Posthuman Subjectivity in BCI-VR Entanglement

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1 Introduction

The idea of minds connecting to machines has been a staple of science fiction movies and fantasy books. Today, however, with the unprecedented advancements in neuroscience, this has become a reality. Brain–computer interfaces (BCIs) are devices that connect the brain to a computer and decrypt brain activity [1]. The brain activity is then analyzed and translated into commands which in turn allows us to communicate with our surrounding environment or others who are physically or virtually present around us [2]. For example, through BCI, a user can move a ball on a computer screen by only imagining the movement [3].

Technologies like BCIs cast doubt on the understanding of the human as an independent isolated entity and question several long-held assumptions about the understanding of subjectivity. These include, for instance, the understanding of the human as a singular, self-contained, unchanging entity that is non-relational and non-transversal (Wilde & Evans, as cited in [4] p 793; Braidotti, as cited in [5] p 6). The intimate relationship between humans and technology today demands a renewed understanding of what it means to be human. Posthumanism is a growing field of study with diverse, often conflicting, theorizations and definitions that is concerned with decentering of the human due to its enmeshment in a wide array of technical, medical, informatic networks that cannot be overlooked or ignored [6]. Posthumanism should not be confused with transhumanism, which takes the enhancement of the human condition using advanced technologies as its focus [7]. Within the posthuman landscape, it has become imperative to rethink the notion of subjectivity as "emergent rather than given, distributed rather than located solely in consciousness,

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emerging from and integrated into a chaotic world rather than occupying a position of mastery and control removed from it" [8]. This understanding reveals that the human being is "a heterogeneous subject whose self-definition is continuously shifting, and that exists in a complex network of human and nonhuman agents and the technologies that mediate between them" [9].

This chapter builds on the understanding of the human being as an entangled subject that is embedded in an ever-shifting network of relations by exploring the integration of brain–computer interface (BCI) in virtual reality (VR) technology. The coupling of BCI and VR is a growing area of interest that promises great potential since BCI can provide a powerful tool for communication and control of virtual reality environments. Simultaneously, and with the rapid development of electronics, optics, and motion tracking technologies, VR is becoming a popular technology [10] that promises to further expand the scope of BCI.

By drawing on some canonical posthumanist and feminist works by Karen Barad and Bruno Latour, this chapter postulates that the human being is part of an intertwined network of human and nonhuman entities with perpetually shifting boundaries. I theorize how the entwinement of the human with the brain–computer interface and VR could transform the understanding of subjectivity. In addition, and by building on Barad's agential realism framework, I critique the existing model of subjectivity and propose to reframe the human–BCI-VR relationship as a posthuman subjectivity, a form of subjectivity that underscores the mutual shaping and perpetually shifting boundaries of the human. This chapter has three sections and a conclusion. The first discusses the history and development of brain–computer interfaces (BCIs). In the second section, I discuss virtual reality (VR) and some of the applications that result from the convergence of BCI and VR, namely therapy and rehabilitation, as well as gaming. In the last section, I provide a theoretical discussion of the posthuman and introduce an alternative view to the conventional understanding of subjectivity through reframing it in light of the co-constitution of the human with BCI and VR as posthuman subjectivity.

2 History of Brain–Computer Interfaces

Although BCI research has advanced at an unprecedented rate in recent years, the history of BCI is not recent. The origins of BCIs can be traced back to the 1920s when Hans Berger, a German scientist, showed that the human brain was producing electrical signals that could be measured using electroencephalography (EEG) (Berger 1929, as cited in Nam et al., as cited in [3] p 2). The development of EEG brought to the fore the idea that the brain could be used as a communication channel [3]. Berger hoped to be able to record the fluctuations of the electrical current from the human skull. In an experiment on a man with a bone defect at the forehead, Berger succeeded in showing that variations in electrical current could be recorded with electrodes placed on the skin [1].

