Heliyon 8 (2022) e11762

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Review article

The promise of the metaverse in mental health: the new era of MEDverse

Antonio Cerasa [a,b,c,*,1], Andrea Gaggioli [d,e,1], Flavia Marino [a], Giuseppe Riva [f,e,2], Giovanni Pioggia [a,2]

[a] *Institute for Biomedical Research and Innovation, National Research Council, IRIB-CNR, 98164 Messina, Italy*
[b] *S. Anna Institute, 88900 Crotone, Italy*
[c] *Pharmacotechnology Documentation and Transfer Unit, Preclinical and Translational Pharmacology, Department of Pharmacy, Health Science and Nutrition, University of Calabria, 87036 Arcavacata, Italy*
[d] *Research Center in Communication Psychology, Catholic University of Milan, Milan, Italy*
[e] *Applied Technology for Neuro-Psychology Lab., Istituto Auxologico Italiano, Milan, Italy*
[f] *Humane Technology Lab, Catholic University of Milan, Milan, Italy*

ARTICLE INFO

Keywords:
Metaverse
Mental disorders
Body dysmorphism disorders
Autism

ABSTRACT

Since Mark Zuckerberg's announcement about the development of new three-dimensional virtual worlds for social communication, a great debate has been raised about the promise of such a technology. The metaverse, a term formed by combining meta and universe, could open a new era in mental health, mainly in psychological disorders, where the creation of a full-body illusion *via digital avatar* could promote healthcare and personal well-being. Patients affected by body dysmorphism symptoms (i.e., eating disorders), social deficits (i.e. autism) could greatly benefit from this kind of technology. However, it is not clear which advantage the metaverse would have in treating psychological disorders with respect to the well-known and effective virtual reality (VR) exposure therapy. Indeed, in the last twenty years, a plethora of studies have demonstrated the effectiveness of VR technology in reducing symptoms of pain, anxiety, stress, as well as, in improving cognitive and social skills. We hypothesize that the metaverse will offer more opportunities, such as a more complex, virtual realm where sensory inputs, and recurrent feedback, mediated by a "federation" of multiple technologies - e.g., artificial intelligence, tangible interfaces, Internet of Things and blockchain, can be reinterpreted for facilitating a new kind of communication overcoming self-body representation. However, nowadays a clear starting point does not exist. For this reason, it is worth defining a theoretical framework for applying this new kind of technology in a social neuroscience context for developing accurate solutions to mental health in the future.

1. Introduction

In 2021 Mark Zuckerberg launched the idea of a new era for the internet, where our body will immerse in a new virtual experience, *called metaverse.* The "deep feeling of presence" through a multi-sensory experience in every place and in every moment will revolutionize our communication and social connections.

The metaverse is a proposed hypercomplex digital setting that could offer novel means of communication while hiding users' own avatars (Sparkes, 2021). Fusion of the physical and virtual worlds should be the primary characteristic of the metaverse: our actions in the real world have an impact on how we feel in the virtual world, and vice versa (Riva et al., 2021a, 2021b; Riva and Wiederhold, 2022). The metaverse has been promoted as a new instrument for accelerating the transition from the real economy to a digital economy, supported by the gaming industry. Investors, decision-makers, and multinational corporations have been drawn to the social and economic prospects that the metaverse would present to us months before the market debut.

This visionary conceptualization of the next virtual internet led to some reluctance by large institutions about the digital risks of the metaverse: a) unwanted contact could become more intrusive; b) security for personal information; c) the risk to exacerbate impulsive and obsessive subtle attitudes in a space where the boundaries between real and virtual world are smoothed. Although the metaverse seems to resemble

* Corresponding author.
E-mail address: Antonio.cerasa76@gmail.com (A. Cerasa).
[1] These authors equally contributed as first authors of this manuscript.
[2] These authors equally contributed as last authors of this manuscript.

https://doi.org/10.1016/j.heliyon.2022.e11762
Received 3 July 2022; Received in revised form 11 October 2022; Accepted 14 November 2022

Augmented Reality (AR) and Virtual Reality (VR) applications, there are important differences between these tools (Park and Kim, 2022). First, these are simulation technologies that are designed to enhance (AR) or replicate (VR) physical environments, whereas the metaverse has a robust service-oriented architecture that emphasizes social and content aspects. In order to connect physical environments with digital ones, metaverse applications may integrate digital information layers into them (e.g., via tablets and smartphones). Furthermore, the metaverse could enable the "federation" of multiple technologies (artificial intelligence, tangible interfaces, blockchain and Internet of Things) to connect the 3D environments to a vast number of cyber-physical devices and their data, thus enabling seamless interaction between the "virtual" and "real" world.

As underlined by Riva and Wiederhold (2022) the metaverse works like our minds. In modern neuroscience (Clark, 2015), the human brain is described as a simulator that has developed the capacity to predict sensory events before they are really experienced (predictive coding). The metaverse works similarly. It uses technology to create a hybrid experience that people can manipulate and explore as if they were there. In other words, like our brain, the metaverse tries to predict the sensory consequences of users' actions by displaying the same outcome that our brains expect in the real world (Riva et al., 2018).

According to Riva and associates (2019a, 2019b), the system keeps a model (simulation) of the body and the area around it to accomplish it, much like the brain does. The expected sensory input is subsequently delivered utilizing the hardware in accordance with this prediction. The model obviously strives to imitate the brain model as closely as possible in order to be realistic: the more the model resembles the brain model, the more the person feels present [in the metaverse].

Despite the disagreement over the concept and nature of the metaverse, future uses of this technology in clinical psychology and medicine could expand the scenarios and applications already made possible by AR/VR. Numerous meta-analyses and systematic reviews conducted over the past two decades have backed recommendations for using VR/AR exposure treatments to address behavioral and cognitive problems (Chitale et al., 2022; Baghaei et al., 2021). Because of this, we think that the metaverse could be a further advancement in the development of new tools for mental wellness by bridging the gap between the virtual and real worlds. Indeed, it should always be remembered that, according to the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD, 2019), in the past 30 years, the number of people with mental disorders has increased from 80.8 to 125.3 million. This confirms that, globally, mental disorders continue to be a major burden, with evidence of further increases following COVID-19 pandemic restrictions and limited access to effective treatments.

