Can Immersive Virtual Reality Reduce Phantom Limb Pain?

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Abstract This paper describes the design and implementation of a case-study based investigation using immersive virtual reality as a treatment for phantom limb pain. The authors’ work builds upon prior research which has found the use of a mirror box (where the amputee sees a mirror image of their remaining anatomical limb in the phenomenal space of their amputated limb) can reduce phantom limb pain and voluntary movement to paralyzed phantom limbs for some amputees. The present project involves the transposition of movements made by amputees’ anatomical limb into movements of a virtual limb which is presented in the phenomenal space of their phantom limb. The three case studies presented here provide qualitative data which provide tentative support for use of this system for phantom pain relief. The authors suggest the need for further research using control trials.

Keywords Phantom Limb Pain, Amputee, Immersive Virtual Reality

Introduction

Following amputation the amputee commonly experiences the amputated limb as still intact [1]. The phantom limb is often painful - a problem which can have far-reaching implications for amputees’ lives. For instance, adjustment to amputation is negatively correlated with levels of phantom limb pain (PLP) [2] and amputees with PLP are less likely to use a prosthetic limb [3]. Non-prosthesis use often results in the restriction of normal activities and is associated with higher levels of depression [4,5].

One promising development in the treatment of PLP is the mirror box [6]. This is created by arranging a mirror in a box in such a way as to allow amputees to view a reflection of their anatomical upper limb in the visual space occupied by their phantom limb. For some patients the box is able to induce vivid sensations of movement originating from the muscles and joints of patients’ phantom arms, and to reduce phantom limb pain and/or gain control over a paralyzed phantom limb [6-8]. The mirror box effect may work by providing a means to link the visual and motor systems to help patients recreate a coherent body image and update internal models of motor control [9,10]. This suggests that other visual therapies which work in a similar way may also be of benefit in treating phantom limb pain.

One drawback of the mirror box is that it operates within a narrow spatial dimension, since it requires the patient to remain in a fairly fixed position with the head oriented towards the mirror and the body held in mid-sagittal plane with the mirror [11]. It also requires that the user attempts to ignore the intact limb providing the
reflection in order to focus in the image of the phantom limb. These issues make the mirror box a fairly restrictive and tentative illusion. One potential solution to these problems is immersive virtual reality (IVR), which can be used in a similar way to the mirror box whilst allowing far more scope for changes in experimental paradigm [11].

The present research to be described here uses an IVR system which transposes movements of amputee's anatomical limbs into movements of a virtual limb in the phenomenal space occupied by their phantom limb. This gives a similar illusion to the mirror box without the confines imposed by reflection-based work: in the virtual environment (VE) only the virtual phantom limb moves in response to motion of the anatomical limb so the illusion is robust, independent of the orientation or focus of the patient. In the remainder of this paper we outline the preliminary observations of the technology in use and feedback from three participants regarding changes in the phenomenology of their phantom limb or phantom pain. The objectives of the present work are to show proof of principle for the development of this kind of technology for the treatment of phantom limb pain.

1. Description of the virtual environment and virtual tasks

A V6 virtual reality head-mounted display (HMD) is used to present the computer-generated environment to participants and to facilitate immersion. In order to monitor and represent participants' arm/hand/fingers and leg/foot movements movements a 5DT-14 data glove and sensors is used for upper-limb amputees, while sensors alone are used for lower-limb amputees. Sensors are attached to the elbow and wrist joints or the knee and ankle joints. A Polhemus Fastrak monitors head movements and arm and leg movements. A minimal virtual environment (VE) represents the participant within a room, from an embodied point-of-view (see Figure 1).

![Figure 1. One possible view participants may see when taking part in the experiment](image)

In the present study participants use the IVR system for a period of 30 minutes, completing four tasks in repetitions. A full virtual body representation is provided for
participants. A virtual representation of the phantom limb is made available by transposing the movement of the participant’s opposite anatomical limb (e.g. their physical left arm) into the phenomenal space of their phantom limb (e.g. their virtual right arm). The tasks are: placing the virtual representation of the phantom limb onto colored tiles which light up in sequence; batting or kicking a virtual ball; tracking the motion of a moving virtual stimulus; and directing a virtual stimulus towards a target.

2. Participants

Participants with severe PLP were recruited through the sub-regional Disablement Services Centre, Manchester. The intensity of the intervention was determined by how often the patients could come for testing since, due to the nature of the equipment, sessions were carried out only at the University of Manchester. All participants are part of an ongoing, longitudinal study which will continue for a minimum of 17 weeks. However, for the purposes of this paper, preliminary indicative qualitative findings are reported here to assess proof of principle for this IVR equipment.

