# Virtual Reality in Clinical Psychology

**Giuseppe Riva**[a,b], [a] Department of Psychology, Università Cattolica del Sacro Cuore, Milan, Italy; and [b] Applied Technology for Neuro-Psychology Lab, Istituto Auxologico Italiano I.R.C.C.S., Milan, Italy





## Introduction

This chapter examines the clinical potential of virtual reality (VR) in the assessment and treatment of mental health diseases. First, it explores the technologies behind the VR experience. In particular, the second paragraph describes the different hardware and software components—input devices, output devices, and the simulated scenario (i.e., the virtual environment)—required for a VR experience, as well as the difference between immersive and non-immersive VR and the evolution of VR technologies.

The third paragraph presents VR as an advanced form of reality simulation that has many similarities with the functioning of the brain. As suggested by the "predictive coding" paradigm, the brain actively creates an internal model (simulation) of the body and the space around it, which it uses to make predictions about the expected sensory input and to minimize the number of prediction errors (or "surprise"). In this view, the VR experience tries to mimic the brain model as much as possible—the more similar the VR model is to the brain model, the more the individual feels present in the VR world—making it the perfect tool for experiential learning.

The fourth paragraph suggests that VR is able to fool the predictive coding mechanisms that regulate the experience of the body, allowing it to make people feel "real" within a virtual environment. In other words, VR can offer new ways to structure, augment, and/or replace the experience of the body for clinical goals. It may also offer new embodied ways to assess the functioning of the brain by directly targeting the processes behind real-world behaviors.

The final paragraph presents and discusses different clinical applications of VR in the mental health domain. In line with the results of two recent meta-reviews assessing more than 53 systematic reviews and meta-analyses exploring the current use of VR in clinical psychology (Riva et al., 2016a, 2019b), existing research supports the clinical use of VR in the assessment and treatment of anxiety disorders, pain management, and eating and weight disorders, with long-term effects that generalize to the real world. Recent studies have also provided preliminary support for the use of VR in the assessment and treatment of psychosis, addictions, and autism.

## The Technology of Virtual Reality

For many clinicians, virtual reality (VR) is primarily a set of fancy technologies: a computer or mobile device with a graphics card capable of interactive 3D visualization, controllers, and a head-mounted display embedding one or more position trackers. The trackers sense the position and orientation of the user and communicate this information to the computer, which updates the images for display in real time.

 https://doi.org/10.1016/B978-0-12-818697-8.00006-6 

This description allows us to clearly identify the key technological components of a VR system (Parsons et al., 2017): input devices, output devices, and the simulated scenario (i.e., the virtual environment).

Input devices include all the sensors and trackers that capture the user's actions (e.g., head and hand movements) to allow the user to interact with the virtual environment. In fact, there are many different input devices that can be used in a VR system:

- *Tracking devices*: data gloves, head-positioning sensors, embedded cameras, eye trackers, etc.
- *Pointing devices*: six-degrees-of-freedom mouse, trackball, joystick, etc.

Output devices include all the technologies that provide continuous computer-generated information to the user. Even though the most important sensory modality for most VR clinical applications is the visual channel, more advanced VR systems also offer auditory, olfactory, and haptic (tactile) feedback.

Finally, the simulated scenario is the computer-generated 3D virtual environment (VE). VEs are designed to be explored, so users can interact (e.g., moving, pushing, picking, rotating, etc.) with their contents. Multi-user virtual environments (MUVEs) allow two or more users to share the same simulated scenario. To allow communication and interaction between users, MUVEs use avatars, which are personalized graphical representations of the individuals that are directly controlled by them in real time. Embodied virtual agents, on the other hand, are graphical representations of the individuals controlled by the computer itself using an artificial intelligence program.

### Immersive and Non-immersive VR

VR technology is usually classified as immersive or non-immersive (Gaggioli et al., 2009).

In general, a VR technology is immersive when it is able to sensorially separate the user from the physical world and to replace his/her sensory stream with the simulated scenario generated by the computer.

Head-mounted displays (HMDs) are the most common immersive VR technology (**Fig. 1**). They occlude any visual contact with the external world, and the internal display replaces it with computer-generated images. Thanks to the sensors embedded in the HMD, the computer-generated image is dynamically adapted to different viewing positions.

A more advanced and expensive immersive VR technology is the *cave automatic virtual environment* (CAVE) (Cruzneira et al., 1992), a cube-like space that surrounds a user in which images on the walls (including the floor and ceiling) are displayed by a series of projectors in stereoscopic modality (**Fig. 2**).

To see the 3D graphics projected in the CAVE, users wear 3D glasses. A motion capture system records the real-time position of the user, who can move inside the space, and adapts the images to continually retain the viewer's perspective.

Non-immersive VR systems use standard high-resolution monitors (desktop or laptop screens) as output devices, but these are unable to fully occlude the visual channel of the user. In addition, they have limited interactive capabilities (e.g., no motion tracking). Non-immersive virtual environments include 3D video games and desktop-based 3D modeling applications.


**Figure 1** Head Mounted Display. Image by Pete Linforth from Pixabay: https://pixabay.com/photos/virtual-reality-technology-3368729/ License Free for Commercial Use.

**Figure 2** CAVE system at Istituto Auxologico Italiano, Milan, Italy (my own picture).

## The Evolution of VR Technology

The use of VR in clinical practice has long been limited by two main factors: the lack of usability and the cost of virtual tools (Lindner et al., 2017; Zanier et al., 2018).

The early generation of VR devices, available between 1990 and 2015, was characterized by low display resolution, limited field of view, and uncomfortable designs. These problems were linked to different side effects such as motion sickness (due to low display quality) and neck pains (due to the weight of the HMD), limiting its use with patients.

Further, the typical immersive VR system required expensive HMDs, often costing more than 10,000 USD, paired with equally expensive high-end computers equipped with professional graphics cards. Finally, the development and use of a VR system required a high degree of technological expertize (to design the environment and operate it) that was typically unavailable in clinical settings.

March 2016 saw the release of the first generation of virtual reality headsets targeted at consumers. The Oculus Rift—an HMD developed and manufactured by Oculus VR, a division of Facebook Inc., and sold for 600 USD—marked a new generation of VR devices (see **Table 1**) that is revolutionizing how VR is used in general. In a few years, the cost of a complete VR device—including input, output, and 3D graphic computation—dropped by tens of thousands of dollars to just a few hundred, the price of the cheapest standalone VR systems.

The simplest and cheapest form of VR comprises nothing but a pair of magnifying lenses and a sheet of cardboard. It sells for 15–20 USD and uses a standard smartphone as a tracker and a display and to generate the 3D environment. Mobile-based VR made VR available even to casual users who own a smartphone, widening its availability to the general population.

Mobile-based VR is particularly suited to a specific VR content that can be very useful for VR-based exposure: *360-degree videos* (Li et al., 2017). These videos, also known as immersive videos or spherical videos, are special video recordings created using a camera with multiple camera lenses or a rig of multiple cameras. The use of different lenses allows the recording of every direction at the same time, effectively giving a full view of what is around the camera. One advantage of projecting a 360-degree video in a VR HMD is that when users turn their head, their view of the live-action video footage turns with them in real time, allowing the user to look around anywhere in the filmed footage.

In other words, 360-degree videos have the power to virtually transport users in the video recording, allowing them to actively explore its content and see the video from any angle. As recently demonstrated by Li et al. (2017), these videos have the ability to induce specific emotions characterized by different levels of valence and arousal. More, they can be used as a sensitive, and ecological tool that captures real-world executive dysfunctions in patients (Realdon et al., 2019). Different from traditional VR content that requires a specific platform and programming skills, 360-degree videos can be easily recorded by a clinical team using specific cameras (e.g., GoPro Max, Insta360 One, or Ricoh Theta SC) that cost less than 500 USD. Finally, immersive videos are directly supported by YouTube and Facebook, allowing for easy sharing of the developed content (Nason et al., 2019) (see Table in a different File)

## VR as a Reality Simulation

In the previous paragraph, VR was described as a set of fancy technologies (Riva et al., 2015): an interactive 3D visualization system (a computer, game console, or smartphone) supported by one or more position trackers and a head-mounted display. However, VR is more than a set of technologies. The word "virtual reality" comprises two words: "virtual" (almost or nearly as described) and "reality" (the actual state of things). Consequently, we can state that the term "virtual reality" basically means "almost reality" or "near reality," suggesting that VR is a form of reality simulation.

In this view, VR can be defined as (Schultheis and Rizzo, 2001) "an advanced form of human-computer interface that allows the user to interact with and become immersed in a computer-generated environment in a naturalistic fashion" (p. 82). From a cognitive

**Table 1** Commercially available VR Devices

| | *PC based* | | | *Mobile based* | | | *Console based* | *Standalone* | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Mobility required** | | | | | | | | | | |
| System | Oculus rift S | HTC cosmos/Vive pro/Pro eye | Valve index | Samsung gear VR | Google cardboard | Google daydream | PlayStation VR | Oculus go | Oculus quest | Lenovo Mirage VR S3 |
| Cost (USD) | 399 | 699/1199/1599 | 999 | 99 | 10–50 | 69–149 | 299 | 149 | 399 | 450 |
| Hardware requirements | High-end PC (>1000 USD) | High-end PC (>1000 USD) | High-end PC (>1000 USD) | High-end Samsung phone (>600 USD) | Middle/High end Android phone or iPhone (>299 USD) | High-end Android phone (>499 USD) | PS4 (299 USD) or PS4 pro (399 USD) | None (internal Snapdragon 821 processor) | None (internal Snapdragon 835 processor) | None (internal Snapdragon 835 processor) |
| Resolution | 2560 x 1440 | 2880 x 1660 | 2880 x 1660 | 2560 x 1440 | Depends on the phone (minimum 1024x768) | Depends on the phone (minimum 1920x1080) | 1920 x 1080 | 2560 x 1440 | 2560 x 1440 | 2160 x 1920 |
| Refresh rate | 80 Hz | 90 Hz | 120/144Hz | 60 Hz | 60 Hz | 90 Hz minimum | 120 Hz | 72 Hz | 72 Hz | 75 Hz |
| Field of view | 115° | 110° | 130° | 101° | From 70° | 96° | 100° | 90° | 100° | 110° |
| Body tracking | High: head tracking (rotation) and volumetric tracking (full room size – 15 × 15 ft - movement) | High: head tracking (rotation) and volumetric tracking (full room size – 15 × 15 ft - movement) | High: head tracking (rotation) and volumetric tracking (full room size – 15 × 15 ft - movement) | Medium: head tracking (rotation) | Medium: head tracking (rotation) | Medium: head tracking (rotation) | Medium/High: head tracking (rotation) and positional tracking (forward/ backward) | Medium: head tracking (rotation) | Medium/High: head tracking (rotation) and volumetric tracking (full room size –15 × 15 ft - movement) | Medium/High: head tracking (rotation) |
| User interaction with VR | High (using controllers) | Very high (using controllers and eye tracking) | High (using controllers) | Medium (using gaze, a built-in pad or joystick) | Low (using gaze or a button) | Medium (using gaze or a joystick) | High (using a joystick or controllers) | Medium (using gaze, a built-in pad or joystick) | High (using controllers or hand tracking) | Medium (using gaze, a built-in pad or joystick) |
| Software availability | Oculus store | Steam store | Steam store | Oculus store | Google play or IOS store | Google play | PlayStation store | Oculus store | Oculus store | Google play and Lenovo thinkreality |

viewpoint, VR is mainly a *subjective experience* that makes the user believe that he/she is there and that the experience is real (Riva et al., 2016a). Specifically, what distinguishes VR from other media is the sense of *presence*: the feeling of "being there" inside the virtual experience produced by the technology.

