

# **An Investigation into the performance of a Virtual Mirror Box for the treatment of Phantom Limb Pain in Amputees using Augmented Reality Technology**

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## **Abstract**

Augmented Reality (AR) and the environments that it creates have the ability to change a person's sensory experience in various ways. The therapeutic potential of AR has only recently been realised and more applications of this technology are gradually being utilised for the treatment of people suffering from phobias, severe burns and spinal cord lesions. Augmented environments can be used to distract the attention of patients from excruciatingly painful or terrifying experiences.

Phantom limb pain occurs when a person feels pain that he/she attributes to the area of a limb that has been removed. Phantom limb pain can be very severe and disabling. It continues to be experienced by two thirds of amputees, eight years post-amputation.

V.S. Ramachandran developed a technique to treat phantom limb pain in upper limb amputees by using an ordinary mirror. The patients placed their intact arm into a box, which contained a mirror down the mid-line, so that when viewed from slightly off-centre, the reflection of their arm gave the impression that the patient had two intact arms. When the patients moved their intact arms, their phantoms appeared to move in synchrony.

Whilst this method had positive therapeutic value for some patients, it was completely ineffective for others. Individual differences were observed in the extent to which patients were susceptible to the illusion that the reflected arm was in fact their own. This led to great variability in the experienced authenticity of the mirror box illusion.

Each amputee has his/her own individual perception of the phantom limb. The phantom limb may be shorter, or longer, have some parts thicker or thinner, be continuous, or have gaps in it, in comparison to the original limb. This would appear to be why the mirror box is so successful for some, yet completely ineffective for others.

We have developed, using a data glove and Augmented Reality, an environment in which upper limb amputees can have their phantom limbs individually tailored to represent their own perception of their missing limb. They can then experience a virtual mirror box by wearing a data glove and a magnetic sensory device on their intact limb, whilst watching their phantom move in unison on a flat screen positioned where the mirror should be. This can also be set up to allow for motion of the phantom in the same direction as that of the intact limb, something that cannot be experienced with the mirror.

## **1. Introduction**

The phenomenon of a phantom limb has been recognised for well over a century (Mitchell, 1871,1872), where a patient with this syndrome experiences an amputated extremity as still present. Phantom limb pain occurs when a person feels pain that is attributed 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 post amputation (Gallagher & MacLachlan, 2001). As many as 70% of phantoms still remain painful 25 years after the loss of the limb (Sherman, Sherman & Parker, 1984). In some amputees the pain is continuous but varying in intensity, while others experience intermittent pain of a high intensity (Sherman & Sherman, 1984).

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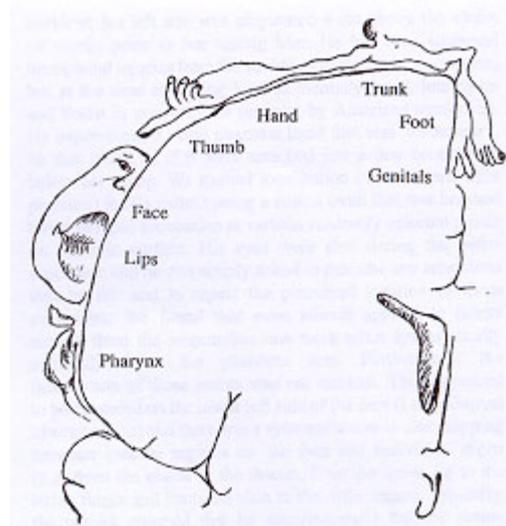
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It is often reported that a phantom limb will occupy a habitual posture, but spontaneous changes in position are also common. The phantom may also assume, either temporarily or permanently, an awkward and painful posture. Phantoms are more vivid and persist longer after traumatic limb loss, or following amputation for pre-existing painful limb pathology, than after a planned surgical amputation of a non-painful limb. This may be due to the greater attention paid to the mutilated or painful limb before it is lost. Memories of the limb's posture and form prior to amputation often survive in the phantom (Katz & Melzack, 1990). In addition, after amputation of a deformed limb, the deformity is often carried over into the phantom (Browder & Gallagher, 1948, Sunderland, 1978).

