immersion* to describe a multitude of varying experiences in the absence of a definitional consensus has obfuscated and diluted the term. The non-exhaustive literature review presented in this paper indicates that immersion is a psychological concept as opposed to being a property of the system or technology that facilitates an experience. An adaptable definition of immersion is synthesized based on the findings from the literature review: a state of deep mental involvement in which the individual may experience disassociation from the awareness of the physical world due to a shift in their attentional state. This definition is used to contrast and differentiate interchangeably used terms such as presence from immersion and outline the implications for conducting immersion research on audiovisual experiences. A new methodology for quantifying immersion is proposed and avenues for future work are briefly discussed.

0 INTRODUCTION

The field of spatial audio has grown over the last decade, leading to a plethora of words for describing new auditory experiences. Immersion is one of the terms that have gained prominence and established their dominance in the vocabulary. It is often equated to realism, naturalness, presence, and the sense of being surrounded, which has made immersion a vague and diluted concept. The ambiguity in the definition of immersion for audio applications was recognized by Berg [1], who acknowledged the convoluted nature of the concept and stated that "in addition to sound, other modalities contribute to immersion and that immersion is something more complex than just a listener being surrounded by any kind of sound(s)." Nevertheless, immersion continues to be confused with terms such as envelopment [2] for audio and acoustic applications since the distinction between the terms and the underlying ideas are not well documented. To conduct research on immersion for audiovisual experiences, there is a need to establish a clear definition of immersion.

Besides audio and acoustics, immersion has been studied in a variety of domains, including video games [3–7], virtual reality [8–11], music [12, 13], film [14–16], and literary works [17]. The use of immersion to describe a multitude of varying experiences and the lack of consensus on the use of terminology can lead to a mismatch between the idea to be investigated and the employed research methods [18]. Furthermore, the emergence of virtual reality and the interchangeable use with terms such as presence, involvement, and engagement creates a risk of confusion between the concepts [18]. Thus, it can be challenging to communicate and comprehend the idea to develop a better understanding of the subject. In order to communicate effectively, it is critical to formalize the meaning of immersion. The primary goal of this paper is to present an adaptable definition of immersion and highlight the implications for research on

*Presented at the 147th Audio Engineering Society Convention, New York City, United States of America, 2019 October 15–19. Correspondence should be addressed to Sarvesh Agrawal (sraj@bang-olufsen.dk).

audiovisual experiences. An overview of previous work on immersion is provided in Sec. 1, followed by a definition proposal in Sec. 2. Interchangeably used terms are contrasted and differentiated from immersion in Secs. 3 and 4. Sec. 5 outlines the subjective, behavioral, and physiological measures that have been used in the literature for measuring immersion. Finally, the implications for immersion research on audiovisual experiences are presented in Sec. 6, and a new methodology for quantifying immersion is proposed in Sec. 7.

1 CONCEPT OF IMMERSION

Although the exact origin of immersion's conceptualization is not known, Murray [19] described the concept as follows:

> *Immersion* is a metaphorical term derived from the physical experience of being submerged in water. We seek the same feeling from a psychologically immersive experience that we do from a plunge in the ocean or swimming pool: the sensation of being surrounded by a completely other reality, as different as water is from air, that takes over all of our attention, our whole perceptual apparatus ([19], p. 99).

Murray expressed that immersion is not simply the outcome of the intensity of the sensory stimulation. She proclaimed that a stirring narrative can deliver immersive experiences even with a limited amount of sensory input, such as in the case of books [19]. While Murray considers attention, a psychological factor, in her illustration of immersion, it has been argued that immersion is purely an objective property of the technology or the system that facilitates an experience [20–22].

Based on a review of previous studies, there are two major perspectives on immersion: an individual's psychological state and an objective property of a technology/system. These have been deduced by surveying articles from a variety of domains, including (but not limited to) multimedia [14–16], psychology [23], telepresence [24], video games [3–7], and human-computer interaction [6, 25]. An overview of these perspectives is provided in the next subsections.

1.1 Immersion as an Individual's Psychological State

Psychological immersion, similar to Witmer and Singer's [24] idea of involvement, is understood as a user's psychological state when they are involved, absorbed, engaged, or engrossed [25]. In McMahan's [26] words, "immersion means the player is caught up in the world of the game's story (the diegetic level);" she added, "[immersion] results from the user's mental absorption in the world." McMahan de-emphasized the role of the system while focusing on the individual and the narrative. Correspondingly, Thon [27] determined that "what is presented is more important than how it is presented [for a user to experience immersion]." This idea is exemplified by the experience of reading books where the sensory input from the stimulus is limited relative to multisensory experiences but the narrative and/or relevance of the narrative to the reader can immerse the reader in the act of reading.

In the context of video games, Sanders and Cairns [3] established that immersion results from focusing one's attention, thoughts, and goals toward the game. The notion of 'shift of attention' is central to the concept of immersion according to Thon [27], who stated that it is the shift of attention along with the construction of mental representation in the brain that leads to an immersive experience. Brown and Cairns [4] discovered that immersion is the degree to which a user is involved with a game. They suggested that the degree of involvement varies with time and is controlled by barriers that can be cleared through human activity, such as concentration.

In the following paragraphs, the three recognized reasons that can lead (independently or along with other reasons) to psychological immersion are described. These are the subjective sense of being surrounded or experiencing multisensory stimulation, absorption in the narrative or the depiction of the narrative, and absorption when facing strategic and/or tactical challenges.

1.1.1 Subjective Sense of Being Surrounded or Experiencing Multisensory Stimulation

One of the prevalent conceptualizations of immersion is the sense of being surrounded or experiencing multisensory stimulation. Biocca and Delaney [28] dubbed this *perceptual immersion*: the extent of submersion of the user's perceptual system in the environment. It is believed that perceptual immersion can be measured objectively by "counting the number of the user's senses that are provided with input and the degree to which inputs from the physical environment are shut out" [29]. McMahan [26] stated that perceptual immersion can be achieved by blocking the external world and constraining the user's perception to the presented stimulus.