## What Is Presence?

VR research includes various descriptions of users believing, at least for a short time, that they were "inside" and "present" in the virtual experience.

But what is presence? This term was first used in 1992 in the title of a new journal dedicated to the study of VR: *Presence: Teleoperators and Virtual Environments.* In the first issue, Sheridan describes "presence" as an experience elicited by technology use (Sheridan, 1992): "*the effect felt when controlling real world objects remotely as well as the effect people feel when they interact with and immerse themselves in virtual environments*" (p. 121).

Following this approach, the International Society for Presence Research today defines "presence" (a shortened form of the term "telepresence") as (ISPR, 2000) "*a psychological state in which even though part or all of an individual's current experience is generated by and/or filtered through human-made technology, part or all of the individual's perception fails to accurately acknowledge the role of the technology in the experience*."

This definition describes the feeling of presence experienced in VR as "media presence," a function of our experience of a given medium (Schloerb, 1995; Sadowski and Stanney, 2002; Lombard and Ditton, 1997; Sheridan, 1992). The main outcome of this approach is the *perceptual illusion of non-mediation* (Lombard and Ditton, 1997) definition of presence: "*The term 'perceptual' indicates that this phenomenon involves continuous (real time) responses of the human sensory, cognitive, and affective processing systems to objects and entities in a person's environment. An 'illusion of non-mediation' occurs when a person fails to perceive or acknowledge the existence of a medium in his/her communication environment and responds as he/she would if the medium were not there.*"

According to this definition, presence is produced by means of the disappearance of the medium from the conscious attention of the subject. As clarified by Lombard and Ditton (1997): "*Presence in this view cannot occur unless a person is using a medium. It does not occur in degrees but either does or does not occur at any instant during media use.*"

The main advantage of this approach is its predictive value: to increase the level of presence, VR has to reduce the experience of mediation offered to the user. At the same time, however, it does not provide any answers to different critical questions: Are we present only in VR? What is presence for?

As underlined by Biocca (1999), "*while the design of virtual reality technology has brought the theoretical issue of presence to the fore, few theorists argue that the experience of presence suddenly emerged with the arrival of virtual reality*" (p. 121).

However, the findings of recent neuroscience studies consider presence as *inner presence* (Waterworth et al., 2010; Revonsuo, 2006; Riva et al., 2011, 2019b), which is the outcome of a broad simulative phenomenon, not necessarily linked to the experience of a medium, used by our brains to minimize the number of prediction errors (or "surprise"). In his book *Inner Presence*, Revuonso (2006) clearly states: "*To be conscious is to have the sense of presence in a world… To have contents of consciousness is to have patterns of phenomenological experience present… In the philosophy of presence, consciousness is an organized whole of transparent surrogates of virtual objects that are immediately present for us in the here-and-now of subjective experience*" (pp. 126–129). Thus, media presence is the result of the ability of VR to reproduce the same simulative mechanisms used by inner presence. In other words, the more similar the VR model is to the brain model, the more the individual feels present in the VR world. We will further explore this claim in the next paragraph.

## The Neuroscience of Presence

"Predictive coding" (Friston, 2010, 2012; Clark, 2013) is an increasingly popular hypothesis in neuroscience suggesting that our brains actively create an internal model (simulation) of the body and the space around it. This model is used to provide predictions about the expected sensory input and to minimize the number of prediction errors (or "surprise").

Specifically, to effectively interact with the world, our brains create an embodied simulation of the body that reflects its expected future states (intentions and emotions). There are two main characteristics of this simulation (Riva et al., 2019b). First, it is a simulation of sensory-motor experiences—types of these experiences include visceral/autonomic (interoceptive), motor (proprioceptive), and sensory (e.g., visual, auditory) information. Second, embodied simulations are based on the expectations of the subject and reactivate multimodal neural networks that have previously produced the simulated/expected effect. A critical goal of this process is to minimize the average of surprise (i.e., the disparity between intentions and the effects of enacting them) across the different representations and to learn how best to model and predict incoming contents. In other words, the embodied simulation is adjusted on the basis of the (dis)agreement (Talsma, 2015) between the perceived sensory activity (perception) and the contents of the simulations used to predict the effects of the being in the world of the individual.

Virtual reality works in a similar way (Riva et al., 2019b): it uses technology to create a virtual experience that individuals can manipulate and explore as if they were in it. In other words, VR technology attempts to predict the sensory consequences of users' actions by showing them the same outcome expected by our brains in the real world. As underlined by Riva et al. (2019b): "*To achieve it, like the brain, the VR system maintains a model (simulation) of the body and the space around it. This prediction is then used to provide the expected sensory input using the VR hardware. Obviously, to be realistic, the VR model tries to mimic the brain model as much as possible: the more the VR model is similar to the brain model, the more the individual feels present in the VR world*" (p. 89).

### The Advantages of Simulation for Clinical Practice

Experiential learning has a long history as a therapeutic technique, and the simulative power of VR makes it the perfect tool for experiential learning. VR allows patients to learn through reflection on doing. As noted by Glantz et al. (1997), "*One reason it is so difficult to get people to update their assumptions is that change often requires a prior step – recognizing the distinction between an assumption and a perception. Until revealed to be fallacious, assumptions constitute the world; they seem like perceptions, and as long as they do, they are resistant to change*" (p. 96). Through the VR experience, it is easier for the therapist to demonstrate to the patient that what looks like a fact is actually a result of his/her mind. Once this concept is understood, individual maladaptive assumptions can be challenged more easily.

VR can also be described as an *advanced imaginal system*: an experiential form of imagery that is as effective as reality at inducing emotional responses (North et al., 1997; Vincelli, 1999; Vincelli et al., 2001). This outcome has been demonstrated by multiple studies. For example, Slater et al. (2006) reproduced Stanley Milgram's 1960s experiment using VR: the selected sample was asked to administer a memory test to a female virtual human (avatar) and to provide an "electric shock" to her in the event of an incorrect answer, increasing the voltage each time. During the VR experiment, like in the original one, the avatar responded to the electric shocks with increasing discomfort, eventually demanding termination of the experiment. Their results confirm the simulative efficacy of VR: even though all participants knew for sure that neither the avatar nor the shocks were real, they responded to the situation at the subjective, behavioral, and physiological levels as if it were real.

More, as demonstrated by Balzarotti and colleagues (Balzarotti et al., 2014), VR avatars are recognized as intentional agents and users adjust their emotion nonverbal behavior according to the behavior of the avatar.

VR is also able to induce emotional responses in clinical patients. As will be described later, numerous studies have shown that VR is capable of increasing subjectively reported anxiety in phobic participants confronted with a threatening virtual situation, similar to the effects experienced in in vivo conditions (Powers and Emmelkamp, 2008; Opris et al., 2012). Consequently, as demonstrated by a recent meta-analysis, VR is an effective and equal medium for exposure therapy.

However, VR does have advantages over in vivo exposure (Riva et al., 2015):

- *Cost*: In vivo exposure is costly because it requires the therapist to go to the feared place with the patient. Exposure interventions "without a therapist" are still not very frequent, and patients are often reluctant to participate in this type of treatment.
- *Availability*: The feared situations are not always easily accessible, and imaginal exposure (that is, exposure to imagined situations) in these cases is less effective.
- *Engagement*: The immersion and interaction offered by VR improves the engagement of the intervention, which in turn would permit to enhance the adherence of participants to the interventions.
- *Control*: VR exposure allows almost total control of everything occurring in the situation experienced by the person in the virtual world, including different elements that can make the situation more or less threatening (e.g., the number or the size of feared persons, animals, or objects; the height of the spaces; the presence of protecting elements, etc.). Furthermore, the therapist is always able to know what is happening in the situation, what elements are being faced by the patient, and what is disturbing him/her. More, in VR it is also possible to control the framing of the experience. As underlined by Balzarotti and Ciceri (Balzarotti and Ciceri, 2014) positively framed experiences generate less fear than negatively framed ones
- *Realism and presence*: Different from imaginal exposure, users in VR feel present and judge their situation as real. This aspect is fundamental since exposure therapy is intended to facilitate emotional processing of fear memories.
- *Going beyond reality*: Virtual worlds allow for the creation of situations or elements so "difficult or threatening" that they would not be expected to happen in the real world.
- *Personal efficacy*: VR is an important source of personal efficacy. It allows for the construction of "virtual adventures" in which the person experiences him/herself as competent and efficacious. The goal is for the person to discover that the obstacles and feared situations can be overcome through confrontation and effort.
- *Safety*: In vivo exposure can be very aversive for patients and can make them feel very insecure, as there is no assurance that something will not go wrong (e.g., an elevator stopping, technical problems on a plane, etc.). Safety is an important advantage of VR. Patients can control the context and the computer-generated setting with the therapist as they wish and with no risk involved.
- *Privacy and confidentiality*: The possibility offered by VR of confronting many fears inside the therapist's office, without the need for in vivo exposure, offers significant advantages of increased privacy and confidentiality.