AR/VR exposure therapies have been demonstrated to be effective in supporting psychotherapeutic approaches for the treatment of depression or anxiety, but the degree of this "effectiveness" has not been well defined yet. The presence of few studies conducted using an RCT approach and the lack of a cost-benefit analysis (Baghaei et al., 2021) limited the real translation of AR/VR exposure therapies in clinical practice, although there is a strong need (Deng et al., 2019). It is imperative to create new protocols based on cutting-edge technology that can utilize standardized computational scenarios and homogeneous psychotherapy techniques to reach millions of people worldwide. In the last few years, the employment of chatbots, apps, and mobile games has been proposed as alternative technological approaches aimed at reaching many vulnerable people (Baghaei et al., 2019; Avani et al., 2018). Despite these solutions having been demonstrated to be effective for the diagnosis or the treatment of mental disorders, the advent of a new federation of multiple technologies that will revolutionize human communication will push us to create new solutions for applying VR/AR tools to mental health.

In this prospective review, we address the possibilities of the metaverse in terms of mental health in this prospective review by fusing more recent technology developments with recent research in cognitive psychology, neuroscience, and behavioral empowerment brought on by immersive experiences. The theoretical underpinnings of the application of this technology in mental diseases lead to the "predictive coding" paradigm until technical challenges in the metaverse technology were overcome. According to this neuroscience idea, our brain actively generates an internal simulation of the body and the environment, and a malfunctioning simulation may be the root of a variety of mental health issues (Riva et al., 2018). Then, starting from previous evidence from VR/AR research, the paper discusses the potential of the metaverse in medicine suggesting that it allows the integration of multiple technologies mimicking the brain functioning and facilitating the virtuality-reality interconnection. Specifically, the paper identifies the key metaverse tools for improving mental health disease in: a) *the embodiment process*: the ability of simulative technologies of generating a feeling of ownership of a digital body or a part of it; b) *the Proteus effect*: the tendency for people to be affected by their digital representation; and c) the *seamless fusion* between the digital and physical dimensions allowing a high level of personalization (using AI) and reorganizing the unhelpful bodily images through the creation of technology-based somatic modification approaches (using interoceptive technologies).

In light of these presumptions and the fact that mental illnesses tend to respond more favorably to immersive exposure therapy, we hypothesize that individuals affected by body dysmorphism symptoms (i.e., eating disorders) and social deficits (i.e. autism) will greatly benefit from the translation of this new technology in clinical protocols.

2. Metaverse in medicine

With the term "MEDverse", we can define the entry of the metaverse into a medical context as early proposed by Riva et al. (2021a, 2021b), Wiederhold and Riva (2022), and Yang et al. (2022).

Yang and colleagues (2022) proposed that this type of platform would provide the opportunity to establish a virtual setting where patients and clinicians may communicate throughout the course of clinical care (examination, diagnosis, in-home care, evaluation of treatment diseases, consultation). Given the growing number of people wanting online mental health care, this type of medical service will be essential in the future. Mesko (2022) also suggested that the metaverse may be transformed into a virtual university where professors could instruct students on the inner workings of the circulatory system, eventually taking the place of real-world medical technologies like chatbots, smartphones, and telehealth systems.

The dual connection between the virtual and physical worlds was identified by Riva et al. (2021a, 2021b) as the key component of the metaverse for health care. According to this perspective, each change in the physical world is reflected (referred to as a digital twin) in its digital counterpart, and vice versa. For instance, if I move in the real world, my virtual avatar will follow suit, and if I touch the avatar in the virtual world, my physical body will receive haptic feedback. Immersive VR systems have been around since the early 1990s (Blanchard et al., 1990, 1992), and they take advantage of stereoscopic viewing, lifelike 3D graphics, and head tracking to produce interactive, first-person experiences that can be more ecologically valid than conventional, non-interactive experimental stimuli and cause users' physiological reactions that mimic real-world experiences (Patil et al., 2014; Chittaro and Buttussi, 2015; Zanon et al., 2014). In a therapeutic environment, VR has so far been used to deceive users into believing that an object is present when it is not. The deep sense of presence is enhanced by the hybrid dimension of the metaverse, which can potentially trick the predictive coding systems that control our bodily experience. This will be accomplished by combining various embodied technologies (haptic and interoceptive technologies), increasing the users' ability to view things from a first- or third-person perspective, and utilizing big data analysis from AI algorithms to improve the immersive experience and enable the intelligence of virtual agents to be comparable to that of humans (Huynh-The et al., 2022).

In conclusion, the primary advancements that the metaverse could make in medicine depend on the development of immersive experiences and the use of a variety of technologies to make it easier for virtuality and reality to interact by simulating how the brain works. Deep learning AI techniques will provide insights into novel treatment strategies, resulting in lower costs and considerably improved patient results (Zhou et al., 2022; Wiederhold and Riva 2022).

3. The basis for applying metaverse in mental health

Predictive coding (Clark, 2013; Hohwy, 2013), a generally accepted idea in neuroscience, states that our brain actively builds an internal model (simulation) of the body and its environment. This model is designed to forecast the sensory input that will be received in order to reduce the number of prediction errors (or "surprise"). Our brains build an embodied simulation of the body that represents its projected future states in order to interact with the world efficiently (intentions and emotions). There are two main aspects of this simulation (Riva et al., 2021a, 2021b). First, it is largely a simulation of sensory-motor experiences using visceral/autonomic (interoceptive), motor (proprioceptive), and sensory (e.g., visual, aural) input as sources. Second, because embodied simulations are based on the subject's expectations, they trigger the multimodal brain networks that were previously responsible for the simulated or anticipated outcome.