The role of sensory information in immersive gaming experiences was recognized by Ermi and Mäyrä [30] for the development of a gameplay experience model (sensory, challenge-based, and imaginative immersion model or SCI model). The authors called it *sensory immersion*: an overpowering of the sensory information from the real environment through large screens and powerful sounds to focus the user entirely on the stimulus. In their study on presence, Witmer and Singer [24] made the distinction between immersion and involvement, such that the former is the subjective experience of being enveloped in an interactive environment and the latter is a psychological state that results from directing attention to the stimulus.

It may appear that what many researchers call perceptual or sensory immersion is a completely different perspective on immersion compared to psychological immersion. Nevertheless, it is instead a facilitator for psychological immersion, since overpowering sensory information or blocking the stimuli from the immediate environment does not guarantee psychological immersion but can prevent "an exogenous shift of attention" [27] away from the

activity, consequently leading to psychological immersion. This can explain why the current trend for creating supposed immersive audiovisual experiences is largely based on this idea of eliciting immersion (e.g., virtual reality, interactive audiovisual experiences, spatial audio, etc.).

1.1.2 Absorption in the Narrative or the Depiction of the Narrative

A number of studies draw attention to the importance of the narrative for immersive experiences. Adams and Rollings [5] conceptualized immersion in a story as "the feeling of being inside a story, completely involved and accepting the world and events of the story as real." In the context of video games, Ermi and Mäyrä [30] acknowledged the importance of the story elements that can mentally absorb the player for experiencing immersion. They called this *imaginative immersion* on the premise that the player has an opportunity to exercise their imagination based on the narrative of the game. It was argued by Arsenault [31] that imaginative immersion should be modified to *fictional immersion*, since one does not need to exercise their imagination to be immersed in the story. The different views on narrative immersion were summed up by Thon [27]: "narrative immersion refers to the player's shift of attention to the unfolding of the story of the game and the characters therein as well as to the construction of a situation model representing not only the various characters and narrative events, but also the fictional game world as a whole."

Ryan [17] categorized narrative immersion into spatial, temporal, and emotional immersion. *Spatial immersion* is experienced when an individual has a strong sense of space and enjoys the act of exploration. *Temporal immersion:* focused attention to the unfolding story [27] results from an individual's curiosity to know what happens next. Finally, *emotional immersion* occurs due to an individual's emotional attachment to the characters or story [17]. It is strongest when an individual can relate to the presented situation and is emotionally invested in the story or characters.

1.1.3 Absorption When Facing Strategic and/or Tactical Challenges

The influence of challenges on the experience of immersiveness is a closely examined topic, since a considerable portion of immersion research is focused on video games. Ermi and Mäyrä [30] explained immersion in response to challenges as mental absorption, which is reached due to a balance between challenges and abilities. They stated that challenges can be related to strategic planning or thinking as well as motor skills. Adams and Rollings [5] classified immersion due to challenges as *strategic immersion* and *tactical immersion*. The former can be observed when a player is absorbed in strategizing, calculating, and making choices while tactical immersion refers to the immersion that is encountered when one is completely attentive to the task at hand due to a stream of demands for quick reactions (e.g., playing video games that require swift tactile movements).

Arsenault [31] asserted that one does not have to be challenged in order to be immersed. He proposed to modify challenge-based immersion to *systematic immersion:* it occurs when a player accepts the game's system (rules, laws, etc.) while rejecting the laws of physics as observed in the real world. Arsenault's idea of systematic immersion is applicable to non-participatory activities,[1] such as watching fictional movies where one is not necessarily challenged by the content and may accept the existence of magic, for example.

In contrast to the idea of immersion being an individual's psychological state, an alternative outlook on immersion is the conception of immersion as an objective property of the system/technology that facilitates an experience. This perspective is discussed below.

1.2 Immersion as an Objective Property of a System/Technology

Proponents of this view advocate that immersion is a set of characteristics of a system that can be objectively determined and quantified. In 2003, Slater [21] expressed:

> Let's reserve the term "immersion" to stand simply for what the technology delivers from an objective point of view. The more the system delivers displays (in all sensory modalities) and tracking that preserves fidelity in relation to their equivalent real-world sensory modalities, the more that is "immersive."

Slater rejected the notion that immersion is a subjective experience. His description implies that increasing the number of channels and loudspeakers augments immersiveness, irrespective of the content, context, and individual preferences. An apparent shortcoming of this conceptualization is that it does not account for perceptual limits, content, context, and individual factors such as preference and mood. Slater's description can be summarized as *fidelity* and does not necessitate the use of the term immersion.

The conceptualization of immersion being an objective property of a system/technology is closely related to sensory/perceptual immersion. A change in the physical properties of the system facilitating the experience (addition of modalities, increase in the number of audio channels, etc.) can augment the sensory information. This change can lead to psychological immersion if it captures the user's attention and/or prevents a shift of attention away from the stimulus, as stated in Sec. 1.1.1. Therefore, it can lead one to believe that immersion is an objective property of the system and directly dependent on its physical parameters as opposed to being a psychological phenomenon.

It is important to mention that the conviction of immersion being an objective property of a system/technology is held by a minority in the literature. It has been proposed that the term *system immersion* [32] can be used to distinguish this view on immersion from the others.

[1] In this paper, non-participatory activity refers to an activity in which the user input or feedback does not influence or alter the outcome of the activity, such as in a traditional movie-screening.