## Future Research Directions

As we will see in the following pages, the most common clinical application of VR is exposure therapy (virtual reality exposure therapy, or VRE), which is used to simulate an external reality. In other words, VR is used clinically to make people feel that what is actually not there is "real." In the previous paragraphs, we have seen the ability of VR to fool the predictive coding mechanisms that regulate the experience of the body, allowing it to make people feel "real" in situations that are not. In other words, VR offers new ways to structure, augment, and/or replace the experience of the body for clinical goals (Riva, 2008, 2016; Riva et al., 2017). Further, it may offer new embodied ways to assess the functioning of our brain (Parsons, 2015; Parsons et al., 2017; Riva, 2008, 2016) by directly targeting the processes behind real-world behaviors (Serino et al., 2017; Cipresso, 2015; Cipresso et al., 2016).

But what is the real clinical potential of VR as an embodied technology? According to neuroscience, the body matrix is a complex brain network (Moseley et al., 2012; Gallace and Spence, 2014; Finotti et al., 2015; Finotti and Costantini, 2016) that serves to maintain the integrity of the body at both the homeostatic and psychological levels by supervising the cognitive and physiological resources necessary to protect the body and the space around it. Specifically, the body matrix plays a critical role in high-end cognitive processes such as motivation, emotion, social cognition, and self-awareness (Tsakiris, 2017; Maister et al., 2013, 2015) while exerting a top-down modulation over basic physiological mechanisms such as thermoregulatory control (Macauda et al., 2015; Gallace et al., 2014) and the immune system (Finotti and Costantini, 2016).

In addition, contents within the body matrix are shaped by predictive multisensory integration (Apps and Tsakiris, 2014; Calvert et al., 2004; Sutter et al., 2014): higher-order networks generate predictions about expected sensory inputs with the ultimate goal of using these predictions to coordinate all bodily inputs in a coherent and functional mental representation (Bayesian principle). In this view, multisensory integration conflicts (Ehrsson, 2012) represent a failure in this functional adaptation process, leading to several pathological conditions. As underlined by Ho et al. (2020): "*Impaired feedback affecting any level of the multisensory hierarchy could disturb the coherent integration of lower-level signals with the bodily self and disrupt the individual's optimal interaction with the external and social world*" (p. 528). Specifically, altered functioning of the body matrix and/or multisensory integration processes might produce disorders of the bodily self that underlie different neurological and psychiatric conditions (Riva, 2008; Riva et al., 2017; Brugger and Lenggenhager, 2014; Tsakiris and Critchley, 2016; Ho et al., 2020).

If this theory is true, VR could be the core of a new *trans*-disciplinary research field—embodied medicine (Riva, 2016; Riva et al., 2017)—the main goal of which is the use of virtual reality to alter the body matrix with the goal of improving people's health and well-being. Specifically, using VR could alter the body matrix in three different ways:

- *By replacing multisensory bodily contents with synthetic ones (synthetic embodiment)*: As we have seen before, VR allows for different types of synthetic bodily experiences. The most advanced of these is *full body swapping*, in which the individual's body is substituted by a virtual body (Petkova and Ehrsson, 2008). In other words, as in the movie *Being John Malkovich*, individuals can experience the perspective of another individual, seeing what the other sees, hearing what the other hears, and touching what the other touches. Recently, Riva and colleagues (Riva et al., 2017; Di Lernia et al., 2018) introduced the concept of "sonoception," a novel non-invasive technological paradigm based on wearable acoustic and vibrotactile transducers, as a possible approach to replacing the contents of the inner body (e.g., interoception). The first outcome of this approach is the development of an interoceptive stimulator that is able to enhance heart rate variability (the short-term vagally mediated component RMSSD) by delivering precise interoceptive parasympathetic stimuli to C-tactile afferents connected to the lamina I spinothalamocortical system (Di Lernia et al., 2018).
- *By structuring multisensory bodily contents through awareness and reorganization (mindful embodiment)*: Individuals have different levels of body awareness, which is the extent of sensitivity and attentiveness to bodily signals and sensations (Ginzburg et al., 2014). VR can be applied to improve body awareness when it is integrated with other technologies like biosensors. For example, in integration with biofeedback training, it can be used to assess and control specific body signals—like heart rate, galvanic skin response, electromyography, or electroencephalography (Gaggioli et al., 2014; Repetto et al., 2009a)—that are normally not consciously perceivable and to report these signals back to the patient. The patient can then learn to shift these measured signals in the desired direction by means of the feedback provided by VR (e.g., a waterfall changes its flow according to the heart rate of the individual).
- *By augmenting multisensory bodily contents by altering/extending their boundaries (augmented embodiment)*: By integrating VR with biosensors, stimulation, and haptic devices, it is possible to map the contents of a sensory channel to a different one (e.g., vision to touch or to hearing) in order to increase sensitivity and replace the impaired channels (Waterworth and Waterworth, 2014). For example, Ward and Meijer (2010) developed a virtual sound experience to convert information normally delivered to the visual field into an auditory representation. In a different study, Suzuki and colleagues (Suzuki et al., 2013) combined feedback of interoceptive information (heart rate) with computer-generated augmented reality to produce a "cardiac rubber hand illusion." Their results suggest that the feeling of ownership of the virtual hand is enhanced by cardio-visual feedback in time with the actual heartbeat, supporting the use of this technique to improve emotion regulation.

With these approaches, it is possible to use VR to reach the following two clinical goals (Riva, 2018). First, VR can be used to facilitate the integration of external and internal body signals (Suzuki et al., 2013; Azevedo et al., 2017) and to improve the multisensory integration processes. Second, VR and sonoception can be used to induce a controlled mismatch between the predicted/dysfunctional content and the actual sensory input (Serino et al., 2016a) that is able to correct the prediction of the brain.

## Clinical Applications and Recommendations*

The clinical potential of VR is clearly supported by clinical outcomes. Two recent meta-reviews (Riva et al., 2016a, 2019b) assessing more than 53 systematic reviews and meta-analyses exploring the current use of VR in clinical psychology support its use in anxiety disorders, eating and weight disorders, and pain management, with long-term effects that generalize to the real world. VR also has significant applicative potential in other areas like psychosis and addictions. In the following paragraphs, we will discuss how VR has been applied in these different areas and the achieved clinical results.

## Anxiety Disorders

According to the American Psychological Association's guidelines for empirically supported treatments (Practice, 2006), exposure-based therapies can be considered as a reference treatment for the treatment of obsessive-compulsive disorder, post-traumatic stress disorder, panic disorder (PD), specific phobias, and social anxiety disorder. However, only a small group of individuals with anxiety disorders receive this treatment (Olatunji et al., 2010); VR technology can increase the number of patients treated with this approach (Fernández-Álvarez et al., 2020).

As discussed previously, VR can be described as an advanced imaginal system, an experiential form of imagery that is as effective as reality at inducing emotional responses (North et al., 1997; Vincelli, 1999; Vincelli et al., 2001). This feature makes VR exposure therapy (VRET) the perfect tool for disseminating exposure therapy. In addition, VRET offers multiple advantages over in vivo exposure (Riva et al., 2015)—cost, availability, safety, etc.—that we discussed before.

A recent meta-analysis confirms strong treatment effects for VR exposure-based therapy for anxiety disorders (Carl et al., 2019): VRET showed a large effect size (Hedge's g = 0.88) compared to waitlist conditions and a medium to large effect size compared to psychological controls. Further, VRET was not significantly more or less effective than in vivo exposure. A recent study (Fernandez-Alvarez et al., 2019) examining the deterioration rates of VR-based treatments for anxiety disorders showed that the number of deteriorated patients coincided with other therapeutic approaches and that deterioration is less likely to occur compared to waitlist conditions.

A common opinion between clinicians is that VR may induce more dropouts than non-VR approaches. However, a recent meta-analysis on attrition rates in VRET (Benbow and Anderson, 2019) showed that among the 1057 participants involved in 46 different studies only 16% dropped out. These results are similar to in vivo exposure. More, the meta-analysis indicates that the inclusion of homework assignments is the most significant predictor of non-attrition, suggesting its implementation in any VRET protocol (Benbow and Anderson, 2019).

Specific phobias were the first anxiety disorders to be treated using VRET, and its efficacy is now supported by multiple meta-analyses (Powers and Emmelkamp, 2008; Opris et al., 2012).

A growing body of literature is now supporting VRET for additional disorders. The meta-analysis (Carl et al., 2019) expands support for the use of VR for social anxiety disorder and performance anxiety (Hedge's $g = 0.96$), post-traumatic stress disorder (Hedge's $g = 0.59$), and panic disorders (Hedge's $g = 1.03$). VRET has also been used in several additional areas of anxiety from stress management (Pallavicini et al., 2016; Shah et al., 2015) to generalized anxiety disorders (Repetto et al., 2013).

Recently, some researchers have also explored the possible use of consumer-ready, gamified self-help VRET applications using low-cost, commercially available VR hardware (Lindner et al., 2017). For example, COVID Feel Good (www.covidfeelgood.com) is a free self-help solution for providing stress management and social support during the COVID-19 pandemic using a smartphone and a low-cost (>20 US$) headset (Riva & Wiederhold, 2020). A randomized controlled study by Freeman et al. (2018) compared an automated VRET protocol for fear of heights versus usual care (control group). The automated psychological intervention delivered by immersive VR was highly effective at reducing fear of heights. In a second randomized controlled trial, Lindner et al. (2019) compared the efficacy of therapist-led VRET for public speaking anxiety with self-led, at-home VRET. Both VRET formats led to significant improvements in the level of anxiety. Moreover, the improvements achieved by the self-led arm were maintained at the six-month follow-up, and patients undergoing the therapist-led arm also continued to improve at the twelve-month follow-up. These results support the use of self-led VRET and suggest that currently available internet-based treatments may benefit from the inclusion of VR exposure tools.

Another emerging approach in the treatment of anxiety disorders is the use of VR biofeedback systems (Fernández-Álvarez et al., 2020; Schoeller et al., 2019).