The works of José Delgado and Eberhard Fetz in the 1960s introduced a rudimentary version of BCIs as we know them today [11]. Delgado developed an implantable chip that was used to simultaneously stimulate the brain and send electrical signals to the brain, permitting the human subject to move freely [11]. In a similar well-known experiment, he used a “stimoceiver” that sent electrical signals to a bull’s brain and manipulated its aggressive impulses [11]. In the same spirit, Fetz showed that monkeys can control their brain activity to obtain food rewards [11]. His experiment demonstrated that the activity of a single neuron in the monkey’s cortex could be acclimatized to control a needle’s movement which was coupled to the neuron’s firing rate. The monkeys learned to move the needle until it reached a certain threshold, which resulted in receiving a reward [11].

It wasn’t until 1973 when Jacques Vidal, a Belgian researcher, coined the term “Brain-Computer Interface” in his seminal paper (Vidal 1973, as cited in Nam et al., as cited in [3] p 2). He defined BCIs as the use of brain signals to control external tools such as computers or prosthetic devices [3]. Vidal’s paper called attention to the “evoked responses” of the brain upon exposure to sensory, visual, auditory, or somesthetic stimuli [2]. In his article, which remains influential to date, Vidal introduced a system that translates EEG signals into computer control signals [12] and delineated all necessary elements to build a BCI [1]. It is worth noting that the first real-time BCI came to light in the 1990s [3]. The basis of clinical trials, however, was founded when Sterman and colleagues undertook some experiments that found that “instrumental training of sensorimotor rhythms in cats increased seizure thresholds” (Sterman et al. 1969, as cited in Chaudhary et al., as cited in [12] p 513). Subsequent case studies using similar techniques in humans with epilepsy resulted in a reduction of grand-mal seizures (Sterman et al. 1972, as cited in Chaudhary et al., as cited in [12] p 514).

The beginning of the twenty-first century witnessed a radical expansion in BCI research that had become a field of its own [3]. Central to BCI research today is the distinction made between active, reactive, and passive BCI. Active BCI revolves around the presumption that users can manipulate their brain activity and consequently are able to give commands to a brain-controlled device [2]. Being in an angry or relaxed state, for instance, is revealed through brain activity. Similarly, imagining the movement of a particular body part can be picked up by electrodes which results in the movement of one’s wheelchair in a particular direction or controlling one’s avatar in video games [2]. This is to say that conscious manipulation of brain activity results in controlling the environment [2]. While in active BCI users manipulate their brain activity to issue commands, in reactive BCI, the application generates stimuli that give rise to changes in brain activity when the user pays attention to them [2]. Such stimuli are usually presented on a computer but can also be presented auditorily or by touch [2]. In passive BCI, the user is not required to evoke a particular imagery, provide a command through their brains, or focus on an external stimulus; instead, brain activity is deployed to induce changes in the environment [2]. Users are simply observed, and their brain activity is measured. Ideally, users are not aware of being measured to prevent the transformation of passive BCI into active BCI in case users become cognizant of their mental states [2]. Affective BCIs are subcategories of passive BCIs which monitor the users’ affective states such as joy or fear in order to create applications which respond to those states (Mühl et al. 2014, as cited in Nam et al., as cited in [3] p 4).

Today, a wide range of BCI applications are being developed and explored, ranging from lie detection and security, to gaming, education, and art, as well as mental and physical augmentation of human capacities [11]. Invasive (implanted) as well as non-invasive (outside the body) BCIs are developed for patients suffering from disorders that restrict their ability to fully interact with the world, such as patients with locked-in syndrome [13]. Similarly, some BCI devices have moved into clinical trials for the purpose of providing artificial vision or bionic eyes, while others are used to help restore human hearing through cochlear implants [14]. In addition, BCIs are being deployed for non-medical purposes such as gaming and human–technology interfaces [13]. Coin and Dubljević [14] contend that it seems probable that "advances in BCI technology in the near future could allow for the enhancement of vision, hearing, and mobility beyond the capabilities of a normal human" (Coin & Dubljević, as cited in [14] p 286). Such expansive applications have resulted in increased interest in BCI technology outside the BCI field such as in human–computer interaction, as well as for the purposes of scientific research [3].

