Immersive VR as a Promising Technology for Computer-Supported Mindfulness

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Abstract. Therapeutic effects of Mindfulness meditation practices in clinical interventions, specifically in the treatment of stress, anxiety, depression, chronic and acute pain are scientifically well founded. Mindfulness is increasingly being supported by technology and among various interventions immersive VR seems rather peculiar due to its ability to improve decentering and interoceptive awareness. A systematic review on Virtual Reality supported Mindfulness is currently being published. In this paper, some preliminary results of this review are presented, also providing a brief discussion about a possible evolutionary technological trend, on the basis of the input and output perceptual domains exploited.

Keywords: Virtual Reality · Mindfulness · Meditation · Biofeedback · Neurofeedback

1 Introduction

In the neuroscience literature [1,2], meditation is described as a set of complex training strategies aimed to perform a regulation of attention and emotions, and oriented to foster general well-being and emotional balance. The term refers to a wide variety of practices, such as techniques to promote relaxation and exercises performed to reach a greater sense of well-being.

The most common forms of meditation can be classified as Focused Attention (FA) or Open Monitoring (OM) Meditation [1]. In the former, selective attention is focused on a specific object (e.g., localised sensation of breathing) in a sustained way. The latter involves non-reactive and continuous monitoring of the events occurring during the meditation experience to promote a non-judgemental awareness.

L. T. De Paolis et al. (Eds.): AVR 2021, LNCS 12980, pp. 156–166, 2021.
https://doi.org/10.1007/978-3-030-87595-4_12

Most of the recent scientific interest in meditation has focused on Mindfulness meditation [2,3], which often directly refers to OM meditation [4,5], but actually includes both the previous categories, with the underlying implicated psychological processes [1]. According to Kabat-Zinn, Mindfulness is *"the awareness that emerges through paying attention on purpose, in the present moment, and non-judgmentally to the unfolding of experience moment by moment"* [6]. It promotes a peculiar attention regulation, which refers to the *"non elaborative awareness of thoughts, feelings, and sensations as they arise"* [7].

A huge interest has grown towards both therapeutic effects in clinical interventions, with a peculiar focus on stress-related problems, leading to several consolidated Mindfulness-Based Interventions (MBIs), and, more in general, to non formal wellness promotion programs. Over the years, an important support to Mindfulness has come from the ICT world, which provided several technological solutions oriented to support users to approach the meditation practice and to increase retention, affection and motivation to it.

In the first computer-supported Mindfulness era, computers were used to deliver and teach Mindfulness techniques, simply presenting them to users without providing interactive practices and immersive solutions [8]. Initially, the clinical field was the most explored, including the treatment of stress syndrome [9], chronic pain [10,11], irritable bowel syndrome [12], and depression in epileptic subjects [13]. Several papers begin to point out the increase in the effectiveness of computer-supported Mindfulness compared to traditional strategies. In [14], one of the first simple interactive exercises is proposed, by offering a tool for emotion labeling and disidentification from recurring thoughts. In a non-judgmental way, the user labels a passing cloud on a blue sky background with his or her emerging thoughts. Then, he/she simply watches his/her thoughts drift away with the cloud.

A further upgrade of computer-supported Mindfulness was achieved through the concept of an embodied conversational agent: in [15], a virtual coach is proposed to support the patient's Mindfulness training via the web.

Immersive Virtual Reality (VR) emerges as a peculiar technology to improve the practice of Mindfulness meditation, thanks to the immersion feature provided and the following sense of presence. It can offer an isolation from outer distractors, also allowing the practitioner to live a multisensory connection with nature-inspired environments and by offering the chance for customized and user-tailored experiences.

In a previous work, an innovative ICT technologies based methodology was discussed in order to protect the vulnerable population in the context of Covid-19 emergency [16]. In particular, the feasibility of a combination of Cross Reality (XR) and therapeutic methods of Mindfulness and Art Therapy was evaluated.

According to Moseley et al. [17], the brain constantly generates and updates a *body matrix*, a predictive representation of the body and the surrounding space, based on all individual's perceptual channels (sensory, interoceptive, proprioceptive and vestibular). Immersive Virtual Reality has in common with the brain the same predictive mechanism, and whether enhanced by neuro/biofeedback, it

can act at both exteroceptive (sensory) and interoceptive level in order to provide vivid and believable experiences [18]. It could then promote and alteration of the body matrix, by correcting dysfunctional body representations.

