A narrative review of the use of augmented and virtual reality as an alternate to traditional mirror therapy in dealing with post amputation phantom limb pain (PLP)

ABSTRACT

This article reviews the existing data on the use of augmented and virtual reality in the treatment of post amputation phantom limb pain (PLP) in order to curb the shortcomings of the treatment modality already in place: traditional mirror therapy. PLP is a highly prevalent condition- as high as used in 65%-70% amputees, which has many therapies in place varying from medicinal options such as anaesthetics, drugs that help cure depression and injections of botulism toxin, inter-positional treatments such as stimulation of spinal cord, correctional surgery and more. Visio- dynamic approaches such as reflective surface therapy (mirror) and augmented reality treatments which attempt at normalizing the representation of the amputated limb from the cortex and improving the correlation between the authentic and anticipated sensory feedback. Previous studies have consistently demonstrated the efficacy of traditional therapy using mirrors in post upper limb amputation PLP where a setup with a mirror is used to trick the mind of the patient in making the patient see a reflection of the good limb and exercising it to give the effect of exercise of the amputated limb, however because of its crude setup, it proves to have a few limitations which can be overcome using virtual reality. Virtual reality is integrating in our lives today as video games and simulations. It has a lot of application in diagnosing, prophylaxis and treatment. Virtual reality is a boon to the medical field in the sense that it allows one to visualize and practice endlessly without needing any additional resources. Incorporating VR into the treatment, patient centered holistic care can be achievable and patient's quality of life and satisfaction can be improved.

Keywords: Augmented reality, Virtual reality, Mirror therapy, Amputation, Post-amputation phantom limb pain, Sensory feedback.

Introduction

Phantom limb pain:

The brain is the command centre of the body. It has to process the signals coming from all the sensory organs of the body. Vision, along with touch, sound, taste and smell is one of the senses that the brain processes. Sight allows us to collect data from our surrounding environment. It can be used as a form of therapy to transfer information to the brain. (1)

People who experience the loss of a limb or have to get a limb amputated commonly have the feeling that the limb which is missing is still present, an occurrence known as ‘Phantom limb ’which is immensely difficult to treat. A ghost limb is **a graphic percept that an amputated or removed limb from the body is still there physically** & is still performing its regular activities. Amputees often experience some sensations like, but not limited to, pain and discomfort in the phantom limb. Pain coming from a phantom limb can traditionally appears soon after or with 7 days of the amputation, however, less commonly, it can also show up after months or years.(2) Experiencing such debilitating pain is often detrimental to the patient in a way that it negatively impacts their quality of life.

Treatment and management of phantom limb pain has been a challenging thing to deal with for researching and medical practitioners alike.

There are many hypotheses in place which work at explaining the causes of Phantom limb pain. One account is that of cortical remapping. Post amputation, the phantom (amputated) limb still has a majority of its neural pathway, responsible for transmitting sensory and motor signals to and from the central nervous system, intact, as most of this neural pathway lies outside the limb. At the amputation site, the dissected endings of the nerves can thicken and are sensitized to the smallest, most insignificant stimuli sending afflicted signaling to the cord of the spine and the brain, which under normal conditions are lessened in the spinal cord’s dorsal horn. However for some reasons that are not yet fully understandable to us, this inhibitory control is lost following an amputation and the signals can become intensified. These signals reach the somatosensory cortex of the brain (where the representation of a body part is directly proportional to the amount of sensory stimuli received from it.) Representation of a body part in the sensory and motor representation of the cortical hemisphere- the homunculus of the cortex (which is the human body model with ratios proportional to the size of the presentation of the parts in the cortical hemisphere) can increase or shrink depending on the change in sensitivity of that part (For example, braille readers have a higher cortical representation of fingers). The brain can also increase the representation of a body part when it has been injured to heighten sensation which can alert us to any danger; this is an attribute that is considered to cause Phantom limb pain.

Another account is that the neurons that had previously commanded muscles in the phantom limb can still send out signals such as those commanding to move the limb, something that is known as ‘maladaptive plasticity. ’When such a signal is sent out, the

brain expects some signals in turn which indicate that a movement has taken place. When such signals aren't sent and received back, it causes miscommunication which scientists call "negative feedback." This can cause unpleasant sensations of tickling, spasms or even pain. (1)

Yet another hypothesis indicates towards neuromas, which are disorders of the nervous system which act in the periphery.