3 Virtual Reality

A natural companion to BCI is virtual reality (VR) [15], which could be broadly defined as "a technological reproduction of the process of perceiving the real" [16]. To understand the BCI-VR alliance, it is necessary to briefly touch on the development of VR technology. The term "VR" was coined by Jaron Lanier when he founded VPL Incorporated, although many track this back to Ivan Sutherland [17]. In his 1965 paper titled *The Ultimate Display*, Sutherland outlined the model for human–computer interface that has inspired the thinking about virtual environments (Sutherland, as cited in [18] p 964). Sutherland's idea was that the computer display could produce a simulation of the physical world [18]. As Ken Hillis argued in *Digital Sensations* [16], the development of VR has been guided by first "an ongoing (Western) motivation to alter conceptions of space" (p 1–2). It wasn't however until 1970 when Sutherland and a team of researchers developed the first head-mounted display system (Rheingold, as cited in [18] p 964) which acted as a starting point for the takeoff of VR technology in later years in areas such as art, robotics, military [18], and gaming.

VR typically functions through bracketing the external physical world and supplanting it by a virtual simulated representation that is distinguishable from yet dependent on the real. It uses "computerized and behavioral interfaces to simulate the behavior of 3D entities such as people, places and objects in a virtual environment (VE)" (Hudson et al., as cited in [19] p 459). Central to the VR experience is the feeling of immersion which is used in different contexts, yet mostly refers to games and virtual reality [20]. Immersion can be defined as "a feeling of isolation from the real world" where performing tasks can increase feelings of immersion [21]. Stated differently, immersion is the manipulation of the user's sensory experience through computer graphics, haptics, sounds, affective computing, and advanced user interfaces that work on increasing the sense of presence [22]. It has to do with what Bollmer and Suddarth [23] explain as "a phenomenal sense of absorbing presence elsewhere" which is produced through a necessary coupling between the body and the technology [23].

VR has become a prominent medium deployed for a range of different purposes. Ranging from shows that aim to attract large audiences, such as *Björk Digital*, to others which force the viewers to witness a violent scene, such as Jordan Wolfson's 2017 *Real Violence* [24], and still others whose purpose is to foster empathy, such as *Project Syria*, a 2013 VR work directed by journalist Nonny de la Peña, that simulates the bombing of Aleppo [25], VR is a medium that is gaining more prominence lately. Despite its abundant representation in popular media and depictions in books demonstrating its great success, there is no clear direction as to where this technology may be headed. Yet, the deployment of VR in a wide array of fields engendered utopian predictions that VR will create new understandings of space and ability to travel to unreachable destinations (Cheong, as cited in [26]), as well as foster new social and cultural relations that produce a sense of empathy (Milk, as cited in [26]). There are, on the other hand, some skeptical considerations including concerns of loss of identity and self (Batchen, as cited in [26]) and a "culture of increasing surveillance and voyeurism" [16].

Notwithstanding those disparate perspectives on VR, its powerful potential can't be underplayed. The companionship between VR and BCI is one of the notable areas demonstrating this. Friedman [15] posits that both technologies complement each other given their powerful capacities. BCI introduces new ways for manipulation and control in VR, while VR provides rich feedback for BCI in a safe environment [15].

4 The Convergence of BCI and VR in Therapy & Gaming

BCIs have been adopted as novel technology that merged with VR producing new ways of interaction in virtual environments. BCI makes it conceivable to explore this natural integration of the brain and VR [27]. For instance, BCIs can be used for navigation in VR as well as controlling avatars and the virtual worlds in full [27]. There are several prototypes that exist today offering innovative ways for users to "navigate in virtual scenes or manipulate virtual objects solely by means of their cerebral activity, recorded on the scalp via electroencephalography (EEG) electrodes" (Lécuyer et al., as cited in [28] p 66).