A systematic review was recently published, focusing more generally on immersive technologies to support Mindfulness meditation [19]. This work highlights body-based innovations specifically provided by Extended Reality (XR) but does not adequately emphasize why XR is so peculiar in supporting Mindfulness in terms of immersion and alterations of the body matrix.

The lack of a specific survey covering exhaustively studies on VR-supported Mindfulness, stimulated us to produce a currently being published systematic review, aimed at assessing appropriately the scientific relevance of the reviewed researches. A framework-background, useful to position future studies on this topic, has also been produced according to Kitchenham's guidelines [20].

In this paper, some preliminary results of the aforementioned review are presented, also providing a brief discussion about a possible evolutionary technological trend, according to the perceptual input and output channels considered by the multimodal immersive VR systems.

In the following, the methods and the preliminary survey results are presented in Sects. 2 and 3, respectively, by dedicating two different subsections to mobile apps (Sect. 3.1) and VR-based solutions (Sect. 3.2) separately. Then, Sect. 4 will be reserved to Conclusions.

2 Methods

A systematic review about immersive VR-supported Mindfulness solutions is currently being published and it has been produced following PRISMA reccomendations in order to report paper extraction process transparently. The literature research has been performed in the period until December 2020, considering Computing Machinery (ACM), Science Direct, Web of Science, Scopus, IEEE (Institute of Electrical and Electronics Engineers) Xplore and PubMed as databases. The included articles were required to have a peer review, published in journal or conference proceedings, and written in English.

The research query applied was: (VR OR Virtual Reality) AND Mindfulness.

Taking into account some exclusion criteria, studies referring to Mindfulness as a dispositional trait or considering non-immersive VR solutions not specifically based on 3D computer graphics or first-person perspective (1PP) were kept out.

A quality assessment of the reviewed papers has been carrying on, by also clustering them according to specific research goals.

In this paper a preliminary results selection is provided, highlighting some technological emerging perspectives.

3 Preliminary Results

Analyzing the preliminary results of the ongoing survey from a technological point of view, interesting evidences emerge which allow us to make some

exploratory considerations on the future trend of computer-supported Mindfulness.

A first general consideration is that the combination of ICT and Mindfulness technologies is having a great impact on the wellness market, leading to a proliferation of companies offering digital Mindfulness solutions on several app stores. Therefore, a first important use of technological solutions to support meditative practice is oriented to the free time of users, having a significant relevance also on the consumer market. Despite their market relevance which is an index of the social impact of the phenomenon, these solutions still appear far from representing a consolidated and well-structured protocol for the promotion of well-being.

At the same time, there is a clinical/therapeutic use of computer-supported Mindfulness solutions, which requires some particular technological conditions. In this context, immersive VR-based solutions take place, offering greater levels of immersion and sense of presence and acting on the interoceptive awareness and the body matrix.

The collected papers generally present VR-based solutions in the context of Computer supported Mindfulness, focusing the phenomenon of mobile apps. Thus, the phenomenon of mobile apps, representing the subset with the greatest impact on the market, are discussed (Subsect. 3.1). Subsequently, VR-based solutions are focused (Subsect. 3.2), considering also the integration of bio/neurofeedback. In this subsection, a perspective table, useful to critically classify current available studies, is provided.

3.1 The Mobile App Invasion

The feasibility of computer supported Mindfulness is made evident by the now disruptive spread of mobile apps. Referring, for example, to the Google Play Store, over 250 Mindfulness and meditation apps were downloadable during December 2020. Nevertheless, the effectiveness of the majority of these applications is not proved yet. A recent study [21] shows the benefits of distributing Mindfulness sessions through mobile apps, suggesting that short guided Mindfulness meditations provided via smartphone and practiced several times a week may improve results related to stress and well-being at work, with potentially long-lasting effects.

In many of the papers collected in the survey, references to smartphone apps appear. Given the economic and social importance of the phenomenon, the cited apps were classified by identifying five main categories (Fig. 1):

- *General support to the practice:* apps offering guided meditations and timer tools to remember or timing the practice [22–27];
- *Thought Distancing Techniques:* working on reaction to thoughts, teaching to become aware and simply observing them as they go away [8,28–31];
- *Breathing Techniques*: the user is asked to pay attention to his own breathing, for example, touching the screen with each breathing cycle [32];

– *Neurofeedback Support:* used in combination with the EEG Muse headset and offering the mental state feedback for modulating the meditation experience [33];
– *Mindfulness Therapy* explicitly dedicated to the clinical/therapeutic field including (i) an app for stress syndrome management by Acceptance and Commitment Therapy (ACT) [34], and (ii) two apps where a generic mobile app-based Mindfulness protocol is implemented, for light depression treatment [35], and stress reduction [36], respectively.

