An Investigation into the performance of Augmented Reality for use in the treatment of Phantom Limb Pain in Amputees

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Abstract

Phantom limb pain is the distressing problem experienced by many amputees, defined as a painful sensation perceived in the area of the missing body part. Phantom limb pain can be very severe and disabling. It continues to be experienced by two thirds of amputees, eight years post-amputation.

Augmented reality has the ability to change a person's sensory experience. More applications of this technology are gradually being utilised for therapeutic purposes as augmented environments can be used both to distract the attention of patients from excruciatingly painful experiences and to promote cortical re-mapping at the site from where the pain arises.

Using augmented reality, an environment has been created where upper limb amputees can both view and control motion of their phantom limb to help alleviate phantom limb pain.

1. Introduction

The phenomenon of a phantom limb has been recognised for well over a century [1,2], where a patient with this syndrome experiences an amputated extremity as still present. Phantom limb sensation can be described as the feeling of the presence of the amputated limb and is experienced by almost all patients post-amputation [3].

Phantom limb pain occurs when a person feels pain that they attribute to the area of a limb that has been removed. Phantom limb pain can be severe and disabling and continues to be experienced by two thirds of amputees, eight years after the loss of the amputated limb [4]. It has been documented that as many as 70% of phantoms still remain painful 25 years post amputation [5].

Phantom limb pain occurs in variable forms. Some amputees experience continuous pain that varies in intensity, while for others the pain is intermittent and of a high intensity [6]. Phantoms tend to be more vivid, and persist longer, after traumatic limb loss, or following amputation for a pre-existing painful limb pathology, than after a planned surgical amputation of a non-painful limb.

It has often been commented that a phantom limb will occupy a habitual posture. However spontaneous changes in position are also common. The phantom may also assume, either temporarily or permanently, an awkward and painful posture. Memories of the posture and form of the limb prior to amputation often survive in the phantom [7]. Also, following amputation of a deformed limb, the deformity is often carried over into the phantom [8,9].

The study of phantom limbs also provides an opportunity to understand exactly how the brain constructs a body image and how this image is continuously updated in response to changing sensory inputs. A complete somatic map of the body surface exists in the somatosensory cortex of primates [10,11], including humans [12] (See Fig.1). Following amputation, it has been shown that cortical reorganisation occurs in the somatosensory cortex [13] and that there is a high positive correlation between the magnitude of phantom limb pain and the amount of cortical reorganisation [14]. By using magnetoencephalography, studies have shown that brain areas which ordinarily represent the hand were activated in arm amputees when either the lower face or upper arm was touched [15,16]. The Penfield Homunculus can be reorganised over a distance of 2-3cm in the adult brain, following loss of a limb [17,18,19].

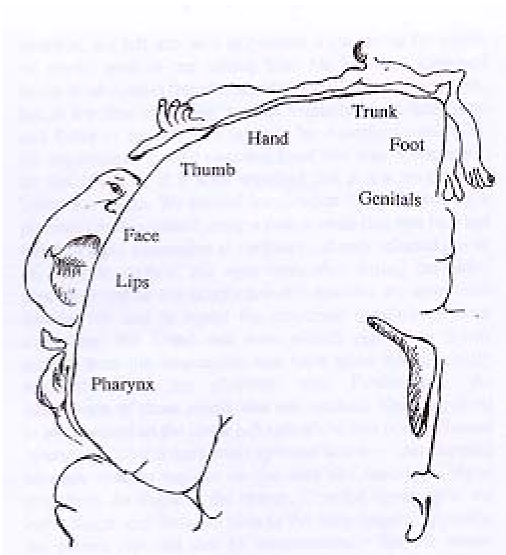

Fig 1: The Penfield Homunculus

2. Mirror Box Illusion

V.S. Ramachandran developed a technique to treat phantom limb pain in upper limb amputees by using an ordinary mirror [20]. The box is made by placing a vertical mirror inside a cardboard box with the roof of the box removed. The front of the box has two holes in it, through which the patient inserts his/her good arm and the phantom arm. (See Fig.2) When viewed from slightly off-centre, the reflection of their "good" arm gave the impression that the patient had two intact arms. By sending motor commands to the intact arm, it gives the impression that both the intact arm and the phantom arm are making symmetric movements in synchrony.

There is great variability in the experienced authenticity of the mirror box illusion and its ability to alleviate phantom limb pain. The effect of this positive visual feedback to the amputee can be very therapeutic. In some cases it was possible to reposition phantom limbs that were perceived to be held in painful or awkward positions, into non-painful postures, giving temporary relief from phantom limb pain.

Figure 2: A member of the Trinity Psychprosthetics Group demonstrating the mirror box illusion.

3. Augmented Reality Mirror Box

The mirror box illusion had quite dramatic therapeutic value for some people, but it was only moderately effective, or completely ineffective for others [20]. For those that found it to be beneficial, it was possibly because the illusory phantom provides feedback that is consistent with actual phantom experiences.

However amputees' perceptions of their phantom limbs often differ greatly from their original limbs [21]. The phantom limb can be shorter, or longer, vary in thickness, have gaps or be continuous, in comparison to the original limb. This is one reason why the mirror box illusion does not have any therapeutic value in some cases, as the reflected image bears no resemblance to the phantom limb as it is perceived by the amputee. These irregularly shaped phantoms cannot be viewed in the mirror, as it necessarily reflects the image of the intact arm.