Biofeedback is an effective way for supporting emotion regulation through the conscious registration of normally unconscious body procedures (e.g., electrocardiogram, electromyography, brain activity, or skin conductance) that are represented by a visual, haptic, or audio signal (Schoenberg and David, 2014). Through the monitoring and visualization of human physiological reactions, individuals can see their body functions and understand their reaction to different anxious or stressful stimuli. In practice, biofeedback helps individuals to understand these habitual patterns and to take steps to change them to reduce symptoms associated with different diseases and disorders. VR offers a significant advantage to these processes (Fernández-Álvarez et al., 2020): it allows to represent the physiological process through virtual stimuli that are connected to biosensors, strengthening the engagement of users and potentially augmenting also the effectiveness of the interventions. A first support to this approach it is offered by different studies with healthy and clinical population (Repetto et al., 2009b, 2013; Fernandez et al., 2019).

Finally, a possible new approach, is the combination of VR with transcranial magnetic stimulation (TMS), transcranial direct current stimulation (tDCS) or intermittent theta burst stimulation (iTBS). As demonstrated by different studies neurostimulation of the dorsolateral prefrontal cortex (DLPFC) has an effect on the processing and memory of emotional visual stimuli (Balzarotti and Colombo, 2016). In this view, combining VRET with neurostimulation may improve the clinical efficacy of this approach, even if strong clinical evidence is still missing (Riva et al., 2019b; Notzon et al., 2015; van 't Wout-Frank et al., 2019).

## Pain Management

VR interventions have been used in acute pain management related to healthcare interventions for over two decades (Chan et al., 2018). Pharmacological approaches remain the mainstay for most interventions, but their significant drawbacks—including narrow therapeutic windows, adverse side effects, and drug misuse and dependence—are making VR-based interventions a valuable option (Wiederhold et al., 2014).

The most common approach used in VR acute pain management is distraction. This approach uses VR to draw the patient's attention to the computer-generated world, diverting it from incoming pain signals (Ahmadpour et al., 2019). As underlined by a systematic review (Triberti et al., 2014), while the feeling of presence in the VR experience influences its effectiveness as a distraction tool, anxiety as well as positive emotions directly affect the experience of pain. In fact, it is well known that negative affect worsens reported pain by activating the insula cortex. In this view, distraction can also be enhanced by the use of VR to induce positive emotions (Sharar et al., 2016).

A more advanced form of distraction is focus shifting (Ahmadpour et al., 2019), which uses agency to improve engagement and shift of attention. In VR focus shifting experiences, the user is required to interact with the virtual environment and achieve specific goals.

A final mechanism used to induce VR analgesia is skill building (Ahmadpour et al., 2019). This approach uses VR to build the skills and competences needed to help individuals regulate their response to painful stimuli. As in focus shifting, the user plays an active role. However, the goal of the VR experience in this case is to help patients self-regulate pain, for example, by controlling respiration during the pain experience to improve the patient's sense of control.

A recent meta-analysis confirmed the efficacy of these approaches (Chan et al., 2018): across 16 trials, it found a −0.49 standardized mean difference reduction in pain score with VR.

More recently, VR-based interventions have also been used for chronic pain management (Jones et al., 2016). Although chronic pain is substantially different from acute pain because of the many psychological factors and central nervous system processes involved, most VR chronic pain interventions are based on the same three approaches previously discussed. And the results are similar: VR is effective during the sessions, but its analgesic effects beyond the VR session are limited (Ahmadpour et al., 2019).

To improve long-term results, some researchers are starting to use synthetic embodiment—the use of VR to replace multisensory bodily contents with synthetic ones—for chronic pain management. The rationale of this approach is to use the embodiment potential of VR to correct a dysfunctional representation of the affected part of the body.

For example, synthetic embodiment is currently used for the treatment of phantom limb pain, an experience caused by dysfunctional alterations in amputees' representations of their body. As discussed by Dunn and colleagues in their review (Dunn et al., 2017), VR has been used to allow patients to gain agency of a virtual limb to perform assigned tasks. Randomized controlled trials are not yet available, but the case studies reveal the great potential of VR intervention as patients achieved reduced pain intensity.

Another form of synthetic embodiment used in VR analgesia is VR body swapping, the illusion of owning a virtual body (Hansel et al., 2011; Martini et al., 2014). A narrative review by Matamala-Gomez et al. (2019b) suggests that this approach can modulate body representation and change pain perception in healthy and clinical populations. Again, even though research in this field is quite new (Matamala-Gomez et al., 2019a), the approach is very promising.

## Eating and Weight Disorders

Over the last 25 years, VR has offered innovative solutions for reducing food cravings, improving body image, and enhancing emotion regulation skills in eating and weight disorders (Riva et al., 2016b, 2019a). In particular, four different randomized controlled trials (Marco et al., 2013; Manzoni et al., 2016; Cesa et al., 2013; Ferrer-Garcia et al., 2019) have shown at long-term follow-ups that VR had a higher efficacy in treating eating disorders and obesity than the gold standard in the field, i.e., cognitive behavioral therapy (CBT).

The first application of VR in this field was in body image research to explore the concept of body image and to aid the evaluation of body image disturbances. The possibility of developing VR-based applications exploring body representations has advanced due to substantial progress in technology that now supports the use of increasingly realistic and interactive "avatars." The term "avatar" refers to virtual self-representations in digital worlds, including online collaborative virtual worlds (e.g., Second Life) as well as video games and virtual environments for clinical purposes (Gaggioli et al., 2003).

Typically, these applications consist of a 3D human figure whose body parts can be modified using sliders. The main advantage of this approach is that the software allows clinicians to assess several dimensions or indexes of body image (e.g., the perceived body, the desired body, the healthy body, etc.) and body weight (actual weight, subjective weight, healthy weight, and desired weight), all in different contexts.

Researchers have also used the ability of VR to reproduce everyday life environments to study whether body image disturbance in patients with eating disorders changes depending on the situation (Ferrer-Garcia and Gutierrez-Maldonado, 2010). Results show that body image distortion and dissatisfaction can be influenced by situational factors. In this view, the use of different virtual scenarios representing a range of stressful real-life situations can provide clear, therapist-independent information about the subjective view that patients have of their bodies (Riva et al., 2019a).

A recent neuroscientific model suggests that eating disorders may reflect a deficit in the processing and integration of multisensory bodily representations and signals (Riva and Dakanalis, 2018; Riva and Gaudio, 2018). Specifically, the multisensory body integration deficit may impair an individual's abilities: (a) to identify the relevant interoceptive signals that predict potential pleasant (or aversive) consequences and (b) to modify/correct the autobiographical allocentric (observer view) memories of body-related events (self-objectified memories).

VR allows the targeting of impaired multisensory body integration through two different strategies—reference frame shifting (Akhtar et al., 2017; Riva, 2011) and body swapping (Normand et al., 2011; Gutiérrez-Maldonado et al., 2016)—that can be integrated within classical cognitive behavioral therapy (CBT).

The first method, reference frame shifting (Akhtar et al., 2017; Riva, 2011), attempts to modify the individual's bodily self-consciousness through the focus and reorganization of body-related memories (Osimo et al., 2015; Riva, 2011). To achieve this goal, the subject re-experiences in VR a negative situation related to the body (e.g., teasing) both from first-person and third-person perspectives (e.g., seeing and supporting his/her avatar in the VR world). In general, the therapist asks the patient to give detailed descriptions of the virtual experience and the feelings associated with it. Furthermore, the patient is taught how to cope with these feelings using different cognitive techniques.

This approach has been successfully used in different randomized trials with obese patients (Cesa et al., 2013; Manzoni et al., 2016), allowing them to both update the contents of their body memory and to improve the clinical outcomes over traditional CBT.

In the second method—body swapping (Normand et al., 2011; Gutiérrez-Maldonado et al., 2016; Serino and Dakanalis, 2017)—VR is used to induce the illusory feeling of ownership of a virtual body with a different shape and/or size. As for chronic pain management, the clinical goal of body swapping is to correct the dysfunctional representation of the body. Although bodily illusions have yet to be tested in an RCT against an active treatment, preliminary results support the rationale of this approach (Serino et al., 2016a,b, 2019; Preston and Ehrsson, 2014, 2016; Keizer et al., 2016).

VR can also reduce eating-related anxiety during and after exposure to virtual food, helping to disrupt the reconsolidation of adverse food-related memories and to modulate food craving, which is the intense desire to consume a specific food (Riva, 2017). As demonstrated by an experimental study (Gorini et al., 2010), real food and VR food produce comparable emotional reactions in patients with eating disorders, and this reaction is stronger than the one produced by photographs of food. In this view, cue exposure therapy (CET) using VR food has been used to extinguish/habituate craving and anxiety responses and thus reduce the associated risk of overeating. A recent randomized controlled trial with a six-month follow-up confirmed the validity of this approach in a sample of patients with bulimia and binge eating disorder: VR CET produced better results than CBT, the gold standard for these pathologies.

Finally, VR-based exergames have been used in the treatment of obesity. The term "exergames"—a portmanteau of the words "exercise" and "gaming"—indicates video games that provide a form of exercise (Rizzo et al., 2011). Via engaging digital gaming interacted with via body movements, exergames increase motivation to participate in calorie-burning cardiovascular exercise activities. In particular, the three factors influencing motivation and compliance (Lyons, 2015)—feedback, challenge, and rewards—are all supported by virtual reality experiences.

### Psychosis

Over the last 15 years, studies have attempted to establish the safety of using VR with individuals experiencing psychosis and to understand the psychological mechanisms behind the onset and maintenance of psychotic symptoms (Valmaggia, 2017).

As underlined by two recent systematic reviews (Valmaggia et al., 2016; Rus-Calafell et al., 2018), VR was first applied in this field to explore the psychological processes and mechanisms associated with the onset and maintenance of psychosis. Specifically, VR has been used as a controlled setting in which to study the effect of adverse life events on real-time response to social situations. Through the manipulation of population density, the ethnic density of avatars, or even the height of the user, it is possible for researchers to control the levels of paranoid ideation and auditory hallucinations (Veling et al., 2014; Freeman et al., 2014).

In addition, by using virtual agents and virtual scenarios, researchers can assess functional capacity, social cognition, and social competence (Freeman et al., 2017).

All these studies suggest that VR is a safe setting for assessing psychotic symptoms. In particular, patients did not show any aggravation of psychotic symptoms after VR exposure, and they did not report any distress related to the VR experience (Valmaggia et al., 2016; Rus-Calafell et al., 2018).

More recently, VR has also been used to improve cognitive remediation therapy for psychotic disorders, a clinical approach that aims at improving cognitive processes with the goal of durability and generalization to functioning in daily life (Wykes and Spaulding, 2011). VR allows for the creation of specific scenarios in which to train and develop problem solving, social, and interpersonal skills (Fernández-Sotos et al., 2020).