Year	Mobile APP	Interactive	Category	Available on the Store	Appl. Field
2010	Mindfulness Meditation [23]	✘	General Support to the Practice	✘	Ed
2011	Just Let Go [27]	✔	Thought Distancing Techniques	✘	Ed
2011	The Shredder [28]	✔	Thought Distancing Techniques	✘	Ed
2011	Throw Your Worry Away! [29]	✔	Thought Distancing Techniques	✘	Ed
2011	Worrydoll Lite [30]	✔	Thought Distancing Techniques	✔	Ed
2012	Lotus Bud Mindfulness Bell [21]	✘	General Support to the Practice	✔	Ed
2012	Zazen Suite - Mindfulness Bell [22]	✘	General Support to the Practice	✔	Ed
2012	The Mindfulness App [24]	✘	General Support to the Practice	✔	Ed
2012	Mindfulness TS [31]	✔	Breathing Techniques	✘	Ed
2013	OIVA [33]	✔	ACT Therapy	✘	Th
2014	AEON Mindfulness App [8]	✔	Thought Distancing Techniques	✔	Ed
2014	Mindfulness [34]	✘	General Guided Meditation	✔	Th
2014	Muse Meditation Assistant [32] (**)	✔	Neurofeedback	✔	Ed
2015	It's time to relax! [35]	✘	General Guided Meditation	✘	Th
2019	HeadSpace [25]	✘	General Guided Meditation	✔	Ed
2019	Buddhify [26]	✘	General Guided Meditation	✔	Ed

Fig. 1. Mobile apps for Mindfulness cited in the scientific literature [Education (Ed), Therapy (Th)].

3.2 VR Based Mindfulness

The growing interest of the clinical world towards computer-supported Mindfulness requires to deeply discuss about specific technological requirements. Two of the most important mechanisms at the base of Mindfulness are body awareness and decentering [37]. The first has to do with the ability to correctly access and appraise body signals [38]. The second refers to the adoption of an objective and non-judgmental attitude towards one's self [39]. When these mechanisms appear dysfunctional, they generate pathological implications: a poor

interoceptive awareness is often linked to anxiety, chronic pain and eating disorders, a high decentering is often connected to depressive symptoms. Mindfulness already prevents and treats these dysfunctional forms in itself [40,41]. By creating a presence in a virtual body and in the surrounding virtual space, VR provides the building of a new vision of the self [42]. Furthermore, through the use of neuro/biofeedback, immersive VR proposes experience able to intervent on body matrix, and on interoceptive awareness.

All the input and output channels considered by a multimodal immersive VR-supported Mindfulness system are shown in Fig. 2. It seems very useful for evaluating which perceptual domains are used by VR-supported Mindfulness and which are not.

	Perceptive Domain	Channel	Technology	A representative study
Input	Sensorial	Visual	Camera	**(Room et al. 2017)**
		Acoustic	Microphone	**(Cikajlo et al. 2016)**
		Tactile	Pressure sensors	**(Gromala et al. 2011)**
		Olfactory	Chemical sensors (aeriform)	(Keller et al. 1995)
		Gustatory	Chemical sensors (liquid and solid)	-
	Vestibular		Accelerometer, gyroscope, magnetometer	**(Blum et al. 2019)**
	Proprioceptive		Optical, acoustic and microwave sensors	(Chessa et al. 2016)
	Interoceptive	Brain	EEG	**(Kosunen et al. 2016)**
		Other organs	Biosignal	**(Seol et al. 2017)**
ouput	Sensorial	Visual	Display	**(Navarro Haro et al. 2017)**
		Acoustic	Speakers	**(Navarro Haro et al. 2017)**
		Tactile	Haptic Interface	**(Seol et al. 2017)**
		Olfactory	Aeriform Synthesizer	(Micaroni et al. 2019)
		Gustatory	Chemical, electrical and acoustic actuators	(Vi et al. 2017)
	Vestibular		Vibro-tactile actuators	**(Paredes et al. 2018)**
	Proprioceptive		Vibro-tactile actuators	(Riva et al. 2017)
	Interoceptive	Brain	Acoustic actuators	**(Sas and Chopra 2015)**
		Other organs	Vibro-tactile actuators	(Riva et al. 2017)

Fig. 2. Perceptual input and output channels considered by the multimodal immersive VR-supported Mindfulness systems. Grey-coloured references refer to non-Mindfulness studies.