2 PROPOSED DEFINITION

The motivation for studying immersion is to recognize the influencing factors so that they may be varied to augment experiences. Hence, it is crucial to establish a definition of immersion based on which the underlying phenomenon can be investigated. In this section, an adaptable definition of immersion is proposed and illustrated using *immersive potential* and *immersive tendency*.

The conceptualization of immersion being an objective property of the system may not always lead to a perceptual difference, rendering it insignificant for the goal of augmenting experiences. Slater's conception of immersion [20, 21] relies on the availability of an external system because it is highly focused on virtual reality applications. This restricts the generalizability of the concept. The role of the individual is of paramount importance since experiences are, by their very nature, subjective. Additionally, the belief that immersion is an objective property of the system or technology that facilitates an experience is held by a minority in the literature. Hence, the notion of immersion being a property of a system/technology can be rejected. Taking into account the wide range of fields where immersion is applied, the following definition is proposed:

> Immersion is a phenomenon experienced by an individual when they are in a state of deep mental involvement in which their cognitive processes (with or without sensory stimulation) cause a shift in their attentional state such that one may experience disassociation from the awareness of the physical world.

This definition has been synthesized using the descriptions of immersion presented in Sec. 1 through 1.1.3. The authors emphasize that immersion is a psychological phenomenon and the idea of attention being central to the concept of immersion is maintained in the proposed definition. Disassociation from the awareness of the physical world is determined to be an important aspect of immersive experiences (see Sec. 5.2 and references in Sec. 1) and thus is included in the definition.

We consider immersion to be a normal occurrence of focused attention during waking consciousness. During immersion, the mind is absorbed in the current motivated activity and conscious attention is focused on the features of the situation that are related to the achievement of the intended goal. Still, during most normal circumstances the mind can easily be disturbed by extrinsic factors (e.g., noise in the environment), intrinsic dynamic tendencies (e.g., unfinished tasks or obligations), and random noise. Unlike hallucinations and dreaming during sleep states, the mind is still attentive or watchful (to some degree) to the occurrences in the world and monitors the present state of the body when immersed in a construction built by intrinsic factors. When something of significance for the maintenance of the subject's life and well-being occurs, the perturbations may usually rather easily destabilize the current state, change the focus of attention, and propel the mind into another and more stable attractor of orientation and search for the nature of the disturbance. For detailed discussions of consciousness, the reader is referred to [33–37].

Involvement in the current view necessitates an interaction between the subject and system not only in a physical sense (the completion of a series of actions and operations upon the system) but also in a psychological sense (the interaction between the subject's motives for the interaction with the system and the system's objective capabilities for the pursuit of the subject's motives). Based on the proposed definition, immersion is a mental state, which is why sensory stimulation is not required to experience immersion (for example, daydreaming can be an immersive experience).

It is important to consider all sensory modalities for determining immersion since the presented stimuli may stimulate only a few senses but humans continue to receive input from all the senses, which can influence immersion. Therefore, all the factors that can either facilitate or disrupt immersion must be considered. It is unreasonable to merely examine the stimulus or system to determine immersion. While the system and content can affect immersion, they are not immersive independent of the human subject. The idea of immersive potential can add clarity to the above explanation.

Immersive potential: The potential of a system or content to elicit immersion.

For a given piece of content presented by a system that does not change, the immersive potential remains constant. It does not simply increase with the betterment of the system's technical specifications. Instead, it depends on its ability to elicit immersion. The immersive potential is barred by the human perceptual limits and the changes to a system must lead to a discernible perceptual change to alter its immersive potential.

In addition to the system and content, immersion also depends on the state of the individual at the moment in time as well as their immersive tendency.

Immersive tendency [24]: An individual's predisposition to experience immersion.

It can be assumed that the immersive tendency of an individual remains constant during the course of an experiment that is conducted over a short duration of time.[2] The immersive tendency can be determined with the help of questionnaires [24, 38] to learn if certain individuals can get immersed relatively easily compared to others.

The five factors that can influence immersion are 1) the system (physical properties of the reproduction system and the content); 2) narrative (content); 3) environment (physical environment and the contextual conditions); 4) individual factors (affective states, mood, preference, skills, previous knowledge, expertise, goals, motivation, etc.); and 5) interaction between the individual and the experience (sig-

[2] Immersive tendency can change over time due to training, learning, experience, changes in personality, etc. Since these factors do not normally vary within a short duration of time (e.g., over the course of a few days), these can be assumed to be constant for conducting experiments.