Recent advancements in neuroscience are defining a new conceptual framework that suggests various mental health disorders are connected to these mechanisms, particularly the processing of multisensory bodily signals (Blanke et al., 2015; Riva et al., 2018). As recently stated by Paulus and colleagues (2019), these conceptual models propose that a general characteristic of mental diseases is a failure in the computation and integration of representations of the internal and external worlds of the body across time. According to this view, a persistent disparity or error signal is produced when outcomes are detected, which, in this theory, leads to shifts in mood and anxiety because of the brain's biased interpretation of what it expects will occur against what is actually happening in these settings.

The use of the metaverse platform to treat problems of body-related mental health is still an unknown area of research. In this case, the metaverse can be employed for clinical purposes to shape, augment, and/or replace the experience of the body.

Virtual reality exposure therapy has mostly shown to be useful in treating pain, phobias, and post-traumatic illnesses (Deng et al., 2019; Georgescu et al., 2020; Carl et al., 2019). However, to boost the sense of immersion, all these applications have been implemented using standard VR design, which primarily depends on the translation of user viewpoints into a first-person perspective. The goal of the metaverse platform is to improve the "embodiment illusion" to produce a new, multi-sensory sense of the physical and self-presence (Spanlang et al., 2014), and the "Proteus Effect" (Yee and Bailenson, 2007) which takes place when participants experience or use a virtual body (Heydrich et al., 2013).

Over the past 20 years, immersive VR systems have developed dramatically, becoming potent inducers of embodiment illusions in both healthy and clinical populations using virtual avatars and synchronous multisensory connections. Using the sensation of embodiment in a virtual body to change people's internal body representations is an effective tactic for controlling various clinical symptoms, according to a recent review (Matamala-Gomez et al., 2021) (such as motor, pain).

However, it remains to be established how the employment of a digital avatar impacts the embodiment processes and which are the perceptual and cognitive mechanisms involved in them. As stated by Gonzalez-Franco and Lanier (2017), avatars are processed in the brain like people. Different levels of familiarity can be detected by humans on avatar faces (Bailenson et al., 2006; Gonzalez-Franco et al., 2016). When engaging with avatars, social conventions (such as interpersonal distance) and social behaviors (such as shyness and agreeableness) are maintained (Bailenson et al., 2003; Sanz et al., 2015).

In general, it is understood that a virtual body boosts the capacities of exploration and engagement in an ego-centered way (Gonzalez-Franco and Lanier, 2017). Otherwise, using a virtual version of oneself (referred to as a "Doppelganger" by Bailenson and Segovia, 2010) can change the perspective to an allocentric frame of reference in space and cause some behavioral changes (Fox et al., 2012), such as increasing users' spatial awareness and perception of the virtual environment around their avatars (Gorisse et al., 2017). Moreover, considering the social learning theory (Bandura, 2001), Bailenson and Segovia (2010), proposed that the employment of virtual avatars can also improve behavioral skills learning. In fact, as demonstrated by a recent meta-analysis (Ratan et al., 2020), through the "Proteus effect" avatars influence their users' behaviors and attitudes both in mediated and actual (unmediated) contexts.

Up to now, VR has focused only on the simulation of the external world. The metaverse, instead, both through the bridging of the digital and physical world, and the integration of emerging technologies such as AI and interoceptive technologies, it is also able to generate somatic modifications (Riva et al., 2021a, 2021b) able to restructure maladaptive bodily representation (Regenerative Virtual Therapy).

The personalization of treatment is the first major benefit that AI brings to the metaverse (Riva et al., 2019a, 2019b). The metaverse enables the collection of physiological and behavioral data during its experience that can be used by AI algorithms for extracting biologic responses specific to therapeutic interventions. These possible biomarkers have a direct connection to how the brain works and can be altered to cure perceptual/cognitive dysfunctions with the person's brain's predictive coding systems. Due to this, AI built into the metaverse platform may be able to optimize a patient's treatment plan, assisting in the shift to a personalized form by utilizing data from the patient's digital biomarkers during the virtual experience.

Moreover, the use of interoceptive technologies allows the direct modulation of interoceptive signals during a metaverse experience. These signals, that generate a representation of the internal state of our organism (Chen et al., 2021), can be altered directly, using technologies like c-fibers stimulation (Di Lernia et al., 2020) and sonoception (Wiederhold and Riva, 2019), or indirectly, by using technologies providing false feedback (e.g., illusions) of the physiological states of individuals (Iodice et al., 2019).

In conclusion, the opportunities offered by the metaverse could be summarized in: a) the seamless fusion between the digital and physical dimensions that allows the simulation and control not only of the external world but also of the internal one (bodily self-consciousness); b) the translation from the first- to a third-person viewpoint allowing the integration of both the embodiment and the Proteus effects; c) the personalization and social dimension of the experience mediated by digital biomarkers and AI algorithms; d) the preference for the allocentric frame of reference in spatial exploration; With this in mind, we propose some fields of applications of the metaverse technology in individuals with specific psychological disorders characterized by altered computation and integration of the inner and outer worlds of the body across time. We propose that future applications of metaverse could positively influence patients affected by body dysmorphism symptoms (i.e., eating disorders), and social deficits (i.e., ASD).

3.1. Body dysmorphic disorders and eating disorders

BDD is a mental illness listed under the category of Obsessive-Compulsive and Related Disorders. People who suffer from BDD are distracted or obsessed with one or more perceived imperfections in their looks, which causes severe emotional discomfort and makes it difficult for them to socially interact appropriately. BDD frequently co-occur with anxiety and social phobia and steer clear of close connections out of a fear of being embarrassed. Neuroimaging analysis confirmed the presence of structural and functional abnormalities in the visual cortices of BDD patients, starting from primary visual cortex (V1 and V2 areas) to several temporo-parietal regions, particularly within the left hemisphere, where structural encoding of visual information occurs (Grace et al., 2017). Threat BDD symptoms have seen limited use of VR up to this point, where maladaptive interpretive biases are a key goal. Additionally, the hypothetical and distant nature of mental scenarios limits existing behavioral standards and prevents them from capturing transient experience threat processes (Summers et al., 2021). For this reason, a new immersive experience capable of stimulating in vivo threat interpretation biases in response to interpersonal scenarios presented via a "federation" of multiple technologies shared by multi users is mandatory for developing new kinds of treatment for these patients.