At the same time, VR offers a safe and controlled environment that provides more insight into brain responses [28]. It is perceived as a new "feedback modality for BCIs and a safe test bed to provide subjects with the opportunity to train and test the BCI applications before using them in reality" (Leeb et al., as cited in [29] p 30). The recent development of VR head-mounted devices (HMD) has "paved the way to the commercialization of combined BCI+VR technology" (Cattan et al., as cited in [30] p 2). The HMD design supports the embedding of the EEG electrodes required for BCIs [30]. Such advancements have attracted the attention of VR and BCI communities alike given the powerful potential that this convergence could result in. For instance, Cattan et al. [30] point out that the Neurable Company has announced a product that combines an HTC Vive, which is referred to as an active device, with an EEG cap [30].

Many BCI-VR applications, mostly based on active and reactive BCIs discussed earlier, have been proposed. In a BCI-VR system, users interact with virtual environments by regulating their brain activity, whereas in a reactive BCI-VR system, VR generates stimuli which prompts changes to the brain activity that results in active controlling of objects in the virtual environment (Kathner et al., Faller et al., & Beveridge et al., as cited in [29]). In addition, the interaction between BCI and VR technology produces new tasks such as navigation to change the view or the control and manipulation of virtual objects in the virtual environment. When it comes to navigation in the virtual world, BCI permits users to control the camera position by using brain signals such as "left- or right-hand motor imagery (MI) or two steady-state visual-evoked potentials (SSVEPs) at different frequencies" (Lécuyer et al., as cited in [28] p 66). For instance, MI BCIs have been used to rotate in a virtual room and move along a virtual street, demonstrating that BCI "could be used to control locomotion events in a CAVE-like [Cave Automatic Virtual Environment] setting" (Friedman et al., as cited in [27] p 101). As for the manipulation of virtual objects, Lécuyer et al. [28] state that most BCIs are based on "P300 or SSVEP signals" where virtual objects deliver "a stimulus that triggers a specific and recognizable brain signal that draws the user's attention to the associated object to select and manipulate it" (Lécuyer et al., as cited in [28] p 66). Such BCIs allow users to control devices such as a virtual TV or lamp by providing the users with a range of commands, each of which is associated with a specific activity (Bayliss, as cited in [28]).

The convergence of BCI and VR technology proves to be of mutual benefit due to the multimodal and multisensory experience gained through VR, which provides a more immersive experience, while BCI could work as a channel to manipulate virtual scenarios as opposed to standard controllers. The addition of BCI to VR technology reduces the need for physical interaction with the environment [2]. This is to say that the use of VR technology comes with promises of "immersion and the creation of interactive, explorable scenes" for the field of BCI [2]. To further explore those possibilities, I emphasize the discussion of converging BCI and VR for therapy and rehabilitation as well as gaming, as two domains that highlight the significance of this convergence.

4.1 Therapy

Therapy and rehabilitation are core areas that have been strongly influenced by the development of both BCI and VR in recent years. In one of their pilot studies, Salisbury et al. [31] assessed the efficacy of VR training used for cognitive rehabilitation for individuals suffering from stroke, brain neoplasm, and anoxic injury. The study focused on treatments associated with certain functions such as cognitive flexibility and memory, among others. While BCI is deeply entrenched in this area, VR is rapidly catching up since it affords a high degree of immersion and feelings of presence that cannot be available otherwise, providing the opportunity to explore new therapeutic approaches that cannot always be implemented in reality [2]. Miloff et al. [32], for instance, underscore the increasing effectiveness of VR in exposure therapy for phobias. In a similar work, Dunn and colleagues [33] review several studies on the role of VR in the treatment of phantom limb pain which note a reduction in pain.