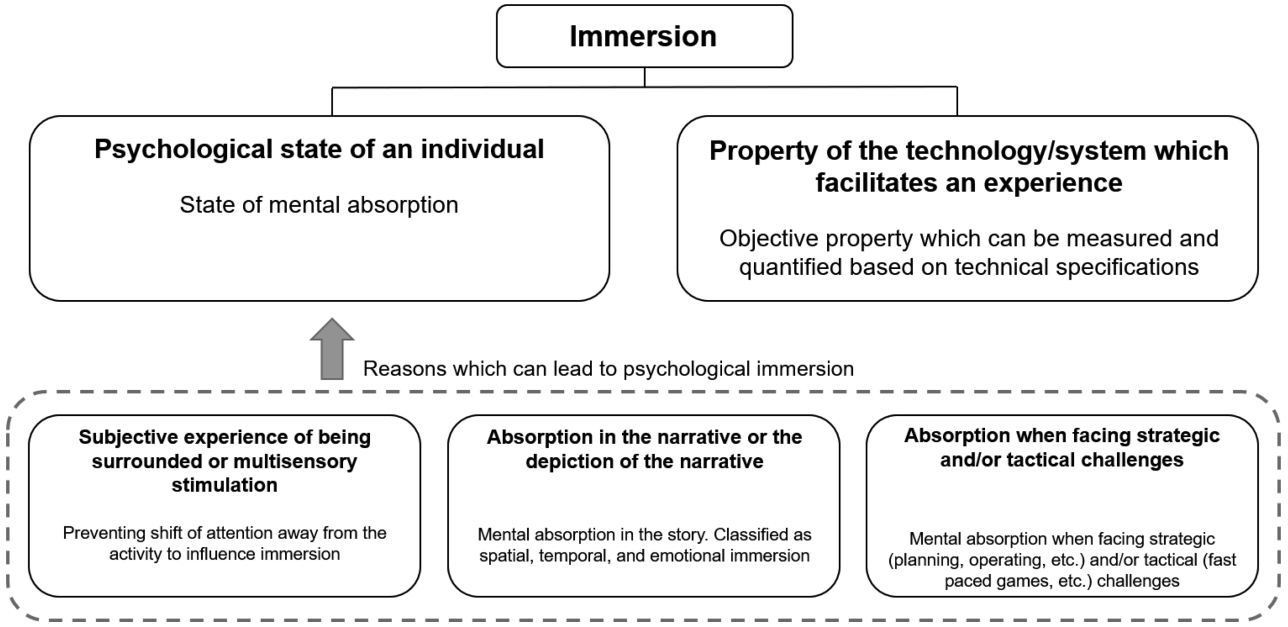

Fig. 1. Summary of the literature review presented in this paper. The reasons that can lead to psychological immersion are often classified as different types of immersion (see [18]).

nificance of the content to the individual, acceptance of the task, and alignment of goal and motivation). These are similar to those that affect the quality of experience (QoE) [39] since immersion is an experience that is dependent on an individual's cognitive state and preference for the content. Nonetheless, the concepts of QoE and immersive experiences should not be confused. An experience must elicit immersion to qualify as an immersive experience while the QoE, theoretically, can be assessed for any experience.

3 OTHER COGNITIVE CONCEPTS

As noted previously, immersion is often used interchangeably with presence, flow, and transportation. In this section, different concepts are weighed and distinguished from immersion based on the proposed definition.

3.1 Presence

Presence has been a crucial research topic in video game and virtual reality studies since the 90s and has been used to describe experiential phenomena in a range of diverse realms such as communication, engineering, psychology, and philosophy [18]. Although presence is often simply conceived as the shortened version of *telepresence*, Steuer [40] distinguished the two terms such that the former is the experience of being in the immediate physical environment while telepresence is the "mediated perception of an environment." Nevertheless, modern use of the term signifies a feeling of "being in one place or environment, even when one is physically situated in another [24]," while the term telepresence is primarily used for teleoperation and teleconferencing applications.

Presence has been defined as "the psychological sense of being in a virtual environment;" [22] "[the] extent to which a person's cognitive and perceptual systems are tricked into believing they are somewhere other than their physical location;" [41] and the feeling of being in the game [4, 42–46]. This is evidence that the term presence refers to the sense of being present in an environment that is not purely the physical environment around us. In addition to physical presence (stated definitions refer to the feeling of being located in a mediated environment), presence is also classified as social presence (the feeling of being together, such as through e-mail or telephone) and co-presence (intersection of physical presence and social presence; examples include shared virtual environments, videoconferencing, etc.) [47]. Nonetheless, with a growing number of virtual reality and multisensory applications, presence generally refers to physical presence.

Jennett et al. [6] stated that a double disassociation exists between immersion and presence. For instance, one can be immersed when listening to electronic music but may not feel present due to a lack of spatial cues in the content, limited spatial capabilities of the reproduction system, etc. On the other hand, playback over headphones of a binaural recording of restaurant ambience can make one feel as if they are present at the restaurant, but such a scenario would most likely fail to immerse the listener due to the rendering system and the content's low immersive potential. This double disassociation can also be observed in participatory activities such as the one that Jennett et al. [6] illustrated through the example of playing Tetris (an abstract game) on a 2D screen. It is unlikely that the player will feel present in an environment where blocks fall around them; however, the player can still be immersed in the activity. Even so,

when asked to perform a boring task in a virtual simulation, one can feel present in the environment but not be mentally involved. Thus, immersion will be absent. It is worth noting that immersion and presence can be experienced simultaneously, such as when listening to a highly spacious recording of one's favorite classical music piece or playing an engaging game in virtual reality.

3.2 Transportation

Transportation is a term that is used when studying narrative worlds to describe the feeling that is commonly described as being lost in the story. It has been defined as "immersion or absorption into a narrative world" [48] and as a "state of detachment from the world of origin" [49]. Discussions of transportation are similar to those of immersion: the idea of being in a different world, through media (here, any form of narrative), and experiencing disassociation from awareness of the world of origin. Although an attempt has been made to spot subtle differences between the concepts of immersion and transportation [49], there is a lack of adequate and conclusive evidence. Consequently, transportation can be viewed as immersion, which is fundamentally focused on the narrative.

3.3 Flow

The concept of *flow* was pioneered by Csikszentmihalyi, who defined flow as "the state in which people are so involved in an activity that nothing else seems to matter; the experience itself is so enjoyable that people will do it even at great cost, for the sheer sake of doing it" [50]. He identified the balance between ability and challenge, concentration/attention, clear goals, immediate feedback, escape from everyday life, sense of personal control (lack of a sense of worry), loss of self-consciousness, and altered sense of time as the eight components of flow [50]. Nevertheless, the minimum requirements that qualify an experience as a flow experience have not been established [51]. The descriptions, causes, and symptoms of a flow experience are inconsistent in the literature and should be approached with caution. In addition, some of the components, such as the balance between ability and perceived challenge, are open to interpretation, hindering the qualification of experiences.