Like BDD, a negative and distorted body image is also a perceptual and cognitive hallmark of eating disorders (Dakanalis et al., 2016; Riva and Dakanalis, 2018). In particular, many phenomenological traits shared by people with BDD and anorexia nervosa (AN) include skewed perceptions of one's appearance, obsessive and compulsive symptoms (Woodside and Staab, 2006), and inadequate insight (Hartmann et al., 2013). When it comes to insight skills, Hartmann and colleagues looked at the delusionality of appearance-related beliefs in people with BDD and AN. They found that those with BDD exhibited significantly higher levels of delusionality, whereas in AN, delusionality was specifically linked to shape concerns and the drive for thinness. This finding was confirmed by Vaughn et al. (2019), who used machine learning algorithms to automatically classify individuals with AN from BDD. Considering several clinical, psychological, and neurobiological features, the most important factor useful to individually distinguish BDD from AN is the presence of poor insight in BDD.

Patients with AN have a multimodal impairment of body perception that includes tactile and proprioceptive sensory elements in addition to visual misinterpretation (Gaudio et al., 2014; Riva and Dakanalis, 2018). Additionally, in AN patients, changes to the parietal cortex may be linked to impairment of the tactile and proprioceptive components. Weak direct investigations of interoception and multisensory integration have been conducted.

VR exposure therapies have already been used for improving body satisfaction and appearance in eating disorders (Clus et al., 2018). Additionally, some studies have shown that VR appears particularly useful in resolving body image issues (Ciążyńska and Maciaszek, 2022). VR systems aid patients in integrating new body knowledge and learning how to distinguish cognitive and emotional experience from the actual body (Matamala-Gomez et al., 2021). The metaverse platform has the potential to further improve these positive effects in two ways:

1) through the integration of interoceptive technologies, allowing the direct modulation of interoceptive signals during a metaverse experience, The merging of the embodiment potential of VR with the one of interoceptive technologies should allow the emergence of Regenerative Virtual Therapy (Riva et al., 2021a, 2021b), a new clinical approach that uses the technology-based somatic modifications allowed by the metaverse to restructure the maladaptive bodily representations behind a pathological condition. The suggested process has been proposed by Riva et al. (2021a, 2021b) in this way:
   - Using the metaverse to create a synthetic multimodal experience (viz., visuotactile and interoceptive) capable of producing large prediction mistakes, for contrast with the defective internal model;
   - The application of brain stimulation methods to lessen the impact of top-down predictions;
   - The application of conscious awareness to enhance the accuracy of the synthetic multisensory experience;
   - The enhancement of the multisensory experience's level of reward through the reconstruction and re-elaboration of its emotional content through cognitive reappraisal.
2) by exploiting its social potential. Indeed, a recent preliminary study by Matsangidou et al. (2022) demonstrated the acceptability and feasibility of using Multi-User Virtual Reality (MUVR) for remote psychotherapy in the treatment of eating disorders. In particular, the authors underlined the potential of embodying a psychotherapy intervention in a playful and gamified MUVR: "Particularly the embodiment of the mirror exposure exercise, where the participant was able to create and adjust the avatar to resemble themselves provides new opportunities for the treatment of eating and other similar disorders." (p. 331).

3.2. Autism spectrum disorder

Autism spectrum disorder (ASD) is a developmental disability that affects children's behavior, social skills, verbal and nonverbal communication, sensory processing, and attention (Campbell et al., 2006). To reduce the impact of these deficits the only effective treatment is behavioral therapy. In the last few years several commissions and committees have proposed to apply AR/VR to induce new ways of interpersonal skills and abilities in autism (Lord et al., 2022). Zhang et al. (2022) asserted that by offering a more realistic and welcoming atmosphere, VR can be turned into the ideal tool for intervention and rehabilitation. People with specific medical or mental disorders may struggle to take care of themselves or manage their conduct, and they may also feel uncomfortable around other people in social situations. For this reason, it is essential that these topics, particularly in adolescence, rehabilitate social interaction skills. VR technology offers a secure, controllable environment where therapies can be carried out gradually and individually under the direction of therapists. It has been shown that behavioral therapies mediated by VR technology improve motivation, attention, and social skills. People with ASD may avoid social situations in part due to social anxiety brought on by failed attempts at interaction (Myles et al., 2001). The use of VR technology helps reduce the anxiety that underlies real-world social skill practice in ASD children or teens because it enables them to do so without worrying about making errors or being rejected, something they frequently experience in real-world face-to-face encounters (Fernández-Herrero et al., 2018). As already proposed for BDD and eating disorders, the employment of VR approaches for treating behavioral disorders has been used using the traditional design, whereas it remains completely unexplored what will change when moving to the metaverse technology. A first randomized controlled trial was launched a few months ago by Lee et al. (2022), to evaluate if a metaverse-based child social skills training program could improve the social interaction abilities of children with ASD. These authors will enroll 24 children and young people with autism, who will undergo an internet-based virtual world game program for 4 months aimed at improving social interaction skills.