Patients are much more likely to test out their competences in VR because they know it is a simulation, but what they learn in VR then transfers to the real world. VR treatment can also include engaging tasks that make treatment much more enjoyable. Finally, VR scenarios can offer graded experiences that allow the individual to repeatedly test situations they find difficult and learn new skills (Freeman et al., 2019).

Despite the low number of published trials, all studies obtained promising results with short-term improvements in social skills and/or social cognition (Fernández-Sotos et al., 2020). A future step, as for anxiety disorders, is the use of automated VR applications using low-cost, commercially available VR hardware. A running trial (Freeman et al., 2019) is currently testing this approach with psychotic patients who have difficulties being in everyday social situations due to anxiety.

### Addictions

VR interventions have been used in the assessment and treatment of addictive disorders for over 15 years (Segawa et al., 2019). The first application of VR in this field was to study cue reactivity (Bordnick et al., 2005, 2008). Specifically, using VR cue environments, researchers assessed craving and reactivity to drug cues. In these studies, participants were exposed to cues in a VR environment, and subjective (e.g., craving or desire to use) and objective (e.g., physiology) measurements were recorded. The VR experience can also be modulated to evaluate behavioral responses to a distressing situation.

As underlined by a recent systematic review (Segawa et al., 2019), VR has been effectively used to elicit craving and cue exposure in people addicted to alcohol, cocaine, gambling, marijuana, methamphetamines, and nicotine. In particular, VR exposition is able to drive cue attentional bias and cognitive distortions and to activate interoceptive reactions such as heart rate variation.

Recently, VR cue exposure has also been used in treatment. However, treatments based exclusively on virtual exposure to drug-related cues have provided heterogenous results (Trahan et al., 2019). As indicated by a recent randomized controlled trial, the integration of VR exposure in a CBT protocol for smoking addiction achieved similar outcomes to CBT alone in both retention and smoking cessation rates (Pericot-Valverde et al., 2019).

### Autism

VR, which has been used in the assessment and treatment of autistic children since 1996 (Strickland et al., 1996), has been used to improve social skills, nonverbal communication, and emotional skills (Lorenzo et al., 2019).

One of the first approaches was the use of VR for social and communicative skills training (Miller et al., 2020). Specifically, VR social simulations that replicate real-life events (e.g., a virtual café, a bus, or a crossing road) have been used to train autistic children to manage different graded scenarios (Moon and Ke, 2019). During the VR experience, they have to initiate social actions and verbal discourses with simulated social actors to reach training goals and build their self and social identities. Another important area is the use of VR to improve emotional skills. For example, Ghanouni et al. (2019) developed a validated library of VR social stories focused on perspective-taking that offer gradual levels of emotion intensity and difficulty. This approach needs to better tailor the VR experiences to the specific coping skills of each child. In a recent randomized controlled trial (Maskey et al., 2019), clinicians used VR to treat autistic children experiencing specific phobias with positive results.

In general, available results suggest that VR is a promising tool for improving social skills, cognition, and functioning in autism. However, existing studies do not clarify if autistic children generalize the learned skills to real life (Lorenzo et al., 2019). In addition, there remain obstacles to developing robust and easy-to-use VR experiences that can really make a difference in real-world classrooms (Parsons and Cobb, 2011).

### Other Mental Health Diseases

The VR protocols and tools discussed above are not exhaustive of all the different applications of VR in mental health. However, evidence of VR's effects in other mental health diseases is sparse, and methodological flaws and/or gaps in reporting are common.

Another area in which VR has been used is the assessment and treatment of sexual disorders. In this field, the integration of VR in the psychodynamic therapy for erectile dysfunction and premature ejaculation achieved interesting preliminary results, even in a small case series with no control conditions (Optale et al., 2004; Optale, 2003). Moreover, Renaud and colleagues (Renaud et al., 2013, 2014) successfully used VR exposure to virtual characters depicting sexual stimuli to assess deviant sexual preferences (e.g., pedophilia).

Another notable area is depression (Zeng et al., 2018). Falconer and colleagues explored body swapping—the illusory feeling of ownership of a virtual body with a different shape and/or size—to increase the level of compassion in depressed patients. Other researchers used VR-based exergames (e.g., VR-based treadmill or stationary bike exercises) to reduce depressive symptoms. In both cases, results were encouraging, even though the study designs and methodology do not allow for a conclusive statement regarding the effectiveness of these approaches.

## Conclusion

From a technological viewpoint, virtual reality (VR) is a set of fancy technologies: a helmet, trackers, and a 3D visualizing system. However, from a psychological viewpoint, VR is simultaneously a simulative technology, a cognitive technology, and an embodied technology.

First, VR is a form of reality simulation. Specifically, what distinguishes VR from other media is the sense of *presence*: the feeling of "being there" inside the virtual experience produced by the technology. The simulative power of VR makes it the perfect tool for experiential learning. On the one hand, VR allows patients to learn through reflection on doing. On the other hand, VR can be described as an *advanced imaginal system*, or an experiential form of imagery that is as effective as reality at inducing emotional responses.

Moreover, VR is also a cognitive technology with the ability to reproduce the mechanisms behind the functioning of the brain. As recently suggested by neuroscience research, our brains are simulation machines that develop an internal model (simulation) of the body and the space around it to provide predictions about the expected sensory input and to minimize the number of prediction errors (or "surprise"). VR works in a similar way: it uses technology to create a virtual experience that individuals can manipulate and explore as if they were in it. In other words, VR technology attempts to predict the sensory consequences of users' actions by showing them the same outcome expected by our brain in the real world. In this view, the more similar the VR model is to the brain model, the more the individual feels present in the VR world.

Finally, VR can also be considered an embodied technology for its ability to fool the brain mechanisms that regulate the experience of the body. This ability offers new ways—at present only partially explored—to structure, augment, and/or replace the experience of the body for clinical goals. In addition, it provides new embodied ways to assess the functioning of our brain by directly targeting the processes behind real-world behaviors.

All of these characteristics make VR an effective clinical tool. As discussed in this chapter, and in agreement with the results of two recent meta-reviews (Riva et al., 2016a, 2019b), existing research supports the clinical use of VR in the assessment and treatment of anxiety disorders, pain management, and eating and weight disorders, with long-term effects that generalize to the real world. Recent studies have also provided preliminary support for the use of VR in the assessment and treatment of psychosis, addictions, and autism.

A further boost to the research and clinical applications of VR comes from the recent availability of low-cost, commercially available VR hardware. Smartphones and 360-degree videos will also make possible the development of a new generation of self-help VR applications that will make mental health treatment more accessible to individuals who do not have enough time or money to see a clinician in person.

However, VR like any other technology, is only a tool, which can be used for better or for worse. In that sense, the core interest for clinical psychology, is to understand the clinical phenomena and not be led by the idea that cutting-edge technologies will necessarily entail solutions for the problems we have to face with. In other words, we will need to elucidate which people can benefit from VR, in which way and at which moments of the psychopathological evolution.

## References


Ahmadpour, N., Randall, H., Choksi, H., Gao, A., Vaughan, C., Poronnik, P., 2019. Virtual Reality interventions for acute and chronic pain management. Int. J. Biochem. Cell Biol. 114, 105568.

Akhtar, S., Justice, L.V., Loveday, C., Conway, M.A., 2017. Switching memory perspective. Conscious. Cognit. 56, 50–57.

Apps, M.A., Tsakiris, M., 2014. The free-energy self: a predictive coding account of self-recognition. Neurosci. Biobehav. Rev. 41, 85–97.

Azevedo, R.T., Bennett, N., Bilicki, A., Hooper, J., Markopoulou, F., Tsakiris, M., 2017. The calming effect of a new wearable device during the anticipation of public speech. Sci. Rep. 7, 2285.

Balzarotti, S., Ciceri, M.R., 2014. News reports of catastrophes and viewers' fear: threat appraisal of positively versus negatively framed events. Media Psychol. 17, 357–377.

Balzarotti, S., Colombo, B., 2016. Effects of unilateral transcranial direct current stimulation of left prefrontal cortex on processing and memory of emotional visual stimuli. PLoS One 11, e0159555.

Balzarotti, S., Piccini, L., Andreoni, G., Ciceri, R., 2014. "I know that you know how I feel": behavioral and physiological signals demonstrate emotional attunement while interacting with a computer simulating emotional intelligence. J. Nonverbal Behav. 38, 283–299.

Benbow, A.A., Anderson, P.L., 2019. A meta-analytic examination of attrition in virtual reality exposure therapy for anxiety disorders. J. Anxiety Disord. 61, 18–26.

Biocca, F., 1999. The Cyborg's Dilemma: progressive embodiment in virtual environments. In: Marsh, J.P., Gorayska, B., Mey, J.L. (Eds.), Humane Interfaces: Questions of Method and Practice in Cognitive Technology. Elsevier, Amsterdam, The Netherlands.

Bordnick, P.S., Graap, K.M., Copp, H.L., Brooks, J., Ferrer, M., 2005. Virtual reality cue reactivity assessment in cigarette smokers. Cyberpsychol. Behav. 8, 487–492.

Bordnick, P.S., Traylor, A., Copp, H.L., Graap, K.M., Carter, B., Ferrer, M., Walton, A.P., 2008. Assessing reactivity to virtual reality alcohol based cues. Addict. Behav. 33, 743–756.

Brugger, P., Lenggenhager, B., 2014. The bodily self and its disorders: neurological, psychological and social aspects. Curr. Opin. Neurol. 27, 644–652.

Calvert, G., Spence, C., Stein, B.E. (Eds.), 2004. The Handbook of Multisensory Processes. The MIT Press, Cambridge, MA.

Carl, E., Stein, A.T., Levihn-Coon, A., Pogue, J.R., Rothbaum, B., Emmelkamp, P., Asmundson, G.J.G., 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.

Cesa, G.L., Manzoni, G.M., Bacchetta, M., Castelnuovo, G., Conti, S., Gaggioli, A., Mantovani, F., Molinari, E., Cardenas-Lopez, G., Riva, G., 2013. Virtual reality for enhancing the cognitive behavioral treatment of obesity with binge eating disorder: randomized controlled study with one-year follow-up. J. Med. Internet Res. 15, e113.