In a different study, Vourvopoulos et al. [34] developed NeuRow, which is a self-paced BCI neurogame in an immersive VR environment with the purpose of motor imagery training (MI). Motor imagery training, which is "the mental rehearsal of movement -without any muscle activation- and is a mental ability strongly related to the body or 'embodied' cognition" (Hanakawa, [35] as cited in Vourvopoulos et al., as cited in [34] p 1), can provide novel communication means to neurologically impaired patients [34]. The game uses "multimodal stimulation through vision, sound and vibrotactile feedback and delivered through a VR Head Mounted Display" (Vourvopoulos et al. 2019, 1). The fusion of BCI and VR provides an illusion of movement to individuals with low levels of motor control. In their designed game, the BCI-VR task involves rowing a boat solely through mental imagery with the purpose of collecting flags (Vourvopoulos et al., as cited in [34] p 6). Similarly, Škola and Liarokapis [36] examine the effect of VR embodiment on motor imagery, a prevalent BCI paradigm that "requires users to consciously replay bodily motor action" (Vourvopoulos et al., as cited in [34] p 59). In their study, the motor imagery BCI training was implemented in a VR environment (Škola and Liarokapis, as cited in [36] p 60). They employed VR to create virtual embodiment "showing the person's hands executing the detected imagined movements" [2]. The results demonstrated that the group trained using embodied VR exhibited higher accuracy [36].

4.2 Gaming

Games can be defined as "a mental contest, played with a computer according to certain rules for amusement, recreation, or winning a stake" (Zyda, as cited in [22] p 25). The integration of BCIs within games appears to be promising and is thus "one of the oldest domains for which the combination of BCI and VR technology has been discussed" [2]. BCI and VR technologies are considered "excellent candidates for enhancing the possibilities of entertainment and satisfaction in video games" since both enhance immersion and consequently increase feelings of amusement (Cattan et al., as cited in [30] 1). VR technologies are suitable companions to BCIs, which are in turn considered efficient interaction devices. Additionally, it has become widely accepted that VR is a competent medium for understanding and enhancing BCI technologies (Lécuyer et al., as cited in [28] p 66).

Immersive games work with three different inputs, namely: visual, auditory, and mental [20]. According to Cattan et al. [30], since BCI works to "transform 'mental' signals into input commands, such an interface may play a unique role in the mentalization process involved in the feeling of immersion" (Cattan et al., as cited in

[30] p 2). In their study, they highlight that BCI integrates well with games that require concentration and thinking such as strategy, puzzles, simulation, among others, while simulation and adventure games work best for VR.

Coyle and colleagues [37] designed a spaceship game with the purpose of testing BCI's users' ability to control objects on the screen. In the game, the user is required to control the location of a spaceship using motor imagery to avoid asteroids. A key advantage of the game is that while users can manipulate the position of the spacecraft, "the asteroids are timed to be consistent with the timing of standard motor imagery trials and appear on either right or left of the screen so that data during game play can be triggered and labeled" (Coyle et al., as cited in [37] p, 1).

5 The Emergence of the Posthuman

The rapid surge in the development of technologies in general and the merging of humans with technologies in particular has resulted in questioning what it means to be human today. A vast body of work has explored the meaning of posthuman, which is a highly contested term with multiple definitions and understandings. Some of those accounts have gained attention due to their version of the posthuman as a "disembodied, high-tech, transcendental subjectivity" [4]. The posthuman is oftentimes portrayed as utopian in a sense that would potentially allow us to overcome, for instance, age and class [4]. Nick Bostrom [7] postulates that being posthuman means possessing general capacities that exceed the maximum attainable capacities by current human beings. Other times, the posthuman is depicted as dystopian in the case of an apathetic and inhuman cyborg [4]. Both views present different understandings of what posthuman is.