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 somatotopic map of the body surface exists in the somatosensory cortex of primates (Kaas, Nelson, Sur, Lin, Merzenich, 1979, Merzenich et al., 1984), including humans ((See Fig. 1) Penfield & Rasmussen, 1950). It has been shown that cortical reorganisation occurs after amputation (Flor et al, 1995) and that there is a high positive correlation between the magnitude of phantom limb pain and the amount of cortical reorganisation (Birbaumer et al, 1997). Studies of arm amputation using magnetoencephalography have shown that brain areas, which ordinarily represent the hand, were activated when either the lower face or upper arm was touched (Ramachandran, Stewart, Rogers-Ramachandran, 1992, Halligan et al, 1993).



**Figure 1:** Penfield Homunculus showing where the site for each limb is located on the somatosensory cortex.

## 2. Mirror Box Illusion

The box is made by placing a vertical mirror inside a cardboard box with the roof of the box removed (See Fig. 2, shows one of our researchers demonstrating the mirror box). The front of the box has two holes in it, through which the patient inserts his/her good arm and the phantom arm. When viewed from slightly off-centre, the reflection of the good arm gave the impression of having two intact arms. By sending motor commands to the intact arm to make symmetric movements, as if conducting an orchestra, it gives the impression that the phantom arm has resurrected and the patient receives positive visual feedback informing the brain that the phantom arm is moving correctly. There is great variability in the experienced authenticity of the Mirror Box Illusion and in its therapeutic value. Whilst this technique had quite dramatic therapeutic value for some people, it was only moderately effective, or completely ineffective for others (Ramachandran & Rogers-Ramachandran, 1996).

In some cases phantom limbs perceived to be held in painful or awkward positions, were repositioned into non-painful postures, giving temporary relief from phantom limb pain.



**Figure 2:** Demonstrating the Mirror Box Illusion.

### 3. Virtual Mirror Box

There is great variability in the experienced authenticity of the Mirror Box Illusion and in its therapeutic value. For those who found it to be beneficial, it was possibly because the illusory phantom provides feedback that is consistent with actual phantom experiences.

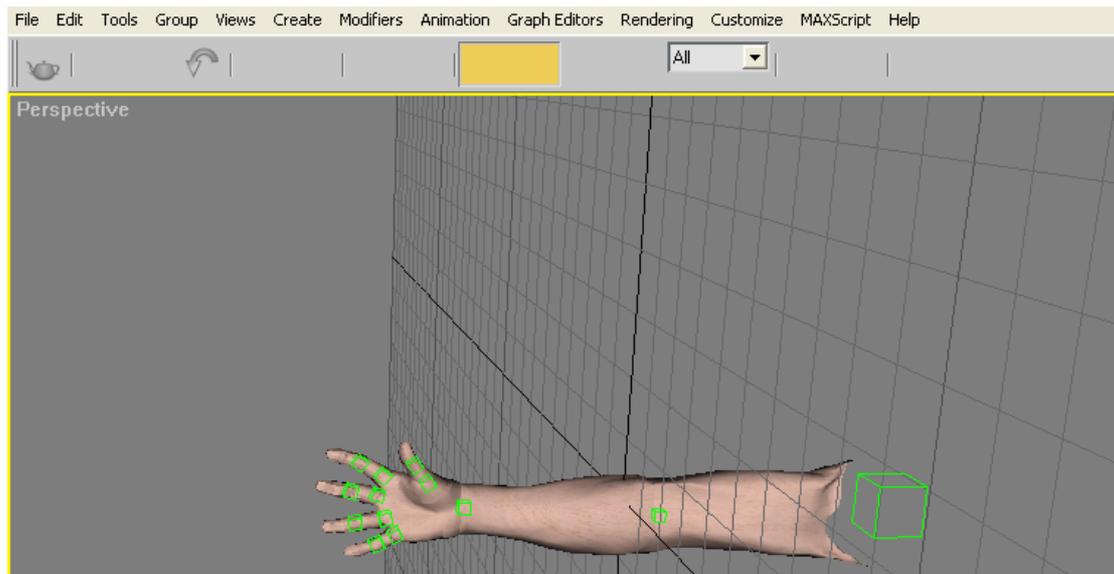
However, patient's perceptions of their phantom limbs can vary greatly from their original limbs. They can be shorter, or longer, vary in thickness, be continuous or have gaps, in comparison to the original limb. This is one reason why the mirror box illusion does not have any therapeutic value in some cases. It is not uncommon for a phantom limb to be disconnected from the amputee's stump (See Fig. 3, Wright, 1997) or for it to resemble only part of the original limb. Such irregularly shaped phantoms cannot be viewed in the mirror, as it necessarily reflects the image of the 'good' arm.