Chan, E., Foster, S., Sambell, R., Leong, P., 2018. Clinical efficacy of virtual reality for acute procedural pain management: a systematic review and meta-analysis. PLoS One 13, e0200987.

Cipresso, P., Serino, S., Riva, G., 2016. Psychometric assessment and behavioral experiments using a free virtual reality platform and computational science. BMC Med. Inf. Decis. Making 16.

Cipresso, P., 2015. Modeling behavior dynamics using computational psychometrics within virtual worlds. Front. Psychol. 6.

Clark, A., 2013. Whatever next? Predictive brains, situated agents, and the future of cognitive science. Behav. Brain Sci. 36, 181–204.

Cruzneira, C., Sandin, D.J., Defanti, T.A., Kenyon, R.V., Hart, J.C., 1992. The cave - audio-visual experience automatic virtual environment. Commun. ACM 35, 64–72.

Di Lernia, D., Cipresso, P., Pedroli, E., Riva, G., 2018. Toward an embodied medicine: a portable device with programmable interoceptive stimulation for heart rate variability enhancement. Sensors 18.

Dunn, J., Yeo, E., Moghaddampour, P., Chau, B., Humbert, S., 2017. Virtual and augmented reality in the treatment of phantom limb pain: a literature review. NeuroRehabilitation 40, 595–601.

Ehrsson, H.H., 2012. The concept of body ownership and its relation to multisensory integration. In: Stein, B.E. (Ed.), The New Handbook of Multisensory Processing. The MIT Press, Cambridge, MA.

Fernandez, J.A., Maes, P., Richer, A.F.R., 2019. Deep reality: an underwater VR experience to promote relaxation by unconscious Hr, Eda, and brain activity biofeedback. ACM. In: ACM SIGGRAPH 2019 Virtual, Augmented, and Mixed Reality, vol. 17.

Fernandez-Alvarez, J., Rozental, A., Carlbring, P., Colombo, D., Riva, G., Anderson, P.L., Banos, R.M., Benbow, A.A., Bouchard, S., Breton-Lopez, J.M., Cardenas, G., Difede, J., Emmelkamp, P., Garcia-Palacios, A., Guillen, V., Hoffman, H., Kampann, I., Moldovan, R., Muhlberger, A., North, M., Pauli, P., Penate Castro, W., Quero, S., Tortella-Feliu, M., Wyka, K., Botella, C., 2019. Deterioration rates in Virtual Reality Therapy: an individual patient data level meta-analysis. J. Anxiety Disord. 61, 3–17.

Fernández-Álvarez, J., DI Lernia, D., Riva, G., 2020. Virtual reality for anxiety disorders: rethinking a field in expansion. In: Kim, Y.-K. (Ed.), Anxiety Disorders: Rethinking and Understanding Recent Discoveries. Springer Singapore, Singapore.

Fernández-Sotos, P., Fernández-Caballero, A., Rodriguez-Jimenez, R., 2020. Virtual reality for psychosocial remediation in schizophrenia: a systematic review. Eur. J. Psychiatr. 34, 1–10.

Ferrer-Garcia, M., Gutierrez-Maldonado, J., 2010. Effect of the mood produced by virtual reality exposure on body image disturbances. Stud. Health Technol. Inf. 154, 44–49.
Ferrer-Garcia, M., Pla-Sanjuanelo, J., Dakanalis, A., Vilalta-Abella, F., Riva, G., Fernandez-Aranda, F., Forcano, L., Riesco, N., Sanchez, I., Clerici, M., Ribas-Sabate, J., Andreu-Gracia, A., Escandon-Nagel, N., Gomez-Tricio, O., Tena, V., Gutierrez-Maldonado, J., 2019. A randomized trial of virtual reality-based cue exposure second-level therapy and cognitive behavior second-level therapy for bulimia nervosa and binge-eating disorder: outcome at six-month followup. Cyberpsychol., Behav. Soc. Netw. 22, 60–68.
Finotti, G., Costantini, M., 2016. Multisensory body representation in autoimmune diseases. Sci. Rep. 6, 21074.
Finotti, G., Migliorati, D., Costantini, M., 2015. Multisensory integration, bodily self-consciousness and disorders of the immune system. Brain Behav. Immun. 49 (Suppl. ment), e31.
Freeman, D., Evans, N., Lister, R., Antley, A., Dunn, G., Slater, M., 2014. Height, social comparison, and paranoia: an immersive virtual reality experimental study. Psychiatr. Res. 218, 348–352.
Freeman, D., Reeve, S., Robinson, A., Ehlers, A., Clark, D., Spanlang, B., Slater, M., 2017. Virtual reality in the assessment, understanding, and treatment of mental health disorders. Psychol. Med. 1–8.
Freeman, D., Haselton, P., Freeman, J., Spanlang, B., Kishore, S., Albery, E., Denne, M., Brown, P., Slater, M., Nickless, A., 2018. Automated psychological therapy using immersive virtual reality for treatment of fear of heights: a single-blind, parallel-group, randomised controlled trial. Lancet Psychiatr. 5, 625–632.
Freeman, D., Yu, L.-M., Kabir, T., Martin, J., Craven, M., Leal, J., Lambe, S., Brown, S., Morrison, A., Chapman, K., Dudley, R., Regan, E., Rovira, A., Goodsell, A., Rosebrock, L., Bergin, A., Cryer, T.L., Robotham, D., Andleeb, H., Geddes, J.R., Hollis, C., Clark, D.M., Waite, F., 2019. Automated virtual reality (VR) cognitive therapy for patients with psychosis: study protocol for a single-blind parallel group randomised controlled trial (gameChange). BMJ Open 9, e031606.
Friston, K., 2010. The free-energy principle: a unified brain theory? Nat. Rev. Neurosci. 11, 127–138.
Friston, K., 2012. Embodied inference and spatial cognition. Cognit. Process. 13 (Suppl. 1), S171–S177.
Gaggioli, A., Bassi, M., Delle Fave, A., 2003. Quality of experience in virtual environments. In: Riva, G., Ijsselsteijn, W.A., Davide, F. (Eds.), Being There: Concepts, Effects and Measurement of User Presence in Synthetic Environment. Ios Press, Amsterdam. Online: http://www.emergingcommunication.com/volume5.html.
Gaggioli, A., Keshner, E.A., Weiss, P.L., Riva, G. (Eds.), 2009. Advanced Technology in Rehabilitation: Empowering Cognitive, Physical, Social and Communicative Skills through Virtual Reality, Robots, Wearable Systems and Brain-Computer Interfaces. IOS Press, Amsterdam.
Gaggioli, A., Pallavicini, F., Morganti, L., Serino, S., Scaratti, C., Briguglio, M., Crifaci, G., Vetrano, N., Giulintano, A., Bernava, G., Tartarisco, G., Pioggia, G., Raspelli, S., Cipresso, P., Vigna, C., Grassi, A., Baruffi, M., Wiederhold, B., Riva, G., 2014. Experiential virtual scenarios with real-time monitoring (interreality) for the management of psychological stress: a block randomized controlled trial. J. Med. Internet Res. 16, e167.
Gallace, A., Spence, C., 2014. In Touch with the Future: The Sense of Touch from Cognitive Neuroscience to Virtual Reality. Oxford University Press, Oxford.
Gallace, A., Soravia, G., Cattaneo, Z., Moseley, G.L., Vallar, G., 2014. Temporary interference over the posterior parietal cortices disrupts thermoregulatory control in humans. PLoS One 9, e88209.
Ghanouni, P., Jarus, T., Zwicker, J.G., Lucyshyn, J., Mow, K., Ledingham, A., 2019. Social stories for children with autism spectrum disorder: validating the content of a virtual reality program. J. Autism Dev. Disord. 49, 660–668.
Ginzburg, K., Tsur, N., Barak-Nahum, A., Defrin, R., 2014. Body awareness: differentiating between sensitivity to and monitoring of bodily signals. J. Behav. Med. 37, 564–575.
Glantz, K., Durlach, N.I., Barnett, R.C., Aviles, W.A., 1997. Virtual reality (VR) and psychotherapy: opportunities and challenges. Presence 6, 87–105.
Gorini, A., Griez, E., Petrova, A., Riva, G., 2010. Assessment of the emotional responses produced by exposure to real food, virtual food and photographs of food in patients affected by eating disorders. Ann. Gen. Psychiatr. 9, 30. Online: http://www.annals-general-psychiatry.com/content/9/1/30.
Gutiérrez-Maldonado, J., Wiederhold, B.K., Riva, G., 2016. Future directions: how virtual reality can further improve the assessment and treatment of eating disorders and obesity. Cyberpsychol., Behav. Soc. Netw. 148–153.
Hansel, A., Lenggenhager, B., von Kanel, R., Curatolo, M., Blanke, O., 2011. Seeing and identifying with a virtual body decreases pain perception. Eur. J. Pain 15, 874–879.
Ho, J.T., Preller, K.H., Lenggenhager, B., 2020. Neuropharmacological modulation of the aberrant bodily self through psychedelics. Neurosci. Biobehav. Rev. 108, 526–541.
ISPR, 2000. The Concept of Presence: Explication Statement. Available: https://ispr.info/about-presence-2/about-presence/. (Accessed 22 January 2020).
Jones, T., Moore, T., Choo, J., 2016. The impact of virtual reality on chronic pain. PLoS One 11, e0167523.
Keizer, A., VAN Elburg, A., Helms, R., Dijkerman, H.C., 2016. A virtual reality full body illusion improves body image disturbance in anorexia nervosa. PLoS One 11, e0163921.
Li, B.J., Bailenson, J.N., Pines, A., Greenleaf, W.J., Williams, L.M., 2017. A public database of immersive VR videos with corresponding ratings of arousal, valence, and correlations between head movements and self report measures. Front. Psychol. 8.
Lindner, P., Miloff, A., Hamilton, W., Reuterskiöld, L., Andersson, G., Powers, M.B., Carlbring, P., 2017. Creating state of the art, next-generation Virtual Reality exposure therapies for anxiety disorders using consumer hardware platforms: design considerations and future directions. Cognit. Behav. Ther. 46, 404–420.
Lindner, P., Miloff, A., Fagernas, S., Andersen, J., Sigeman, M., Andersson, G., Furmark, T., Carlbring, P., 2019. Therapist-led and self-led one-session virtual reality exposure therapy for public speaking anxiety with consumer hardware and software: a randomized controlled trial. J. Anxiety Disord. 61, 45–54.
Lombard, M., Ditton, T., 1997. At the heart of it all: the concept of presence. J. Comput. Mediat. Commun. 3. https://onlinelibrary.wiley.com/doi/full/10.1111/j.1083-6101.1997.tb00072.x.
Lorenzo, G., Lledó, A., Arráez-Vera, G., Lorenzo-Lledó, A., 2019. The application of immersive virtual reality for students with ASD: a review between 1990–2017. Educ. Inf. Technol. 24, 127–151.
Lyons, E.J., 2015. Cultivating engagement and enjoyment in exergames using feedback, challenge, and rewards. Game. Health J. 4, 12–18.
Macauda, G., Bertolini, G., Palla, A., Straumann, D., Brugger, P., Lenggenhager, B., 2015. Binding body and self in visuo-vestibular conflicts. Eur. J. Neurosci. 41, 810–817.
Maister, L., Sebanz, N., Knoblich, G., Tsakiris, M., 2013. Experiencing ownership over a dark-skinned body reduces implicit racial bias. Cognition 128, 170–178.
Maister, L., Slater, M., Sanchez-Vives, M.V., Tsakiris, M., 2015. Changing bodies changes minds: owning another body affects social cognition. Trends Cognit. Sci. 19, 6–12.
Manzoni, G.M., Cesa, G.L., Bacchetta, M., Castelnuovo, G., Conti, S., Gaggioli, A., Mantovani, F., Molinari, E., Cardenas-Lopez, G., Riva, G., 2016. Virtual reality-enhanced cognitive-behavioral therapy for Morbid obesity: a randomized controlled study with 1 Year follow-up. Cyberpsychol., Behav. Soc. Netw. 19, 134–140.
Marco, J.H., Perpina, C., Botella, C., 2013. Effectiveness of cognitive behavioral therapy supported by virtual reality in the treatment of body image in eating disorders: one year follow-up. Psychiatr. Res. 209, 619–625.
Martini, M., Perez-Marcos, D., Sanchez-Vives, M.V., 2014. Modulation of pain threshold by virtual body ownership. Eur. J. Pain 18, 1040–1048.
Maskey, M., Rodgers, J., Grahame, V., Glod, M., Honey, E., Kinnear, J., Labus, M., Milne, J., Minos, D., Mcconachie, H., Parr, J.R., 2019. A randomised controlled feasibility trial of immersive virtual reality treatment with cognitive behaviour therapy for specific phobias in young people with autism spectrum disorder. J. Autism Dev. Disord. 49, 1912–1927.
Matamala-Gomez, M., Diaz Gonzalez, A.M., Slater, M., Sanchez-Vives, M.V., 2019a. Decreasing pain ratings in chronic arm pain through changing a virtual body: different strategies for different pain types. J. Pain 20, 685–697.
Matamala-Gomez, M., Donegan, T., Bottiroli, S., Sandrini, G., Sanchez-Vives, M.V., Tassorelli, C., 2019b. Immersive virtual reality and virtual embodiment for pain relief. Front. Hum. Neurosci. 13, 279.
Miller, I.T., Wiederhold, B.K., Miller, C.S., Wiederhold, M.D., 2020. Assessment and treatment of autism spectrum disorders with virtual reality: a comprehensive research chart. Cyberpsychol., Behav. Soc. Netw. 23, 60–65.
Moon, J., Ke, F., 2019. Exploring the treatment integrity of virtual reality-based social skills training for children with high-functioning autism. Interact. Learn. Environ. 1–15.
Moseley, G.L., Gallace, A., Spence, C., 2012. Bodily illusions in health and disease: physiological and clinical perspectives and the concept of a cortical 'body matrix. Neurosci. Biobehav. Rev. 36, 34–46.
Nason, E.E., Trahan, M., Smith, S., Metsis, V., Selber, K., 2019. Virtual treatment for veteran social anxiety disorder: a comparison of 360° video and 3D virtual reality. J. Technol. Hum. Serv. 1–21.
Normand, J.M., Giannopoulos, E., Spanlang, B., Slater, M., 2011. Multisensory stimulation can induce an illusion of larger belly size in immersive virtual reality. PLoS One 6.