The development of a nerve tumor consequently with dissection of the nerve which gets cut in the amputation process can cause discharges which are ectopic in nature and the feeling of utmost pain and discomfort. The truth that anesthetic blocking of the nerve leads to a reduction in pain in a few people who have undergone amputation directs us to the thinking that maybe this theory can account for pain of the ghost limb in some cases...

However, all people do not experience a decrease in PLP from the application of anesthetic at the residual part of the missing limb. This conclusion, along with the fact that individuals who have a missing extremity from birth do not experience this disorder leads us to the thinking that suggests that it arises from an alteration that is central in nature as has been implicated above.

The above mentioned speculative accounts aren't mutually exclusive of each other and together might accommodate the differences that have been seen in the experience of various people with this condition. (2)

Objective: To explore the uses of new age virtual reality in treatment of patients suffering from phantom limb pain and study the existing literature on the same.

Presently there are a few treatments in place to help combat phantom limb pain. Some of these include acupunctures, drugs, hypnosis and mirror therapy.(y) No treatment works for every amputee, and all have shown varying degrees of success.

Over the past two decades, mirror therapy has been used to help combat PLP, which includes placing the mirror at the subject's midline to observe and engage in the intact limb's mirrored movements, so as to create an illusion of moving both limbs in synchrony. Why mirror therapy works can be better understood by understanding the concept of "mirror neurons." Mirror neurons are neurons that activated on performing a task and also when one sees a task being performed by someone else, given that the task in question is something that the person can perform by himself. For an instance, they aren't stimulated when watching a leaf sway in the wind. It is even more surprising that these neurons are

also activated when someone imagines doing a task. This also explain why watching someone get physically hurt can create a sensation of pain in us. Because our brain is not a rigid network, but a very flexible organ that is constantly finding better way to deliver signals and forming newer networks to transmit information- a phenomenon known as neuroplasticity, it is possible for the visual system to convey to the mirror neurons that a limb that does not exist is able to move. (1)

A mirror placed at an angle before the torso of the amputee can help create an illusion of a symmetrical body.(3)
So far, mirror therapy proves to be successful in effectuating a noteworthy decrease in the pain experienced, an increased sensation of control of motor activities over the phantom over the changes in the facets of the ghost extremity. (4)

Despite its many successes, traditional mirror therapy has limitations such as insufficient realism of mirrored exercises, deficient range of the feedback (sensory in nature) that is derived from the nonexistent limb and failing to be as effective in easing PLP of the lower limb, which interfere with the effectiveness of the treatment. (5) The need of having to sit in front of the mirror, keep the eyes fixated on it and requirement of sitting in a confined space can easily lead to the breaking of the illusion. (3)
Although the participant may experience the visual and auditory illusion of movement in the phantom, the effect is not as pronounced due to the crude nature of the apparatus, making the illusion non-compelling for the patient, so much so, that its use in treatment is not efficacious. Because the patients are unable to independently control the extremity which is mirrored, so only the modelling of symmetric actions is possible. (6)
Yet another drawback is that the patient often does not complete the prescribed course of therapy because of a fun and engaging experience.

Virtual Reality as an Alternative

Virtual reality is an immersive simulation of a virtual which is created by computer technology and electronic equipment that can be experienced in 360 degrees. In the present scenario, the intervention of augmented and virtual reality training can present as an efficient and cheap treatment, even in amputees with a missing lower limb. It works on the similar principle of traditional mirror therapy: ‘Fooling the brain to cool the pain’ (1)

Virtual reality can provide a more immersive optical insert that is more variable, over a broader spectrum and which is much more realistic than can be attained in a crude setting such as that in front of a mirror. Augmented reality (AR) innovation could give novel roads to manage pain. It can be tailor made to suit the need of each individual patient, fitting with their psychological needs, predilections and characteristics, something that is not possible with other therapeutic options for this condition. Utilizing an assortment of equipment and programming applications, AR as a treatment option is speculated to further develop management of pain and discomfort through systems like unwinding, interruption, social association, and commitment (2). The adaptability inborn to AR applications (e.g., the capacity to configuration modified AR conditions) and the quickly lessening expenses of AR headsets and related equipment empower AR medicines to be progressively accessible to address a scope of painful conditions.