Michailidis et al. [46] suggested that there is a lack of evidence to conclude that immersion and flow are dissimilar concepts. However, even though there is an overlap between the two concepts, they should not be considered synonymous. The literature suggests that flow is an "all-or-nothing" experience [52] while immersion is a graded experience (see Sec. 7 for future investigations on the nature of immersion) [4]. Flow is an extreme experience [3, 6, 53], which limits it to optimal, positive experiences. Additionally, the absence of key components of flow (e.g., balance between ability and challenge, clear goals, and immediate feedback) in activities such as watching a movie or listening to music essentially disqualifies passive activities as flow experiences. Naturally, a piece of music or a movie can certainly engage the user and induce immersion, exemplifying that flow and immersion are independent ideas.

4 DISTINCTION BETWEEN ENVELOPMENT AND IMMERSION

Envelopment is a widely studied topic in concert hall acoustics. With the growing popularity of spatial audio, however, envelopment is being used in a much broader sense for audio and acoustic applications. Francombe et al. [2] found that 90 percent of the participants felt that envelopment and immersion were synonymous in an experiment conducted for determining the attributes of different spatial audio reproduction methods. This can be explained by the use of the analogy 'experience of swimming underwater' for describing both immersion and envelopment. Rumsey [54] classified envelopment as *environmental envelopment* and *source-related envelopment*. Environmental envelopment, also known as listener envelopment (LEV), is the feeling of being surrounded by the reverberant sound field while source-related envelopment can be defined as "envelopment by one or more dry or direct foreground sound sources" [54]. LEV is primarily dependent on late arriving reflections [55] while source-related envelopment can be experienced when sounds are placed around the listener [56].

Although the differences between immersion and envelopment are often considered to be subtle, there is a noteworthy distinction: envelopment is perceptual whereas immersion is cognitive, because unlike envelopment, immersion accounts for cognitive factors and is based on an integrative frame of mind. Furthermore, a double disassociation exists between immersion and envelopment. For instance, monophonic reproduction of one's preferred music can deliver an immersive experience but would not be reported as being enveloping. In contrast, reproduction over headphones of a binaural recording of restaurant ambience can be perceived to be enveloping but will likely fail to immerse the listener due to a lack of engaging narrative and low immersive potential. Hence, one can be immersed when envelopment is absent and vice versa.

Following the proposed definition and outlining the differences between the interchangeably used terms and immersion, the succeeding section presents an overview of experimental paradigms for measuring immersion. These methods include subjective measures (questionnaires), physiological measures, and behavioral measurements.

5 MEASURING IMMERSION

The challenge with measuring immersion is multifold: the absence of a definitional consensus, a lack of knowledge regarding the causes and attributes of immersion, and the inability to ensure that the assessors were immersed in an experience. The fragile nature of immersion [19] also adds to the complexity of measuring immersion.

The following sub-sections provide an overview of experimental paradigms and discuss their advantages and limitations for quantifying immersion. Please note that the definition of the terms immersion and presence may differ from those determined earlier in Secs. 2 and 3.1 due to a lack of definitional consensus.

5.1 Questionnaires

Post-experience questionnaires are attractive as they do not interfere with the experience and are easy for the participants to use. Questionnaires developed for measuring presence [24, 25, 57–59], engagement [42, 60], and transportation [48] with immersion as a factor under investigation can be adapted for measuring immersion. The multidimensionality of the concept, nonetheless, varies the particular dimension (narrative, system, etc.) examined by these questionnaires (see [25, 61, 62]). In addition, many of the questionnaires are context specific (video games, virtual reality, audiovisual, books, etc.) and cannot be adapted directly. For instance, questionnaires based on transportation or narrative engagement principally focus on the narrative of the content while those for video games [6, 42, 61, 63] are aimed at interactive experiences. To navigate this issue, Lessiter et al. [59] developed the Independent Television Commission Sense of Presence Inventory (ITC-SOPI), which is independent of the media system and the content properties and similar in concept to the Measurement, Effects, Conditions Spatial Presence Questionnaire (MEC-SPQ) proposed by Vorderer et al. [58].

Questionnaires developed for quantifying immersion and presence often have a long list of items for evaluation with overlapping concepts (see [6, 24, 62, 64]). It has been suggested that the measurement items in existing questionnaires should be viewed as a modular system and only the minimum set of items required to fulfill the task should be selected [65].

A shortcoming of post-experience questionnaires is that they can lead to inaccurate recall and recency effect [66]. In addition, they bar the measurement of temporal variations of immersion and presence. IJsselsteijn et al. [67] attempted to measure the variation of presence over time using a slider, which can disrupt the sense of presence by including elements from the real environment in the virtual experience and hence lead to inaccurate measurements.

5.2 Physiological and Behavioral Measures

Physiological and behavioral measures provide an objective and non-invasive way to measure immersion. Results from such measurements must be interpreted prudently, as the relationship between the concepts (immersion, presence, etc.) and their suspected attributes (spatial and temporal disassociation, altered emotional state, etc.) are not well-established.

Several studies have suspected *a lack of awareness of the non-mediated world* to be one of the fundamental attributes of immersion [27, 48, 68]. This can be investigated through various behavioral and physiological methods. On the behavioral level, *secondary task reaction time (STRT)* [69–71] can be used to measure attention to the non-mediated world. The assumption for immersion research is that if the cognitive resources are primarily allocated to the mediated experience, less attention would be available for other tasks. Thus, the reaction time for the secondary tasks will be longer. However, Klimmt et al. [69] reported a weak negative correlation between attentional measures and the STRT responses that contradict the assumption stated above.

On the physiological level, Haffegee and Barrow [72] and Cox et al. [73] have recommended eye tracking to investigate the attentional attributes. Jennett et al. [6] found different fixation patterns between immersive and non-immersive conditions, which was supported by Wissmath et al. [74]. Nevertheless, the results of eye-tracking measures on immersion are sparse and further research is required to understand the underlying relationship.