North, M.M., North, S.M., Coble, J.R., 1997. Virtual reality therapy: an effective treatment for psychological disorders. Stud. Health Technol. Inf. 44, 59–70.

Notzon, S., Deppermann, S., Fallgatter, A., Diemer, J., Kroczek, A., Domschke, K., Zwanzger, P., Ehlis, A.C., 2015. Psychophysiological effects of an iTBS modulated virtual reality challenge including participants with spider phobia. Biol. Psychol. 112, 66–76.

Olatunji, B.O., Cisler, J.M., Deacon, B.J., 2010. Efficacy of cognitive behavioral therapy for anxiety disorders: a review of meta-analytic findings. Psychiatr. Clin. 33, 557–577.

Opris, D., Pintea, S., Garcia-Palacios, A., Botella, C., Szamoskozi, S., David, D., 2012. Virtual reality exposure therapy in anxiety disorders: a quantitative meta-analysis. Depress. Anxiety 29, 85–93.

Optale, G., Pastore, M., Marin, S., Bordin, D., Nasta, A., Pianon, C., 2004. Male sexual dysfunctions: immersive virtual reality and multimedia therapy. Stud. Health Technol. Inf. 99, 165–178.

Optale, G., 2003. Male sexual dysfunctions and multimedia immersion therapy. Cyberpsychol. Behav. 6, 289–294.

Osimo, S.A., Pizarro, R., Spanlang, B., Slater, M., 2015. Conversations between self and self as Sigmund Freud-A virtual body ownership paradigm for self counselling. Sci. Rep. 5.

Pallavicini, F., Argenton, L., Toniazzi, N., Aceti, L., Mantovani, F., 2016. Virtual reality applications for stress management training in the military. Aerosp. Med. Hum. Perform. 87, 1021–1030.

Parsons, S., Cobb, S., 2011. State-of-the-art of virtual reality technologies for children on the autism spectrum. Eur. J. Spec. Needs Educ. 26, 355–366.

Parsons, T., Gaggioli, A., Riva, G., 2017. Virtual reality for research in social neuroscience. Brain Sci. 7, 42.

Parsons, T.D., 2015. Virtual reality for enhanced ecological validity and experimental control in the clinical, affective and social neurosciences. Front. Hum. Neurosci. 9, 660.

Pericot-Valverde, I., Secades-Villa, R., Gutiérrez-Maldonado, J., 2019. A randomized clinical trial of cue exposure treatment through virtual reality for smoking cessation. J. Subst. Abuse Treat. 96, 26–32.

Petkova, V.I., Ehrsson, H.H., 2008. If I were you: perceptual illusion of body swapping. PLoS One 3, e3832.

Powers, M.B., Emmelkamp, P.M., 2008. Virtual reality exposure therapy for anxiety disorders: a meta-analysis. J. Anxiety Disord. 22, 561–569.

Practice, A. P. A. P. T. F. O. E.-B., 2006. Evidence-based practice in psychology. Am. Psychol. 61, 271–285.

Preston, C., Ehrsson, H.H., 2014. Illusory changes in body size modulate body satisfaction in a way that is related to non-clinical eating disorder psychopathology. PLoS One 9.

Preston, C., Ehrsson, H.H., 2016. Illusory obesity triggers body dissatisfaction responses in the insula and anterior cingulate cortex. Cerebr. Cortex 26, 4450–4460.

Realdon, O., Serino, S., Savazzi, F., Rossetto, F., Cipresso, P., Parsons, T.D., Cappellini, G., Mantovani, F., Mendozzi, L., Nemni, R., Riva, G., Baglio, F., 2019. An ecological measure to screen executive functioning in MS: the Picture Interpretation Test (PIT) 360°. Scient. Rep. 9, 5690.

Renaud, P., Chartier, S., Rouleau, J.-L., Proulx, J., Goyette, M., Trottier, D., Fedoroff, P., Bradford, J.-P., Dassylva, B., Bouchard, S., 2013. Using immersive virtual reality and ecological psychology to probe into child molesters' phenomenology. J. Sex. Aggress. 19, 102–120.

Renaud, P., Trottier, D., Rouleau, J.-L., Goyette, M., Saumur, C., Boukhalfi, T., Bouchard, S., 2014. Using immersive virtual reality and anatomically correct computer-generated characters in the forensic assessment of deviant sexual preferences. Virtual Real. 18, 37–47.

Repetto, C., Gorini, A., Algeri, D., Vigna, C., Gaggioli, A., Riva, G., 2009a. The use of biofeedback in clinical virtual reality: the intrepid project. Stud. Health Technol. Inf. 144, 128–132.

Repetto, C., Gorini, A., Vigna, C., Algeri, D., Pallavicini, F., Riva, G., 2009b. The use of biofeedback in clinical virtual reality: the intrepid project. J. Vis. Exp. 33, 1554.

Repetto, C., Gaggioli, A., Pallavicini, F., Cipresso, P., Raspelli, S., Riva, G., 2013. Virtual reality and mobile phones in the treatment of generalized anxiety disorders: a phase-2 clinical trial. Pers. Ubiquitous Comput. 17, 253–260.

Revonsuo, A., 2006. Inner Presence, Consciousness as a Biological Phenomenon. Mit Press, Cambridge, MA.

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.

Riva, G., Gaudio, S., 2018. Locked to a wrong body: eating disorders as the outcome of a primary disturbance in multisensory body integration. Conscious. Cognit. 59, 57–59.

Riva, G., Waterworth, J.A., Waterworth, E.L., Mantovani, F., 2011. From intention to action: the role of presence. New Ideas Psychol. 29, 24–37.

Riva, G., Wiederhold, B.K., 2020. How Cyberpsychology and Virtual Reality Can Help Us to Overcome the Psychological Burden of Coronavirus. Cyberpsychol., Behav. Soc. Netw 5, 227–229.

Riva, G., Botella, C., Baños, R., Mantovani, F., García-Palacios, A., Quero, S., Serino, S., Triberti, S., Repetto, C., Dakanalis, A., Villani, D., Gaggioli, A., 2015. Presence-inducing media for mental health applications. In: Lombard, M., Biocca, F., Freeman, J., Ijsselsteijn, W., Schaevitz, R.J. (Eds.), Immersed in Media. Springer International Publishing, New York.