Case Studies

- A study reported how a single subject, who had initially been subjected to mirror therapy because of suffering from long-standing, severe upper limb phantom limb pain, had ultimately gained relief from employment of virtual reality when mirror therapy had failed him. In the study, employment of a system of virtual reality to produce a visual of the nonexistent hand on a monitor of a computer was done. They made use of surface electromyography output from the good hand to allow the participant in question to exercise power over the other hand and workout a series of actions which were reaching and grasping in nature. This whole experiment did wonders in reducing the pain of the patient. (6) Beneficiary effects of a similar nature have also been received in much larger samples of people suffering from phantom pain, stressing on the fact that virtual and augmented reality has a lot of potential in the treatment of this condition. (7)
- Mercier and Sirigu in their brilliant experiment subjected eight people who had undergone amputation of the upper limb to a training that taught them to use their good limb to recreate and copy the motions of the virtual extremity which had been fabricated from the mirrored image of their intact hand. The conclusion that they reported was that their was an reduction of an average of thirty eight percent phantom pain in the eight subjects. (8)

- In a close fashion, Perry et al. demonstrated a mean decrease in pain by forty percent in five amputees who had lost their upper limb. These people were made to undergo training with twenty sessions filled with activities that made active and passive use in imitation of the movements of an avatar. Their sole aim in conducting this experiment was to provide a virtual reality modality of treatment which was within the monetary reach of the masses. This modality made use of components which were of good quality and at the same time were affordable to make use of. The headset that they employed for their experiment made accommodation for the users view by matching with their real time position of head. This made available a absorptive, riveting and engrossing visual of the augmented environment. Use of auditory effects made the game all the more enthralling for the users and they had control over a range of motions from extension, flexion, adduction and abduction of the hip and knee.(9)

- Cole et al. in their study showed that there was an average reduction in the experienced pain by sixty four percent. Making use of trackers of motion of the limb, which was existent, they created an environment where the subjects could both see and control the virtual limb. Ten out the fourteen people who participated in this study showed positive effects after only attending one session, as was reported from this study.(10)

- In a study conducted by Ortiz Catalan and his peers, augmented reality was used as a therapeutic approach for a man who's PLP hadn't subsided with any other form of therapy. Electric signals from his muscles of the stump of his arm were recorded using electrodes and a software was used to convert them into a virtual arm's movement. This was supplemented with a webcam video recording of the patient. The setting created an effect which allowed the patient to will the movement of his phantom arm and control it into performing functions such as playing a simulated race car game. Feedback from the patient was a positive one and he reported his hand feeling relaxed instead of tensed and clenched like it usually did. (6)

- Another report of a case study involving two subjects, one of whom underwent a transtibial amputation and the other a left foot amputation post gangrene that the two participants exhibited a considerable lessening in the torment soon after every session, which employed augmented reality treatment modality. The first subject experienced a complete hundred percentage decline in the pain that was experience after the session

as compared to the pain that was experiment before the session, whereas the subject two reported an average of 93.7 percentage decrease in the pain that was initially experience by him, after attending both of the sessions conducted. Also, both of subjects reported a decline in the pain that was experienced before the treatment and it's severity. It is also interesting to note that the pain progressively lessened across all the following sessions that were conducted. The qualitative feedback had also been informative of the fact that both subjects responded to the treatment with great vigour and we're very open to the idea of continuing treatment under this novel modality. (11-15)

Conclusion

VR systems provide the subjects with an indulging virtual reality encounter where the participants can play in a spectrum of immersive simulations using their phantom limbs. An experience of full control of a virtual phantom limb, for even sessions as short as an hour long, shows promising results. Approaches of virtual reality that succeed in providing enhanced, realistic and lifelike response are considerably more efficient because of the fact that they allow for broad and diverse movements of the limbs and provide with enhanced cues of sensations. Because of its affordability and user friendly interface, virtual reality can be a perspective representative for treatment of phantom limb pain that in based at home. It works on principle of fine-tuning the primary sensory-motor cortex neurons to provide the brain with a response as if coming from the amputated limb so as to reduce the sensation of "noise" in the representation of the missing extremity which is often manifested as pain.

From these and more experiments with the use of augmented and virtual reality in treatment of PLP, we can be assured that developing low cost, high quality, commercially available immersive software that can make for a more realistic approach towards treating phantom limb symptoms is not unforeseeable in the near future.

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