A lack of awareness of the non-mediated world can also be viewed as an alteration of time perception [4, 6, 75]; however, the links between immersive experiences and time perception are unclear [4].

Brain responses have been proposed to measure immersion in a non-invasive manner. Electroencephalography (an EEG test) has been conducted to measure event-related potential [76] and brain oscillations [77] as a measure of immersion. Attempts have also been made to measure presence with functional magnetic resonance imaging (fMRI) [78–80] and EEG [81, 82]. Michailidis et al. [46] found that flow and immersion may share some neural mechanisms different from the ones associated with presence.

It is believed that immersion can also be investigated via emotions [6, 48, 60, 61], under the assumption that immersive experiences affect the emotional state of an individual. Nonetheless, the results obtained through studies based on electro-dermal activity (EDA) [83–85] do not provide evident conclusions.

Thus, physiological and behavioral measures can be explored to measure immersion physically and in non-invasive ways. The results should be interpreted carefully due to the exploratory nature of such studies and the lack of evidence confirming the links between the concepts to be assessed and the measured attribute(s). A drawback of physiological measures is that they often require specialized equipment, controlled laboratory environments, and qualified experts to operate the equipment, rendering them expensive and time consuming.

6 IMPLICATIONS

The literature review illustrates that there is a difference of opinion among researchers that must be resolved to develop a common understanding of the term across disciplines. Even though absorption in the narrative, absorption when facing intellectual and/or tactical challenges, and the sense of being enveloped have been viewed as reasons that lead to psychological immersion in this paper, additional research is required to analyze if the phenomena they cause warrant the classification of psychological immersion.

The proposed definition and explanation presented in Sec. 2 have several implications for researching immersion in audiovisual settings. These implications are discussed in the following sub-sections.

6.1 Stimuli

The relevance of the narrative to the individual plays an important role in determining the possibility of experiencing immersion. Since the relevance of the same content can vary among individuals, it should not be assumed that a particular stimulus will immerse all the assessors under consideration. Furthermore, there is no guarantee that an assessor will experience immersion in every trial for a given stimulus since every trial modifies the knowledge and expectations of the stimulus. Such modifications could potentially lead to bias, influencing the likelihood of experiencing immersion when a stimulus is repeated. Given the lack of understanding regarding the experience of immersion when a stimulus is repeated, it is important that the assessors evaluate a stimulus only once in an experiment until further research is conducted. Participants' familiarity with the content should also be documented and accounted for in the analysis. Hence, to achieve the desired statistical power, there must be a sufficient number of experimental subjects and stimuli (with a variety of narratives) for assessment, since repetitions cannot be performed.

The length of the stimuli is another major factor in the assessment of immersion. Considering the limited knowledge regarding the temporal nature of immersion and the time required being immersed, it has been proposed that the stimuli must be at least several minutes (10-15 minutes as per ITU-T P.809 recommendation) long for evaluating immersion [86]. Zhang et al. [64] found that the seven-minute duration led to greater spatial immersion overall as compared to three and eleven-minute duration in an experiment with three stimuli. We suspect that for non-participatory experiences, stimuli between five to twelve minutes should be used to allow sufficient time for the narrative to develop and the assessor to reach the state of immersion.

It is imperative to use audiovisual stimuli that do not require prior knowledge about the presented narrative to avoid disinterest and confusion. While it can be difficult to find content that can be used as a standalone excerpt and resolve in a matter of minutes, we suggest that excerpts from nature documentaries are a good starting point.

6.2 System

Studying the immersive potential systems is of great interest to researchers and engineers. A deeper understanding of immersive potential can help to improve technical systems such that they can have a greater influence on the experience of immersion. To investigate immersion in spatial audio, Aspöck et al. [87] used the questionnaire developed by Colsman et al. [88] that assumes attribution (causality), attention, room perception, and source perception to be the four key aspects that influence immersion. These factors are different from the factors identified in Sec. 2 due to a difference in the definition of immersion. An apparent shortcoming of such an approach is that there is a risk of measuring the presumed aspects rather than immersion due to a lack of information regarding the links between them. The measured phenomenon may be different from immersion since the experience is not assessed to verify its qualification as an immersive experience. Similarly, surveying professionals to identify the system factors that influence immersion [89] perpetuates the general understanding of the term rather than assessing the underlying framework. We assert that although the system can influence immersion, it is not the determining factor for every experience.

6.3 Experimental Paradigm

The primary challenge in quantifying immersion is the lack of suitable measurement methods. Although physiological and behavioral measures are attractive to objectively quantify immersion, a lack of validated methods restricts research to subjective assessment techniques for the evaluation and quantification of immersion [65]. Physiological measures can be used to complement subjective assessment to assess emotional states, fatigue, etc. [90].

Subjective assessment of audiovisual experiences has been explored extensively (see [91–93]). Many measurement techniques such as the multiple stimuli with hidden reference and anchor (MUSHRA) [94] allow the participants to switch between stimuli and provide relative judgments. Unlike methods designed for sensory evaluation or factors that do not lead to an altered mental state, subjective assessment of immersion must be performed post-experience to prevent the infringement of the immersive state. Accordingly, the authors of this paper suggest that comparative judgments should be avoided in favor of absolute rating methods. There must be sufficient time between stimuli to ensure that the assessors are not mentally caught up in past experiences. The time required for individuals to return to their initial psychological state must be determined experimentally. Distractor tasks or stimuli in the same modality as the experimental stimuli can be incorporated in experiments to help the participants return to their initial psychological state before every experience.

Immersion experiments can get substantially lengthy with the addition of every new stimulus. It is known that participants in non-interactive tests such as those that involve experiencing audiovisual presentations suffer from fatigue faster than in interactive tests [86]. The experiments for every assessor should be completed in one session to avoid changes to individual factors, thereby limiting the number of stimuli that can be evaluated by each participant. To overcome this, a between subjects design or a blocked within subject design can be used to reduce fatigue, avoid repetitions, and limit the time commitment for each assessor.