Broadly speaking, the posthuman is related to the radical deconstruction of the human which began in the 1960s. Posthumanism does not grant primacy to the human, and by deconstructing the human, it seeks to destabilize and reinvestigate dualisms such as human/machine, life/death, and natural/artificial [38]. In Philosophical Posthumanism, Francesca Ferrando [38] explains that the term "posthuman" has become a key concept that is used to show the urgency of redefining the notion of the human, following the "onto-epistemological, as well as scientific and bio-technological developments" (Ferrando, as cited in [38] p 1). Cary Wolfe [6] posits that the posthuman is not the evolution of the human into something new; it opposes transhumanism and the traditional understanding of humanism which lead to the intensification of the human. Today, there is a "new reality" where "the human occupies a new place in the universe, a universe now populated by what I am prepared to call nonhuman subjects" (Wolfe, as cited in [6] p 47). This understanding underscores the fact that the human needs to be understood as one actor among other human and nonhuman actors.

Katherine Hayles [8] argues that while the concept of the posthuman has multiple articulations, there are some foundational assumptions by which the term could be defined. Central to those is the posthuman view that the body is a prosthesis that can be manipulated or extended, and that the human being can be united with intelligent machines (Hayles, as cited in [8] p 3). A posthuman perspective holds that there are “no essential differences or absolute demarcations between bodily existence and computer simulation, cybernetic mechanism and biological organism, robot teleology and human goals” [8]. That said, Hayles [8] points out that the creation of a posthuman does not necessarily entail bodily interventions or that the human be transformed into a cyborg per se. Rather, a defining characteristic of the posthuman is the “construction of subjectivity” (Hayles, as cited in [8] p 4). We are a “posthuman collectivity, an ‘I’ transformed into the ‘we’ of autonomous agents operating together to make a self” [8]. The posthuman subject is, simply put, is a set of diverse components [8].

The concept of subjectivity has often been described as “posthuman” through the human’s relation to the animal, the machine, or the environment [4]. The understanding that I want to draw on here postulates that new forms of subjectivity emerge in our relationship and co-production with technology [8]. For Hayles [8], technology reveals a more networked and co-produced understanding of the human. In the following section, I discuss how the human-BCI-VR enmeshment introduces a new understanding of subjectivity, namely posthuman subjectivity. This conceptualization of posthuman subjectivity can describe the human-BCI-VR relation as a “fluid, horizontal and relational experience between human and machine” [4].

6 Posthuman Subjectivity in the Human-Technology Entanglement

A longstanding Western assumption is that subjectivity is constructed in relation to the ownership of a biological body [39]. However, this traditional understanding of subjectivity that is bound to corporeality needs to be revisited since “any transformation in our dominant model of the body will or should effectuate a transformation in our dominant model of subjectivity” [9]. In other words, and considering the understanding of the human as a part of a shifting network of relations, it has become necessary to reevaluate the classic notion of subjectivity associated with a corporeal human body. In this section, I call this assumption into question and propose to understand posthuman subjectivity as that which arises from a mutual reciprocation of entwined entities previously defined as distinct. By drawing on Bruno Latour and Karen Barad, I want to apply the human-BCI-VR entanglement as a case study to argue that subjectivity is not exclusively human and that the human is not an independent entity. Instead, by discussing several examples, I will first build on Latour to demonstrate that the distinction between humans and nonhumans cannot be maintained. In other words, the rigid boundaries between human users, BCI, and VR technologies cannot be upheld within this human-nonhuman network. Subsequently, I build on Barad’s agential realism to suggest that subjectivity is intra-actively constituted through the entanglement of the human users, the BCI, and the VR and is not limited to the corporeal human body.

Latour [40] criticizes the dualism between nature and society or subject and object that provide the foundation for modernist thought. He rejects the separation arguing that it has never existed in pre-modernism and highlights the need to rethink dualism because while modernity invokes such segregation, this is not actually the case. Humans and technology are always entangled. He redefines the social to include nonhumans, which range from a doorknob to technologies and scientific apparatuses. Therefore, for Latour [41], everything is part of the social construction of the world, including technology.