Despite this general overview, only a part of these channels have been already taken into account by the reviewed literature. As regards outputs, most of the solutions consider only visual and acoustic sensory channels. This is the case, for instance, of Navarro-Haro and colleagues [43]. In accordance with Attention Restoration Theory (ART), the authors proposed a nature-inspired virtual scenario aimed at treating Borderline Personality Disorder, by implementing Dialectical Behavior Therapy (DBT) (see Fig. 3.A). The study hightlights the long-term benefits in patients, who gain higher levels of acceptance with a better therapeutic outcome.

Seol et al. [44] extends multimodality also to haptic channel: the proposed system feeds back the heart rate information by means of an haptic physical model of the user's heart beating in his/her hand (see Fig. 3.B). This represents a peculiar example of how concentration on the present moment could be improved through an augmented virtuality strategy. Dramatically lower is the number of studies which consider interoceptive and vestibular outputs. Regarding the former, Paredes and colleagues [45] proposed a mindful in-car virtual reality intervention in order to adequately stimulate the vestibular system: the use of relaxing VR content in a dynamic context like a moving car, can lead to lower autonomic arousal levels. The only reviewed paper that works with interoceptive feedbacks is [46]. The authors stress the advantages of using EEG-based binaural feedback in order to reach deeper meditative states. The interoception is oriented to the brain directly, and the brain activity modulation is induced on a physiological level. None of the collected papers exploit other interoceptive, proprioceptive or alternative sensory channels (e.g. olfactory and gustatory), even though a consistent literature in a more general VR context has been consolidating [18,47,48].

As regards input, sensory channels are sometimes exploited: the visual information captured by a camera has received in input in augmented reality scenarios [49], while acoustic data can be acquired by using a microphone and sent to the meditation platform, like in [50] which proposes a web-based delivered VR Mindfulness. An interesting case study about the haptic input is [51], where a virtual meditative walk is implemented and the movement of the user into the virtual environment is allowed by a treadmill.

Neuro/biofeedback enhanced system are characterized by exploiting interoceptive input: in [52] alpha and theta waves activity are both involved during meditation and they are connected to relaxation and concentration respectively (see Fig. 3.C). Vestibular input is quite exploited by all systems using HMD equipped by inertial sensors [53].

Immersive VR-supported Mindfulness has not been used in many perceptual domains: therefore it is not yet used to its full potential to support Mindfulness. Generally, the higher will be the number of perceptive channels considered, the more VR tool will be well exploited to support Mindfulness. The overall use of all channels will lead scientists to broaden the discussion not limiting it only to immersive VR, by including all the possibilities in the XR spectrum.

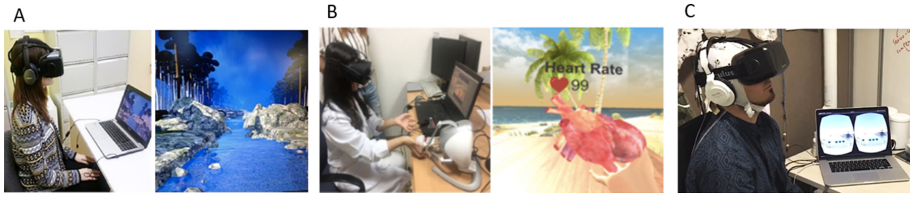

Fig. 3. A. A virtual reality world watched by the participant through the Oculus Rift; B. A biofeedback based VR-haptic system; C. A neurofeedback based immersive VR solution.

4 Conclusions

Immersive virtual reality turns out to be one of the most peculiar technologies in support of Mindfulness meditation, due to some specific technological features. In particular, immersion is defined as the ability to actively stimulate the user through a wide set of perceptual channels, both external (sensory) and internal (e.g. interoceptive). Immersion and its psychological product, the sense of presence, make the immersive VR system capable of altering the body matrix and intervening on decentralization and interoceptive awareness.

Until now, there are no literature surveys specifically focused on virtual reality assisted Mindfulness. In this paper, some preliminary results of an ongoing review on VR supported Mindfulness are presented. In particular, a brief discussion is developed on possible evolutionary technological trends, according to the perceptive input and output VR channels.

Immersive Mindfulness supported by virtual reality still appears to be underused in many perceptual domains. Researchers are supposed to consider the most of the perceptual domains properly, in order to get the highest potential by VR in supporting Mindfulness meditation.

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