**Figure 3:** This amputee perceives his phantom to resemble a hand disjointed from the elbow stump (Wright et al, 1997).

We have created a Virtual Mirror by developing a graphical 3-d representation of an arm (See Fig. 4), incorporating it into an Augmented environment where it is controlled by a wireless data glove (5DT Data Glove 5W, Transmission Freq. 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 a flat computer screen that takes the place of the mirror. As the intact arm moves, the virtual arm on the screen representing the phantom also moves in unison.

The main advantage of the Virtual Mirror is that all types of phantom limbs can be graphically represented on the screen. In effect, phantom limbs can be tailored to visually resemble what the amputee perceives them to be.



**Figure 4:** Graphical representation of an arm in 3-d that can be altered to represent the phantom limb as it is perceived to look by the amputee.

The Virtual Mirror can also be set up to give more general movements of the virtual arm, for example, in the same direction as the intact arm. This is not possible to achieve with the ordinary mirror.

#### 4. Pilot Case Study

A control group of able-bodied people participated in the study under conditions of informed consent and in accordance with ethical procedures. The subjects varied in age from 18 to 50 (mean age = 24.875, standard deviation = 12.978).

The participants were first instructed to try the mirror box illusion for a time of 2 mins. For the first minute, they were instructed to move an arm in front of the mirror as if they were conducting an orchestra, and to flex their fingers accordingly. For the second minute, they were instructed to place the hand in front of the mirror flat on a table and to drum their fingers rhythmically against the flat surface.

Next, they were fitted with the data glove and an image of an arm appeared on the flat screen. In this initial experiment the virtual arm, while realistic, was not tailored to the real arm of any subject. The same experimental procedures were carried out as before, with the participants instructed to keep their gaze fixed on the graphical image on the screen.

#### 5. Results

After all the participants had completed the study, it was shown that 87.5% found that they could agree with the effect created by the mirror box illusion. They agreed that the sensation of visualising their reflection moving in unison with their controlling arm was quite satisfactory. When using the Virtual Mirror, 75% of the subjects found that the computer generated image responded and behaved in a satisfactory manner to that of their controlling arm wearing the glove.

An interesting observation in our study was that when some of the able-bodied participants of our study were using both the mirror box illusion and the virtual mirror box, they sub-consciously moved and flexed the fingers of the arm hidden behind the mirror, in unison with the image. This effect will be quantified later. It is felt that it could be very significant in explaining the therapeutic effect of the Mirror Box and the Virtual Mirror.

#### 6. Discussion

By harnessing the potential of Augmented Reality technology, computer generated images of amputee's experienced phantom limbs can be created in such a way that they move and look like their

own phantom experience. This brings the therapeutic value of the visual illusion created by the mirror box to a wider range of amputees.

It may then be possible that Augmented Reality has the potential to reduce or maybe remove phantom limb pain by the visual feedback received from the augmented environment. This may help reduce the influence of cortical remapping, reverse it, or maybe even prevent it from occurring.

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