Latour [42] introduced the concept of "translation" which does not refer to the shift from one thing to another, rather, translation is about mediation and "the creation of a link that did not exist before and that to some degree modifies the original two" (Latour, as cited in [42] p 179). So, in discussing whether guns kill people or people kill people, Latour points out that neither is responsible for the killing, but someone else is, namely "a citizen-gun, a gun-citizen" (Latour, as cited in [42] p 179). An actor with a gun in his hand is not the same person as an actor without one. Therefore, a more productive approach to study technoscientific practices includes what Latour [42] labels as "symmetry" where subjects and objects have a symmetrical effect on each other. Translations are symmetrical in that "you are different with a gun in your hand; the gun is different with you holding it. You are another subject because you hold the gun; the gun is another object because it has entered into a relationship with you" (Latour, as cited in [42] at p 179). This is to say that the concept of symmetry blurs the dichotomy between subjects and objects and instead focuses on their connections and associations within the given network.

When we look at the human-BCI-VR from Latour's perspective, it becomes plausible to abandon the subject-object dichotomy. It seems imperative to overcome the understanding of the human user as a subject that operates and controls the BCI-VR technology as an object. From this Latourian perspective, we are more attentive to "the understanding of collectives" [42]. For instance, a human actor does not autonomously move the ball on a computer screen by imagining its movement nor does the BCI induce the motion. Similarly, individuals with low-level motor abilities do not row the boat independently, nor does the VR head-mounted display. Instead, "responsibility for action must be shared among the various actants" (Latour, as cited in[42] at p 180). The human user and the BCI-VR are together responsible for the action. Outputs, such as moving the ball or rowing a boat, are a result of the simultaneous interaction of the different individual actors in this network. As Latour [42] writes, "action is a property of associated entities" (Latour, as cited in [42] p 182).

Every individual actor in any given network could only be afforded action by the other actors. For instance, Yeh et al. [29] proposed a BCI-VR car racing game which allows multiple users at different locations to mentally play the game. The car's movement is prompted by electromyographic (EMG) activity; therefore, the game is "based on a hybrid BCI control (EEG plus EMG)" [29]. Consequently, the car racing game is "a property of the whole association of entities" that includes the players, EEG, EMG, massive amounts of data, servers, cloud-computing-based signals, etc. [29]. Action, accordingly, is not a human characteristic but the relations and associations of the different actors [42]. This is not to claim that either BCIs or

VR can create outputs independently of the human user; rather, the different outcomes are a co-production of the human-BCI-VR entanglement.

While this understanding of actors as a part of a more extensive network is plausible, the nature of interaction between the individual actors remains somewhat murky in Latour's framework. In other words, while Latour makes it clear that no one acts alone, his framework seems to fall short when it comes to highlighting the way action itself is produced between the actors. Barad, on the other hand, surveys the nature of this interaction, which she calls "intra-action." In Barad's [43] agential realism framework, matter is a dynamic and intra-active actor. Barad posits that matter is about engagement with a new understanding of the world where bodies and the environment are intra-actively co-constituted. Intra-action, unlike the conventional notion of interaction, presumes the prior existence of independent entities and is understood as "the mutual constitution of objects and agencies of observation within phenomena" ([43] p 197). That is to say, while interaction is concerned with separate entities that interact, intra-action is about the inseparability and mutual emergence of the subject and object through their interaction [44]. In this way, Barad (2007) challenges dichotomies between the human and nonhuman, material and discursive, natural and cultural and stresses that subjects and objects are intertwined as they intra-act with one another. Intra-action conceptualizes that "it is the action between (and not in-between) that matters" ([44] p 14). Entities, therefore, Barad posits, do not exist independently, but intra-act with one another [44].