The system, narrative, environment, individual factors, and interaction between the individual and the experience were identified as the five components that can influence immersion in Sec. 2. When assessing the experience of immersion for a set of stimuli presented over a non-dynamic system and environment, immersion is dependent on individual factors (immersive tendency and the state of an individual at the time of experience), the stimuli (narrative, artistic choices made in production, etc.), and their subsequent interaction (the significance of the content to the individual, etc.). While immersive tendency can be gauged

by questionnaires, fluctuating factors such as mood, preference, and affective states are rather difficult to assess. The significance of the content to an individual is largely unquantifiable, adding to the complexity of assessing immersion.

7 PROPOSED METHODOLOGY AND FUTURE WORK

The literature review presented in Sec. 1 suggests that immersion is a multidimensional concept. Nevertheless, the dimensions identified in the literature are largely based on qualitative studies for interactive activities and cannot be generalized for the concept of immersion. The dimensions of immersion may be dynamic and change according to the application (e.g., absence of challenge when watching a movie as opposed to when playing video games). Thus, we propose a top-down approach where the relevant dimensions of immersion are obtained based on the application (in our case, audiovisual experiences). To determine the dimensions underlying immersion, we recommend methodologies inspired by sensory analysis techniques that have been proven to be effective and successful for audiovisual applications (see [91, 92] for an overview).

Before immersion can be evaluated, it must be determined whether immersion is a binary or graded experience. This step is critical to pick the appropriate response format (scale and scaling method) for conducting experiments. The hypothesis for determining the nature of immersion can be that immersion is a binary experience for non-participatory audiovisual experiences. If true, this would imply that the assessors report all experiences under consideration to either be immersive or not immersive. The initial condition to test the hypothesis would be that subjective evaluation of a number of experiences by various assessors is conducted and the results accurately represent the encountered degree of immersion. The stimuli used for creating the experiences must be spaced appropriately across the immersive potential scale to cover the entire immersion spectrum. Since there is no objective measure of immersive potential, the choice of stimuli and its spacing must be determined experimentally. A continuous scale should be used for the assessment to provide the participants with sufficient steps to respond. The results obtained from the investigation can be checked for multimodality using statistical tests such as Hartigan's dip test [95] and Silverman's mode estimation method [96].

Evaluation scales implemented for sensory evaluation in food science can be used for assessing immersion and determining the nature of immersion. An unstructured line scale for Quantitative Descriptive Analysis (QDA) was selected in [97]. It is six inches long with word anchors at a half-inch distance from either end. The participants are instructed to insert a mark on the scale according to their perception. The distance of the mark from the left end of the scale is then used as the numerical rating for computation. This scale can be adapted for evaluating immersion by disregarding the word anchors to reduce bias and substituting them with end-points a half-inch from either end. The intensity of immersion increases from left to right. Analysis of variance (ANOVA) can be used for statistical analysis of scores obtained from the line scale [97]. Nevertheless, other quantitative methods for the analysis of interval data can also be employed.

The unstructured line scale can work well if immersion is determined to be a graded experience. For binary experiences, a categorical scale can be incorporated. The only options available to the assessors are yes/immersive and no/not immersive. The analysis of categorical data has been discussed at length in [98].

For experiments where only immersive experiences are to be assessed, all experiences must be classified as either immersive or non-immersive. This step is critical to ensure that immersion was elicited during the assessed experience to avoid erroneous measurements. A qualification filter must be designed to filter out non-immersive experiences. This can be achieved by providing a description of immersion to the participants and asking if immersion was encountered in the experience. As a result, only the experiences reported as being immersive must be included in the analysis. Since previous knowledge of the stimuli can influence the results, participants' knowledge of the stimuli must be recorded, reported, and accounted for in the analysis.

Quantitative assessment of immersion can be complemented with a verbalization task to obtain descriptors for the experience, similar in concept to the techniques used for sensory analysis of sound (see [91, 92]). Verbalization not only helps in extracting the dimensions underlying the concept of immersion but also in understanding the assessor's understanding of immersion and gauging the inter-participant alignment of the empirically established evaluations made by the participants. Data obtained from verbalized descriptions of experiences can be analyzed using Verbal Protocol Analysis (VPA) [99] for their "logical sense, stimulus-relatedness and semantic aspect" [99]. Additionally, the descriptors can be grouped and reduced using the many techniques implemented for sensory analysis as described in [100]. Finally, an open-ended questionnaire or short interview session should be incorporated in the experimental paradigm to gather feedback and amend the method.

Successful implementation and validation of the described method can pave the way for assessing immersion for a variety of audiovisual experiences, including those in virtual reality. An important research question is to determine if and how the three reasons that lead to psychological immersion (see Sec. 1) influence immersion for audiovisual applications. Spatial audio reproduction is an interesting scenario to evaluate immersion. The influence of envelopment on immersion for delivering engaging auditory experiences can be assessed to compare and benchmark various spatial audio systems. Future work should investigate the influence of physical parameters of the system (e.g., video screen resolution, number of channels in the audio rendering system, etc.) on the experience of immersion in audiovisual environments.

Presence or place illusion is seen as the most important factor for virtual reality (VR) applications. Nonetheless, immersion in VR experiences can be evaluated to determine the mental absorption along with presence. Consequently, determining the relationship between presence and immersion in audiovisual applications can be beneficial in advancing our understanding of the subject and harnessing the results for delivering enhanced experiences. The idea of immersive tendency and how it may relate to immersion was presented in Sec. 2. Future endeavors should aim at quantifying the role of the individual for experiencing immersion and explore novel ways to capture, analyze, and model this role. Identifying and understanding the factors that influence immersion can help accomplish the goal of augmenting experiences for the users.