Riva, G., Baños, R.M., Botella, C., Mantovani, F., Gaggioli, A., 2016a. Transforming experience: the potential of augmented reality and virtual reality for enhancing personal and clinical change. Front. Psychiatr. 7.

Riva, G., Gutierrez-Maldonado, J., Wiederhold, B.K., 2016b. Virtual worlds versus real body: virtual reality meets eating and weight disorders. Cyberpsychol., Behav. Soc. Netw. 19, 63–66.

Riva, G., Serino, S., DI Lernia, D., Pavone, E.F., Dakanalis, A., 2017. Embodied medicine: mens sana in corpore virtuale sano. Front. Hum. Neurosci. 11.

Riva, G., Gutierrez-Maldonado, J., Dakanalis, A., Ferrer-García, M., 2019a. Virtual reality in the assessment and treatment of weight-related disorders. In: Rizzo, A.S., Bouchard, S. (Eds.), Virtual Reality for Psychological and Neurocognitive Interventions. Springer, New York, NY.

Riva, G., Wiederhold, B.K., Mantovani, F., 2019b. Neuroscience of virtual reality: from virtual exposure to embodied medicine. Cyberpsychol., Behav. Soc. Netw. 22, 82–96.

Riva, G., 2008. From virtual to real body: virtual reality as embodied technology. J. Cyber. Rehabil. 1, 7–22.

Riva, G., 2011. The key to unlocking the virtual body: virtual reality in the treatment of obesity and eating disorders. J. Diabetes Sci. Technol. 5, 283–292.

Riva, G., 2016. Embodied medicine: what human-computer confluence can offer to health care. In: Gaggioli, A., Ferscha, A., Riva, G., Dunne, S., Viaud-Delmon, I. (Eds.), Human Computer Confluence: Transforming Human Experience through Symbiotic Technologies. De Gruyter Open, Warsaw.

Riva, G., 2017. Letter to the editor: virtual reality in the treatment of eating and weight disorders. Psychol. Med. 47, 2567–2568.

Riva, G., 2018. The neuroscience of body memory: from the self through the space to the others. Cortex 104, 241–260.

Rizzo, A.S., Lange, B., Suma, E.A., Bolas, M., 2011. Virtual reality and interactive digital game technology: new tools to address obesity and diabetes. J. Diabetes Sci. Technol. 5, 256–264.

Rus-Calafell, M., Garety, P., Sason, E., Craig, T.J.K., Valmaggia, L.R., 2018. Virtual reality in the assessment and treatment of psychosis: a systematic review of its utility, acceptability and effectiveness. Psychol. Med. 48, 362–391.

Sadowski, W.J., Stanney, K.M., 2002. Measuring and managing presence in virtual environments. In: Stanney, K.M. (Ed.), Handbook of Virtual Environments Technology. Lawrence Erlbaum Associates, Mahwah, NJ.

Schloerb, D., 1995. A quantitative measure of telepresence. Presence Teleop. Virt. Environ. 4, 64–80.

Schoeller, F., Bertrand, P., Gerry, L.J., Jain, A., Horowitz, A.H., Zenasni, F., 2019. Combining virtual reality and biofeedback to foster empathic abilities in humans. Front. Psychol. 9.

Schoenberg, P.L., David, A.S., 2014. Biofeedback for psychiatric disorders: a systematic review. Appl. Psychophysiol. Biofeedback. 39, 109–135.

Schultheis, M.T., Rizzo, A.A., 2001. The application of virtual reality technology in rehabilitation. Rehabil. Psychol. 46, 296–311.

Segawa, T., Baudry, T., Bourla, A., Blanc, J.V., Peretti, C.S., Mouchabac, S., Ferreri, F., 2019. Virtual reality (VR) in assessment and treatment of addictive disorders: a systematic review. Front. Neurosci. 13, 1409.

Serino, S., Dakanalis, A., 2017. Bodily illusions and weight-related disorders: clinical insights from experimental research. Ann. Phys. Rehabil. Med. (60) 3, 217–219.

Serino, S., Pedroli, E., Keizer, A., Triberti, S., Dakanalis, A., Pallavicini, F., Chirico, A., Riva, G., 2016a. Virtual reality body swapping: a tool for modifying the allocentric memory of the body. Cyberpsychol., Behav. Soc. Netw. 19, 127–133.

Serino, S., Scarpina, F., Keizer, A., Pedroli, E., Dakanalis, A., Castelnuovo, G., Chirico, A., Novelli, M., Santino, G., Riva, G., 2016b. A novel technique for improving bodily experience in a non-operable super-super obesity case. Front. Psychol. 7. https://doi.org/10.3389/fpsyg.2016.00837.
Serino, S., Baglio, F., Rossetto, F., Realdon, O., Cipresso, P., Parsons, T.D., Cappellini, G., Mantovani, F., DE Leo, G., Nemni, R., Riva, G., 2017. Picture interpretation test (PIT) 360 degrees: an innovative measure of executive functions. Sci. Rep. 7.
Serino, S., Polli, N., Riva, G., 2019. From avatars to body swapping: the use of virtual reality for assessing and treating body-size distortion in individuals with anorexia. J. Clin. Psychol. 75, 313–322.
Shah, L.B., Torres, S., Kannusamy, P., Chng, C.M., He, H.G., Klainin-Yobas, P., 2015. Efficacy of the virtual reality-based stress management program on stress-related variables in people with mood disorders: the feasibility study. Arch. Psychiatr. Nurs. 29, 6–13.
Sharar, S.R., Alamdari, A., Hoffer, C., Hoffman, H.G., Jensen, M.P., Patterson, D.R., 2016. Circumplex model of affect: a measure of pleasure and arousal during virtual reality distraction analgesia. Game. Health J. 5, 197–202.
Sheridan, T.B., 1992. Musing on telepresence and virtual presence. Presence Teleop. Virt. Environ. 1, 120–125.
Slater, M., Antley, A., Davison, A., Swapp, D., Guger, C., Barker, C., Pistrang, N., Sanchez-Vives, M.V., 2006. A virtual reprise of the Stanley Milgram obedience experiments. PLoS One 1, e39.
Strickland, D., Mesibov, G.B., Hogan, K., 1996. Two case studies using virtual reality as a learning tool for autistic children. J. Autism Dev. Disord. 26, 651–659.
Sutter, C., Drewing, S., Musseler, J. (Eds.), 2014. Multisensory Integration in Action Control. Frontiers Media SA, Lausanne.
Suzuki, K., Garfinkel, S.N., Critchley, H.D., Seth, A.K., 2013. Multisensory integration across exteroceptive and interoceptive domains modulates self-experience in the rubber-hand illusion. Neuropsychologia 51, 2909–2917.
Talsma, D., 2015. Predictive coding and multisensory integration: an attentional account of the multisensory mind. Front. Integr. Neurosci. 9, 19.
Trahan, M.H., Maynard, B.R., Smith, K.S., Farina, A.S.J., Khoo, Y.M., 2019. Virtual reality exposure therapy on alcohol and nicotine: a systematic review. Res. Soc. Work. Pract. 29, 876–891.
Triberti, S., Repetto, C., Riva, G., 2014. Psychological factors influencing the effectiveness of virtual reality-based analgesia: a systematic review. Cyberpsychol., Behav. Soc. Netw. 17, 335–345.
Tsakiris, M., Critchley, H., 2016. Interoception beyond homeostasis: affect, cognition and mental health. Phil. Trans. Biol. Sci. 371.
Tsakiris, M., 2017. The multisensory basis of the self: from body to identity to others. Q. J. Exp. Psychol. 70, 597–609.
Valmaggia, L.R., Day, F., Rus-Calafell, M., 2016. Using virtual reality to investigate psychological processes and mechanisms associated with the onset and maintenance of psychosis: a systematic review. Soc. Psychiatr. Psychiatr. Epidemiol. 51 (7), 921–936.
Valmaggia, L., 2017. The use of virtual reality in psychosis research and treatment. World Psychiatr. 16, 246–247.
Van 't wout-Frank, M., Shea, M.T., Larson, V.C., Greenberg, B.D., Philip, N.S., 2019. Combined transcranial direct current stimulation with virtual reality exposure for posttraumatic stress disorder: feasibility and pilot results. Brain Stimul. 12, 41–43.
Veling, W., Brinkman, W.P., Dorrestijn, E., Van der Gaag, M., 2014. Virtual reality experiments linking social environment and psychosis: a pilot study. Cyberpsychol. Behav. Soc. Netw. 17, 191–195.
Vincelli, F., Molinari, E., Riva, G., 2001. Virtual reality as clinical tool: immersion and three-dimensionality in the relationship between patient and therapist. Stud. Health Technol. Inf. 81, 551–553.
Vincelli, F., 1999. From imagination to virtual reality: the future of clinical psychology. Cyberpsychol. Behav. 2, 241–248.
Ward, J., Meijer, P., 2010. Visual experiences in the blind induced by an auditory sensory substitution device. Conscious. Cognit. 19, 492–500.
Waterworth, J.A., Waterworth, E.L., 2014. Altered, expanded and distributed embodiment: the three stages of interactive presence. In: Riva, G., Waterworth, J.A., Murray, D. (Eds.), Interacting with Presence: HCI and the Sense of Presence in Computer-Mediated Environments. De Gruyter Open, Berlin. www.presence-research.com.
Waterworth, J.A., Waterworth, E.L., Mantovani, F., Riva, G., 2010. On Feeling (the) Present: an evolutionary account of the sense of presence in physical and electronically-mediated environments. J. Conscious. Stud. 17, 167–178.
Wiederhold, B.K., Soomro, A., Riva, G., Wiederhold, M.D., 2014. Future directions: advances and implications of virtual environments designed for pain management. Cyberpsychol., Behav. Soc. Netw. 17, 414–422.
Wykes, T., Spaulding, W.D., 2011. Thinking about the future cognitive remediation therapy-what works and could we do better? Schizophr. Bull. 37, S80–S90.
Zanier, E.R., Zoerle, T., DI Lernia, D., Riva, G., 2018. Virtual reality for traumatic brain injury. Front. Neurol. 9, 345.
Zeng, N., Pope, Z., Lee, E.J., Gao, Z., 2018. Virtual reality exercise for anxiety and depression: a preliminary review of current research in an emerging field. J. Clin. Med. 7.