We have created an environment using Augmented Reality (AR), that simulates the mirror box illusion. It consists of a 3-d graphical representation of an arm on a flat screen that is controlled by a wireless data glove (5DT Data Glove 5W, Transmission Frequency 433.92MHz.). The appearance of the arm can be altered to resemble the phantom limb of the patient. The data glove is worn on the intact arm, whilst the phantom appears on the flat screen in place of the mirror. As the intact arm moves, the arm on the screen representing the phantom also moves in unison.

The main benefit of this AR mirror is that all types of phantom limbs can be graphically represented on the screen. In effect, phantom limbs can now be tailor made to visually resemble what the amputee perceives them to be. Another interesting property of the AR mirror is that it can also be set up to give more general movements, for example, motion of the virtual arm in the same direction as the intact arm. This is not possible to achieve with the ordinary mirror.

4. Study

A control group of 18 able-bodied people participated in the study under conditions of informed consent and in accordance with ethical procedures. The subjects consisted of 11 males and 7 females, ranging in age from 20 to 26. (mean age = 22.056, standard deviation = 1.8401).

Initially, each subject was introduced to the mirror box illusion and he/she tried to experience the sensation of a phantom limb. The participants were then required to try the mirror box illusion for a period of 2 minutes, during which they were instructed to move their left arm in front of the mirror as if they were conducting an orchestra and also to flex their fingers accordingly.

The participants were then fitted with the left-handed 5DT data glove. They positioned their left arm in front of the flat screen and their right arm behind it. An image of a right arm appeared on the screen. The subjects were instructed to keep their eyes fixed on the screen right throughout the experiment. The same experimental procedures as before were carried out, with the flat screen taking the place of the mirror.

5. Results

After all the participants had completed the study and all the results had been correlated, it was found that 88.89% were able to experience a phantom sensation by using the ordinary mirror box illusion. They agreed that the sensation of visualising their reflection moving in unison with their controlling arm was quite satisfactory.

It was also found that 88.89% were convinced when using the AR mirror, that they could relate to the image on the screen as their own limb and that it responded as they expected it to most of the time. When asked to compare the effectiveness of both mirror techniques, 44% opted for the AR Mirror, whilst 28% chose the mirror box illusion. 28% found both methods to be equally effective.

We observed in our study that when some of the participants (55.6%) were using both the ordinary mirror and the AR mirror, that they sub-consciously moved and flexed the fingers of the arm hidden behind the mirror, in unison with the image. It is felt that this could be significant in explaining the therapeutic effect of the both mirror box techniques and will be quantified at a later date.

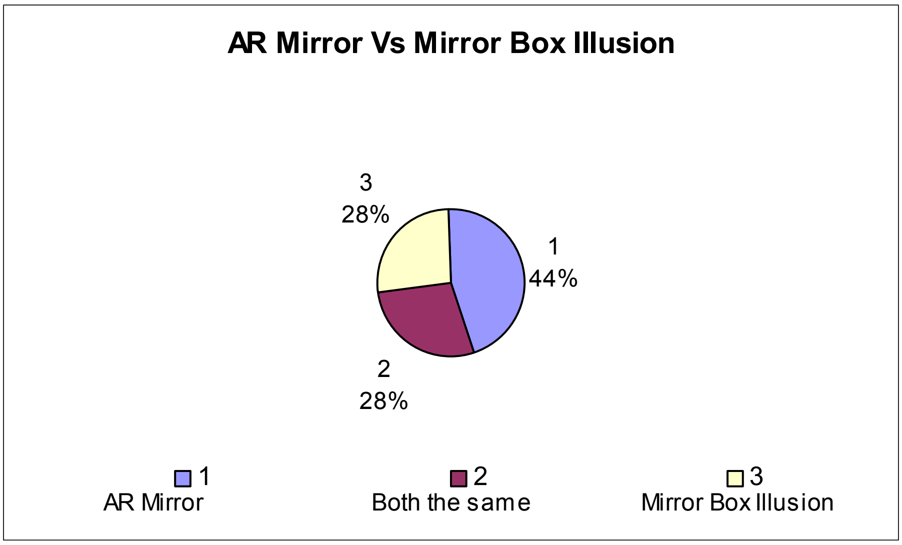

Figure 3: Chart depicting which mirror technique was more effective.

6. Discussion

The ultimate goal of this research group is to create an environment using AR technology that will allow amputees to visually experience their phantom limbs first hand. They should be able to see their phantom limbs as they are perceived, as well as have the ability to control their position, motion and orientation. Using the potential of AR technology, computer generated images of phantom limbs, whatever their shape or form, can be created.

AR technology may have the potential to reduce or remove phantom limb pain by harnessing the therapeutic value of the visual feedback received from the augmented environment. This may help reduce the influence of cortical remapping, reverse it or maybe prevent it from occurring.

Obviously, the AR mirror in the form presented above would be of no benefit to a double upper-limb amputee as he/she would be unable to control the phantom image on the screen without the data glove. The mirror box illusion would also be of no use to such a patient for the same reason. However, this is but a part of on-going research into the creation of an environment which will allow for all amputees to both visualise and control motion of their phantom limbs by use of AR technology. The control signals could conceivably be derived from other limbs, or we could use signals such as electromyogram (EMG), electro-oculogram (EOG), galvanic skin response (GSR), etc. In addition, the illusion could be heightened by having the phantom limb screen perform a task, such as closing a switch.

7. References

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