8 SUMMARY

A non-exhaustive literature review of immersion has been presented in this paper. The descriptions of immersion have been categorized into two paradigms: an individual's psychological state and the objective property of the technology or the system that facilitates an experience. The review reveals that immersion is a cognitive construct based upon which an adaptable definition of immersion from a psychological perspective has been proposed as follows:

> Immersion is a phenomenon experienced by an individual when they are in a state of deep mental involvement in which their cognitive processes (with or without sensory stimulation) cause a shift in their attentional state such that one may experience disassociation from the awareness of the physical world.

The terms *immersive potential* and *immersive tendency* are suggested to develop the foundation for conducting experiments and quantifying immersion. Presence, transportation, flow, and envelopment are contrasted with the proposed definition of immersion to signify the underlying differences between the ideas. The system, content, environment, individual factors, and interaction between the individual and the experience are identified as the five factors that can influence immersion.

The overview of the subjective and objective measurement techniques illustrates the scarcity of reliable and robust methods for measuring immersion, suggesting a clear need for additional research. To study immersive experiences, it is important to understand each of the five factors that can influence immersion. The proposed methodology for subjectively quantifying immersion takes into consideration the several implications on the experimental paradigm discussed in the paper. Approaching immersion as an integrated experience rather than merely investigating the system or the stimuli is determined to be of paramount importance. Future work should aim to identify the attributes and causes of immersion, investigate the influence of the different factors on immersion, and improve the efficiency and effectiveness of measurement methods. A deeper understanding of the topic can help in creating new avenues for augmenting audiovisual experiences and delivering engaging experiences.

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THE AUTHORS


Sarvesh R. Agrawal


Adèle Simon


Søren Bech


Klaus Bærentsen


Søren Forchhammer

Sarvesh Agrawal was born and raised in Mumbai, India. He moved to the United States in 2014 and received a B.S. in audio production with a minor in entertainment technology from Middle Tennessee State University (MTSU) in 2016. Following a brief stay at MSE Audio Group in Kansas, he moved to New York, where he attained a graduate degree in architectural acoustics from Rensselaer Polytechnic Institute (RPI) in 2018. Sarvesh joined Bang & Olufsen in 2018 as a research fellow and has been pursuing a Ph.D. from the Department of Photonics Engineering at the Technical University of Denmark (DTU) as an early stage Marie Curie fellow. Psychoacoustics, perceptual evaluation of sound, and subjective assessment of multimodal experiences are his primary research interests. Currently, Sarvesh is investigating the concept of immersion in domestic audiovisual environments.

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Adèle Simon holds an M.Sc. in acoustic, signal processing, and computer science for music from Ircam/University Pierre & Marie Curie (France) and an M.A. in music psychology and neurosciences from the University of Jyväskylä (Finland). She joined Bang & Olufsen in 2018, where she is now pursuing an industrial Ph.D. with Aalborg University. Her research interests relate to human auditory perception and the cortical mechanisms underlying auditory attention.

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Søren Bech received an M.Sc. and Ph.D. from the Department of Acoustic Technology (AT) of the Technical University of Denmark. From 1982–1992 he was research fellow at AT studying perception and evaluation of reproduced sound in small rooms. In 1992 he joined Bang & Olufsen, where he is Director of Research. In 2011 he was appointed Professor in Audio Perception at Aalborg University and he is Adjunct Professor at Surrey University (GB) and McGill University (CAN). He is a Fellow of the Acoustical Society of America and Audio Engineering Society (AES). He is past Governor and Vice-President of the AES and now serves as associate technical editor of the AES Journal. He has been vice-chair of the International Telecommunication Union working group 10/3. In 2006 he and Dr. Zacharov published the book *Perceptual Audio Evaluation - Theory, Method and Application* (Wiley and Sons). His research interest includes psychoacoustics and in particular human perception of reproduced sound in small and medium-sized rooms. Other interests include experimental procedures and statistical analysis of data from sensory analysis of audio and video quality.

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Klaus B. Bærentsen is an associate professor at the Department of Psychology at the University of Aarhus, Denmark. He received his M.Sc. and Ph.D. in psychology from the Department of Psychology at the University of Aarhus. During the period 1983 to 1995 he was an assistant professor engaged in various research projects concerning man-machine interaction and was teaching at the Department of Psychology at the University of Aarhus. In 1995–2000 he worked at Bang & Olufsen as a specialist in user interaction technology and concurrently held various temporary and part-time engagements at the University of Aarhus, the University of Aalborg, and Grundfos A/S. In 2000–2001 he was an assistant professor at the MR Research Center at Skejby Hospital doing fMRI research. In 2001 he was appointed associate professor at the Department of Psychology at the University of Aarhus, doing research and teaching on neuroscientific psychology, man-machine interaction, and general cognitive psychology. His interests span a wide range of phenomena related to human life activity, consciousness and personality, encompassing motivation, sensory-motor control, perception and cognition and its neurological foundation, and cultural-historical development of societal activity and technology, as well as synergetics, complex self-organizing systems, classical yoga, and Buddhist psychology.

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Søren Forchhammer received an M.Sc. degree and a Ph.D. degree from the Technical University of Denmark, Lyngby. Currently, he is a professor with DTU Fotonik, Technical University of Denmark, where he has been since 1988. He is Head of the Coding and Visual Communication Group at DTU Fotonik. He is Coordinator of the EU MSCA ITN RealVision. He is flagship lead in the DNRF CoE SPOC. His research interests include source coding, image and video coding, processing of image and video, processing for image displays, quality of coded multimedia data, multi-camera and light field images and video, two-dimensional information theory, and visual communications.