We are not unitary human subjects independent of our interaction with "others," where "others" include all human and nonhuman agents. Rather than understanding that either "me" or the "BCI" or the "VR" is individually responsible for the actions, we need to understand that action stems from the intra-action between myself, the BCI and the VR resulting in a distributed subjectivity. Such a "relationality implies a more rhizomatic relationship between human and machine, as each is dependent on the other in order to emerge as an entity" ([45] p 376). For instance, central to the integration of BCI and VR with the human user is the way in which cognition and brain signals are distributed between the human and the technologies displacing a single unified human subjectivity, rendering it posthuman. Ma et al. [46] discuss gaze input, which solely depends on eye movement, as an input method of interaction in VR applications. They designed and implemented "a hybrid gaze-based text-entry system in VR for high-speed typing" which combined an SSVEP-based BCI with eye-tracking module in virtual reality head-mounted display resulting in the detection of the eye gaze direction and text entry (p 264). Similarly, Lécuyer et al. [28] discuss the way some games involve controlling a 3D character within a virtual environment where the objective "is to gain one-dimensional control of the character's balance on a tightrope using only the player's EEG" (Lécuyer et al., as cited in [28] p 67). These examples demonstrate that neither the user nor the BCI or VR technologies could act independently of the other. The human, as well as the act of text entry in the first example and controlling the virtual character in the second are all interdependent, creating a posthuman subjectivity. In such instances, the boundaries disintegrate, and human-technology is understood as enmeshed. There exists a dynamic and inseparable intra-action between both [4].

The intra-active relationship between the human and technology complicates notions of a single body and single subjectivity given the various actors (Sundén, [47] as cited in Wilde & Evans, as cited in [4] p 792). By focusing on the entanglement of the users with BCI-VR and the way action is distributed, it becomes difficult to demarcate the boundaries which consequently results in engendering a posthuman subjectivity. Hayles [8] stresses that our bodies do not end at our skin. Referring to her VR experience, she implies that "in these systems, the user learns, kinesthetically and proprioceptively, that the relevant boundaries for interaction are defined less by the skin than by the feedback loops connecting body and simulation in a technobio-integrated circuit" (Hayles, as cited in [8] p 27). This understanding is not about "leaving the body behind but rather of extending embodied awareness in highly specific, local, and material ways that would be impossible without electronic prosthesis" (Hayles, as cited in [8] p 291). It points to the ways in which subjectivity transcends bodily boundaries through technology. The human-BCI-VR entwinement demonstrates that the rigid distinction between biology and technology collapses. In this co-constitutive relationship, it becomes difficult to identify where the human body ends, and the technology begins. What is being created here demonstrates a "posthuman subjectivity that blends the embodied materiality" of the human user with the technical and informational BCR and VR technologies [4]. This posthuman understanding demonstrates the impossibility of any separation between the "self," "other," and "environment" [4]. The "I" is no longer an isolated subjectivity but is rather "constructed and experienced in a permeable fluidity with a range of different external stimuli" ([45] p 376). Subjectivity in this sense is fragmented rather than unified and no longer pertains to the human "I" but is rather the result of the interaction between the different intra-acting actors. Put differently, subjectivity is the product of mutual intra-actions among various interdependent subjectivities. This is to say that the body is always interacting with the world, and therefore changes in the body can change subjectivity itself. In other words, "insofar as subjectivity is tied to the body…that a shift in the formulation of bodies can have a direct implication on the formulation of subjectivity" [9].

7 Conclusion

In discussing the human-BCI-VR entanglement, it becomes pertinent to underscore that the idea of an independent human subject no longer stands. In this chapter, I have attempted to describe how this human–technology relationship complicates the understanding of the subject as a unified entity and necessitates a re-thinking of the notion of the self as distributed with dynamic and perpetually shifting permeable boundaries. This requires a shift from the limited understanding of subjectivity that is bound to corporeality to a more encompassing conceptualization of subjectivity, namely posthuman subjectivity. Subjectivity should rather be re-defined as "the notion that the human being is not an independent and autonomous entity with clear cut boundaries but a heterogeneous subject whose self-definition is continuously shifting, and that exists in a complex network of human and nonhuman agents and the technologies that mediate between them" [9]. If we maintain the misguided understanding of the human as an autonomous standalone subject, as Hayles [8] contends, our relationship to technology will remain that of real life on the one hand and an illusion on the other, concealing the influence of the development of technologies [8].

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