4. The pitfalls

There are various issues associated with the use of unproven technologies in mental health. The probable aggravation of mental illnesses is the first plainly visible restriction. Abuse of virtual realities may result in additional symptoms including addiction, anxiety, or sadness. Next, the validation of AI algorithms for increasing the human-like interaction of virtual agents in the metaverse platform is a field of study unexplored and highly expensive. Again, the great volume of digital personal health data that should be processed by metaverse platform raises huge security and privacy concerns. Finally, there is a lack of information about the anthropometric (i.e., humanized) features of digital avatars. Which is the best three-dimensional body scanning technology to acquire the best avatar's body and how does the human-likeness of anthropomorphic avatars (i.e., realism) impact the creation of the embodiment illusion? The well-known uncanny valley phenomenon has already been defined for describing the relationship between the realism of humanoid robots and psychological affective state in observers (Mori, 1970), but how the objective realism of anthropomorphic 3D digital avatars would impact perceivers' emotion and information processing is a matter of debate (Shina et al., 2019).

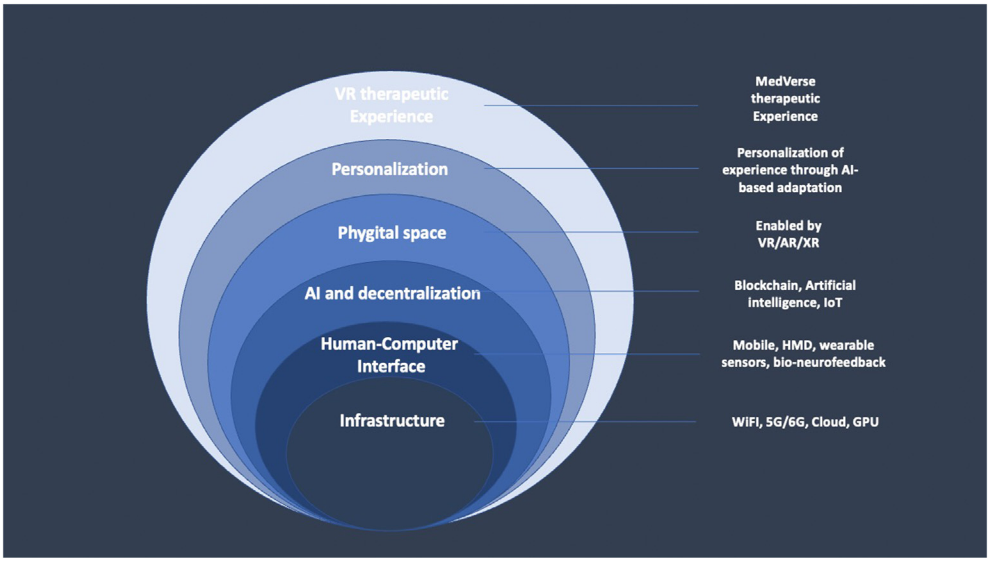

Figure 1. The MedVerse layers (adapted from Jon Radoff, https://medium.com/building-the-metaverse/the-metaverse-value-chain-afcf9e09e3a7). The infrastructure layer, which consists of the hardware and network technologies that enable the distribution of content, is the foundation of the MedVerse in this illustration, which the MedVerse shares with all Metaverse apps. Higher layers are particular to MedVerse: The Human-Computer Interface layer incorporates wearable sensors and brain-based technologies into the MedVerse experience. The AI and decentralization layer makes use of blockchain-based protocols to enable the integration of AI services and other distributed online capabilities. The whole spectrum of physical-digital places made possible by VR systems is referred to as the "Phygital space layer." The MedVerse therapeutic experience's content should be customized to the unique clinical requirements of the patients with mental illnesses, according to the personalization layer. The personalization layer is all about the content of the MedVerse therapeutic experience, which should be tailored to the specific clinical needs of the patients with mental disorders. The MedVerse therapeutic experience's content should be customized to meet the unique clinical requirements of patients with mental disorders. This is what the personalization layer is all about.

5. Conclusions

Clinical psychology's use of metaverse technology will undoubtedly be a promising area of study in the near future (Riva et al., 2022). To better understand how the brain and body engage with the simulated environment and how social (virtual) communication mediated by AI could be tailored for enhancing human-computer interaction, more basic neuroscientific study is necessary.

Undoubtedly, however, the advent of the metaverse will stimulate future researchers in social neuroscience. Historically, discoveries relating to the "Social Brain" have enhanced awareness of the neurocognitive skills it incorporates (Adolphs, 2009). There has been an increase in interest in measuring and modeling "social cognition" and "social competence" over the past ten years. In order to comprehend the reciprocal relationships and influences between the social and biological levels of organization, social neuroscience aims to define the neurological, hormonal, cellular, and genetic mechanisms driving social behavior (Cacioppo et al., 2008). For this reason, the "metaverse" concept should be translated for neuroscientists in a less attractive concept of "Social VR-AI mediated", where engineers, computer scientists and psychologists should work together to develop new platforms able to balance simulations of real-life social activities in a more ecological manner for creating new validated protocols customized on psychological deficits, useful to stimulate new abilities. Indeed, we argue that the lack of social interaction within virtual worlds has been one of the main limitations of current applications of VR in mental health and rehabilitation. In most existing applications the patient is immersed in a virtual environment that exposes him/her to clinically relevant stimuli (e.g. threatening stimuli presented to patients with specific phobias), but the experience is lived in isolation (although, depending on the clinical protocol, the therapist can interact with the patient from outside the virtual environment). However, the social interaction component is crucial to increasing the effectiveness of treatment. This obviously includes the therapeutic interaction between the clinician and the patient, but also the possibility for the patient of interacting with other simulated people within the VR environment, thus creating a compelling sense of social presence. With respect to the traditional VR applications, developed for individual use, immersive social VR emerged only a few years ago, because technological challenges were too high to allow the realization of multi-user immersive virtual worlds. However, thanks to the rapid development of hardware and software pushed by the gaming industry and the increasing communication capability of 4G/5G networks and beyond, VR technology may soon realize the promise of enabling shared simulated spaces. Undoubtedly, the introduction of social VR environments in mental healthcare will not only open new avenues for treatment and prevention but will also present clinicians with a number of research questions that still need to be answered. For instance, what role does non-verbal communication play in an immersive clinical setting where the therapist and the patient interact via an avatar, or what concerns are associated with the potential introduction of artificial intelligence?

In conclusion, the advent of the metaverse in clinical psychology still must overcome numerous barriers as summarized in Figure 1. Indeed, before declaring the beginning of a new MEDverse era, several methodological and infrastructural advances should be carried out starting from the actual VR applications experienced alone to a multi-sensory experience based on multiple (intelligent) technologies shared by multi users.

Declarations

Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

No data was used for the research described in the article.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

Adolphs, R., 2009. The social brain: neural basis of social knowledge. Annu. Rev. Psychol. 60, 693–716.
Avani, S., Kraemer, K., Won, C., Black, S., Hasenbein, W., 2018. Developing digital intervention games for mental disorders: a review. Game. Health J. 7, 213–224.
Baghaei, N., Hach, S., Liang, H.-N., Brucker, M., 2019. MoodJumper: an exploration of game interface preferences in users with/out mood disorder. Front. Public Health 7, 220.
Baghaei, N., Chitale, V., Hlasnik, A., Stemmet, L., Liang, H.N., Porter, R., 2021. Virtual reality for supporting the treatment of depression and anxiety: scoping review. JMIR Ment. Health 8 (9), e29681.
Bailenson, J.N., Segovia, K.Y., 2010. Virtual doppelgangers: psychological effects of avatars who ignore their owners. In: Bainbridge, W.S. (Ed.), Online Worlds: Convergence of the Real and the Virtual. Springer, London, pp. 175–186.
Bailenson, J.N., Blascovich, J., Beall, A.C., Loomis, J.M., 2003. Interpersonal distance in immersive virtual environments. Pers. Soc. Psychol. Bull. 29, 819–833.
Bailenson, J.N., Yee, N., Merget, D., Schroeder, R., 2006. The effect of behavioral realism and form realism of real-time avatar faces on verbal disclosure, nonverbal disclosure, emotion recognition, and copresence in dyadic interaction. Presence Teleoperators Virtual Environ. 15, 359–372.
Bandura, A., 2001. Social cognitive theory of mass communication. Media Psychol. 3, 265–299.
Blanchard, C., Burgess, S., Harvill, Y., Lanier, J., Lasko, A., Oberman, M., et al., 1990. Reality built for two: a virtual reality tool. ACM SIGGRAPH Comput. Graph. 24, 35–36.
Blanchard, C., Burgess, S., Harville, Y., Lanier, J., Lasko, A., Oberman, M., Teitel, M., 1992. Reality built for two: a virtual reality tool. ACM SZGGRAPH Comput. Graph. 24 (2), 35–36.
Blanke, O., Slater, M., Serino, A., 2015. Behavioral, neural, and computational principles of bodily self-consciousness. Neuron 88 (1), 145–166.
Cacioppo, J.T., Berntson, G.G., Decety, J., 2008. Social neuroscience and its relationship to social psychology. Soc. Cognit. 28 (6), 675–685.
Campbell, S.B., Spieker, S., Burchinal, M., Poe, M.D., 2006. The NICHD Early Child Care Research Network. Trajectories of aggression from toddlerhood to age 9 predict academic and social functioning through age 12. J. Child Psychol. Psychiatry 47, 791–800.
Carl, E., Stein, A.T., Levihn-Coon, A., Pogue, J.R., Rothbaum, B., Emmelkamp, P., Asmundson, G.J., Carlbring, P., Powers, M.B., 2019. Virtual reality exposure therapy for anxiety and related disorders: a meta-analysis of randomized controlled trials. J. Anxiety Disord. 61, 27–36.
Chen, W.G., Schloesser, D., Arensdorf, A.M., Simmons, J.M., Cui, C., Valentino, R., Gnadt, J.W., Nielsen, L., Hillaire-Clarke, C.S., Spruance, V., Horowitz, T.S., 2021. The emerging science of interoception: sensing, integrating, interpreting, and regulating signals within the self. Trends Neurosci. 44 (1), 3–16.
Chitale, V., Baghaei, N., Playne, D., Liang, H.N., Zhao, Y., Erensoy, A., Ahmad, Y., 2022. The use of videogames and virtual reality for the assessment of anxiety and depression: a scoping review. Game. Health J. PMID: 35881854.
Chittaro, I., Buttussi, F., 2015. Assessing knowledge retention of an immersive serious game vs. a traditional education method in aviation safety. IEEE Trans. Visual. Comput. Graph. 21, 529e538.
Ciążyńska, J., Maciaszek, J., 2022. Various types of virtual reality-based therapy for eating disorders: a systematic review. J. Clin. Med. 11 (17), 4956.
Clark, A., 2013. Whatever next? Predictive brains, situated agents, and the future of cognitive science. Behav. Brain Sci. 36 (3), 181–204.
Clark, A., 2015. Surfing Uncertainty: Prediction, Action, and the Embodied Mind. Oxford University Press, Oxford.
Clus, D., Larsen, M.E., Lemey, C., Berrouiguet, S., 2018. The use of virtual reality in patients with eating disorders: systematic review. J. Med. Internet Res. 20 (4), e157.
Dakanalis, A., Gaudio, S., Serino, S., Clerici, M., Carrà, G., Riva, G., 2016. Body-image distortion in anorexia nervosa. Nat. Rev. Dis. Prim. 2, 16026.
Deng, W., Hu, D., Xu, S., Liu, X., Zhao, J., Chen, Q., Liu, J., Zhang, Z., Jiang, W., Ma, L., Hong, X., Cheng, S., Liu, B., Li, X., 2019. The efficacy of virtual reality exposure therapy for PTSD symptoms: a systematic review and meta-analysis. J. Affect. Disord. 257, 698–709.
Di Lernia, D., Lacerenza, M., Ainley, V., Riva, G., 2020. Altered interoceptive perception and the effects of interoceptive analgesia in musculoskeletal, primary, and neuropathic chronic pain conditions. J. Personalized Med. 10, 201.
Fernández-Herrero, J., Lorenzo, G., Lledó, A., 2018. A bibliometric study on the use of virtual reality (VR) as an educational tool for high-functioning autism spectrum disorder (ASD) children. In: Çetinkaya, ¸S. (Ed.), Contemporary Perspective on Child Psychology and Education. IntechOpen, London, UK, pp. 59–81.
Fox, J., Bailenson, J., Ricciardi, T., 2012. Physiological responses to virtual selves and virtual others. J. CyberTherapy Rehabil. 5, 69–72.
Gaudio, S., Brooks, S.J., Riva, G., 2014. Nonvisual multisensory impairment of body perception in anorexia nervosa: a systematic review of neuropsychological studies. PLoS One 9 (10), e110087.
GBD 2019, 2022. Mental Disorders Collaborators. Global, regional, and national burden of 12 mental disorders in 204 countries and territories, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet Psychiatr. 9 (2), 137–150.
Georgescu, R., Fodor, L.A., Dobrean, A., Cristea, I.A., 2020. Psychological interventions using virtual reality for pain associated with medical procedures: a systematic review and meta-analysis. Psychol. Med. 50 (11), 1795–1807.
Gonzalez-Franco, M., Bellido, A.I., Blom, K.J., Slater, M., Rodriguez-Fornells, A., 2016. The neurological traces of look-alike avatars. Front. Hum. Neurosci. 10, 392.
Gonzalez-Franco, M., Lanier, J., 2017. Model of illusions and virtual reality. Front. Psychol. 8, 1125.
Gorisse, G., Christmann, O., Amato, E.A., Richir, S., 2017. First- and third-person perspectives in immersive virtual environments: presence and performance analysis of embodied users. Front. Robot. AI 4, 33.
Grace, S.A., Labuschagne, I., Kaplan, R.A., Rossell, S.L., 2017. The neurobiology of body dysmorphic disorder: a systematic review and theoretical model. Neurosci. Biobehav. Rev. 83, 83–96.
Hartmann, A.S., Thomas, J.J., Wilson, A.C., Wilhelm, S., 2013. Insight impairment in body image disorders: delusionality and overvalued ideas in anorexia nervosa versus body dysmorphic disorder. Psychiatr. Res. 210, 1129–1135.
Heydrich, L., Dodds, T.J., Aspell, J.E., Herbelin, B., Bülthoff, H.H., Mohler, B.J., et al., 2013. Visual capture and the experience of having two bodies– evidence from two different virtual reality techniques. Front. Psychol. 4, 946.
Hohwy, J., 2013. The Predictive Mind. Oxford University Press, Oxford.
Huynh-The, Thien, Pham, Quoc-Viet, Pham, Xuan-Qui, Thi Nguyen, Thanh, Han, Zhu, Kim, Dong-Seong, 2022. Artificial intelligence for the metaverse: A survey. arXiv.
Iodice, P., Porciello, G., Bufalari, I., Barca, L., Pezzulo, G., 2019. An interoceptive illusion of effort induced by false heart-rate feedback. Proc. Natl. Acad. Sci. U. S. A 116, 13897–13902.
Lee, J., Lee, T.S., Lee, S., Jang, J., Yoo, S., Choi, Y., Park, Y.R., 2022. Development and application of a metaverse-based social skills training program for children with autism spectrum disorder to improve social interaction: protocol for a randomized controlled trial. JMIR Res. Protoc. 11 (6), e35960.
Lord, C., Charman, T., Havdahl, A., Carbone, P., Anagnostou, E., Boyd, B., Carr, T., de Vries, P.J., Dissanayake, C., Divan, G., Freitag, C.M., Gotelli, M.M., Kasari, C., Knapp, M., Mundy, P., Plank, A., Scahill, L., Servili, C., Shattuck, P., Simonoff, E., Singer, A.T., Slonims, V., Wang, P.P., Ysrraelit, M.C., Jellett, R., Pickles, A., Cusack, J., Howlin, P., Szatmari, P., Holbrook, A., Toolan, C., McCauley, J.B., 2022. The Lancet Commission on the future of care and clinical research in autism. Lancet 399 (10321), 271–334.
Matamala-Gomez, M., Maselli, A., Malighetti, C., Realdon, O., Mantovani, F., Riva, G., 2021 Jan 3. Virtual body ownership illusions for mental health: A narrative review. J. Clin. Med. 10 (1), 139.
Matamala-Gomez, M., Maselli, A., Malighetti, C., Realdon, O., Mantovani, F., Riva, G., 2021. Virtual body ownership illusions for mental health: a narrative review. J. Clin. Med. 10 (1), 139.
Matsangidou, M., Otkhmezuri, B., Ang, C.S., Avraamides, M., Riva, G., Gaggioli, A., et al., 2022. "Now i can see me" designing a multi-user virtual reality remote psychotherapy for body weight and shape concerns. Hum. Comput. Interact. 37 (4), 314–340.
Mesko, B., 2022. The promise of the metaverse in cardiovascular health. Eur. Heart J. 22, ehac231.
Mori, M., 1970. The uncanny valley. Energy 7, 33–35.
Myles, B.S., Barnhill, G.P., Hagiwara, T., Griswold, D.E., Simpson, R.L., 2001. A synthesis of studies on the intellectual, academic, social/emotional and sensory characteristics of children and youth with Asperger syndrome. Educ. Train. Ment. Retard. Dev. Disabil. 36, 304–311.
Park, S.-M., Kim, Y.-G., 2022. A metaverse: taxonomy, components, applications, and open challenges. IEEE Access 4209–4251, 2022.
Patil, I., Cogoni, C., Zangrando, N., Chittaro, L., Silani, G., 2014. Affective basis of judgment-behavior discrepancy in virtual experiences of moral dilemmas. Soc. Neurosci. 9, 94–107.
Paulus, M.P., Feinstein, J.S., Khalsa, S.S., 2019. An active inference approach to interoceptive psychopathology. Annu. Rev. Clin. Psychol. 15, 97–122.
Ratan, R., Beyea, D., Li, B.J., Graciano, L., 2020. Avatar characteristics induce users' behavioral conformity with small-to-medium effect sizes: a meta-analysis of the proteus effect. Media Psychol. 23 (5), 651–675.
Riva, G., Dakanalis, A., 2018. Altered processing and integration of multisensory bodily representations and signals in eating disorders: a possible path toward the understanding of their underlying causes. Front. Hum. Neurosci. 12 (49).
Riva, G., Wiederhold, B.K., 2022. What the metaverse is (really) and why we need to know about it. Cyberpsychol., Behav. Soc. Netw. 6, 355–359.
Riva, G., Wiederhold, B., Chirico, A., Di Lernia, D., Mantovani, F., Gaggioli, A., 2018. Brain and virtual reality: what do they have in common and how to exploit their potential. Annu. Rev. CyberTherapy Telemed. 16, 3–7.
Riva, G., Wiederhold, B.K., Mantovani, F., 2019a. Neuroscience of virtual reality: from virtual exposure to embodied medicine. Cyberpsychol., Behav. Soc. Netw. 22 (1), 82–96.
Riva, G., Wiederhold, B.K., Di Lernia, D., Chirico, A., Riva, E.F.M., Mantovani, F., Cipresso, P., Gaggioli, A., 2019b. Virtual reality meets artificial intelligence: the

emergence of advanced digital therapeutics and digital biomarkers. Ann Rev Cyber Telemed 18, 3–7.

Riva, G., Di Lernia, D., Sajno, E., Sansoni, M., Bartolotta, S., Serino, S., Gaggioli, A., Wiederhold, B.K., 2021a. Virtual reality therapy in the Metaverse: merging VR for the outside with VR for the inside. Annu. Rev. Cyber Telemed. 19, 3–8.

Riva, G., Serino, S., Di Lernia, D., Pagnini, F., 2021b. Regenerative virtual therapy: the use of multisensory technologies and mindful attention for updating the altered representations of the bodily self. Front. Syst. Neurosci. 15, 749268.

Riva, G., Villani, D., Wiederhold, B.K., 2022. Call for sSpecial issue papers: HUMANE METAVERSE: opportunities and challenges towards the development of a humane-centered metaverse. Cyberpsychol. Behav. Soc. Netw.

Sanz, F.A., Olivier, A.-H., Bruder, G., Pettré, J., Lécuyer, A., 2015. Virtual proxemics: locomotion in the presence of obstacles in large immersive projection environments. In: Virtual Reality (VR), 2015 IEEE. IEEE), Arles, pp. 75–80.

Shina, M., Kima, S.J., Biocca, F., 2019. The uncanny valley: No need for any further judgments when an avatar looks eerie. Comput. Hum. Behav. 94, 100–109.

Spanlang, B., Normand, J.M., Borland, D., Kilteni, K., Giannopoulos, E., Pomés, A., González-Franco, M., Perez-Marcos, D., Arroyo-Palacios, J., Muncunill, X.N., Slater, M., 2014. How to build an embodiment lab: achieving body representation illusions in virtual reality. Front. Robot. AI 1 (9).

Sparkes, M., 2021. What is a metaverse? New Sci. 251 (3348), 18.

Summers, B.J., Schwartzberg, A.C., Wilhelm, S., 2021. A virtual reality study of cognitive biases in body dysmorphic disorder. J. Abnorm. Psychol. 130 (1), 26–33.

Vaughn, D.A., Kerr, W.T., Moody, T.D., Cheng, G.K., Morfini, F., Zhang, A., Leow, A.D., Strober, M.A., Cohen, M.S., Feusner, J.D., 2019. Differentiating weight-restored anorexia nervosa and body dysmorphic disorder using neuroimaging and psychometric markers. PLoS One 14 (5), e0213974.

Wiederhold, B.K., Riva, G., 2019. Virtual reality therapy: emerging topics and future challenges. Cyberpsychol., Behav. Soc. Netw. 22, 3–6.

Wiederhold, B.K., Riva, G., 2022. Metaverse creates new opportunities in healthcare. Annu. Rev. Cyber Telemed. 20, 3–7.

Woodside, B.D., Staab, R., 2006. Management of psychiatric comorbidity in anorexia nervosa and bulimia nervosa. CNS Drugs 20, 655–663 pmid:16863270.

Yang, D., Zhou, J., Chen, R.C., Song, Y.L., Song, Z.J., Zhang, X.J., Wang, Q., Zhou, C.Z., Sun, J.Y., Zhang, L.C., Bai, L., Wang, Y.H., Wang, X., Lu, Y.T., Xin, H.Y., Powell, C.A., Thüemmler, C., Chavannes, N.H., Chen, W., Wu, L., Bai, C.X., 2022. Expert consensus on the metaverse in medicine. Clin. eHealth 5, 1–9.

Yee, N., Bailenson, J., 2007. The Proteus effect: the effect of transformed self-representation on behabvior. Hum. Commun. Res. 33 (3), 271–290.

Zanon, M., Novembre, G., Zangrando, N., Chittaro, L., Silani, G., 2014. Brain activity and prosocial behavior in a simulated life-threatening situation. Neuroimage 98, 134–146.

Zhang, M., Ding, H., Naumceska, M., Zhang, Y., 2022. Virtual reality technology as an educational and intervention tool for children with autism spectrum disorder: current perspectives and future directions. Behav. Sci. 12, 138.

Zhou, S., Zhao, J., Zhang, L., 2022. Application of artificial intelligence on psychological interventions and diagnosis: an overview. Front. Psychiatr. 13, 811665.