2.1 Case Study One: PK

A 63 year old male left upper-limb amputee (above elbow). He had been an amputee for 12 years and 3 months, as the result of a swimming accident. PK suffered with severe PLP “twenty-four seven – I’m never ever out of pain”. His phantom limb was shorter than his anatomical limb in a fixed position with the elbow bent at roughly right angles and the fingers in a cupped position. PK suffered with intense flashes of pain attacks in his phantom which can be very severe; he would often find himself immobilized by the pain. Despite the severity of PK’s condition, he insisted on keeping himself busy and, as such, PK came for 3 testing sessions over the 3 week period, with a maximum 5 days in between sessions.

2.2 Case Study Two: WW

A 60 year old male right lower-limb amputee (below knee). He had been an amputee for 12 years and 10 months as the result of a work-related accident. His phantom pain was less severe than PK, but he was still constantly aware of it: “it’s always there, like a nagging sensation”. The most distressing part of the phantom pain would be the intense flashes of pain he would experience in his phantom foot which felt “as if someone’s ramming a sharp knife into the sole”. These attacks would vary in frequency but the severity would often interfere with his sleep and his everyday life. WW attended 3 sessions over the course of 3 weeks. The second and third sessions were both carried out two days apart in the same week, two weeks after the first session.

2.3. Case Study Three: DT

DT was a 65 year old female left upper-limb amputee (below elbow). She had been an amputee for 1 year, as the result of a fall. The phantom pain DT experienced is mainly localized to the phantom hand; a constant pins and needles sensation which can vary in severity. DT’s phantom hand is immobile with the fingers in a clenched position which
is accompanied by a pain she describes as in "...the palm because I think it’s like the nails of my fingers digging into my palm." The pain interferes with her sleep on a regular basis. DT has attended only 2 sessions so far in a 3 week period with 2 weeks in between trials.

3. Data Collection

In the present paper we emphasize the importance of achieving a qualitative understanding of patient’s phantom limb experience, and of their experience of using the IVR system, in their own words. This is achieved through semi-structured interviews carried out at each session and these interviews provide the core focal point for analysis in this paper, since the authors feel they highlight important aspects of the system which are not encapsulated by quantitative assessment. These interview data are supplemented in the findings reported here, where informative, by pain diaries completed by participants in the interim period between each trial.

4. Indicative Results

During each period of IVR use PK reported a decrease in his phantom limb pain. However, he also reported that this would be accompanied by the pain coming back “with a bit of a vengeance” within a few hours after completion of each testing session. He attributed this to the fact that the pain would be returning after a lull during the sessions which would make the comparative return of the pain seem more severe. During the 3rd session, PK reported vivid sensations of movement in his phantom arm: “During it, I actually felt as if it was my left arm that was doing the work and chasing the ball. My actual phantom arm rather than my right... and that was more like reality than virtual reality.” PK commented that “If I could harness that (the movement in his phantom limb) maybe I could open my fingers and ease the cramping pain a little”. Interestingly, in the following week to this session, a pain diary measure showed an average rating of 6.8 (out of 10) over the following 3 days, which then increased to an average of 8.3 for the subsequent 3 days. Obviously, this improvement in PLP ratings is short-lived but given the relatively low frequency of testing sessions, this could be considered a promising result. Self-reported evidence from PK suggested a positive change in his sleep patterns after the first session of IVR which has continued throughout the 3 week period: “I’ve actually been sleeping a little better over the last few days... I’m getting about 5-6 hours of uninterrupted sleep as opposed to 2-3 hours and I’m doing nothing else different in my life except coming here.”

WW's results indicate a more variable pattern than PK's. There were no consistent alterations in pain ratings during use of the IVR system for the first two sessions. It is worth mentioning however, that WW did suffer with simulator sickness which meant the first session had to be terminated early. At one point during the second session, his anatomical left leg collided with his stationary prosthetic leg. WW commented that this was an “uneasy sensation... it looks on the thing (HMD) like it’s not in the way but then you bang into it and it feels queer.” When asked to try and elaborate on this, WW mentioned his phantom pain had increased slightly during this period. This is consistent with research which sites sensory-motor incongruence as a possible source for painful sensations [12]. WW chose to remove his prosthesis for the third session to avoid this.
situation and consequently, he engaged more in the 3rd session and reported no feelings of nausea for the first time. Interestingly, his pain rating at the end of the session compared to the beginning showed a decrease of 4 points (from a 7 initially to a 3 on leaving). WW also commented that “It feels as though I’m doing something with my right (phantom) leg… It’s a queer sensation but it feels good that I’m achieving something with my right leg. That I’m doing the task with my right leg.”

DT has attended the fewest number of sessions out of all three participants but interestingly reported a drastic change in her phantom hand after just one session: “It’s funny… one of my fingers is coming out, sort of pointing out now.” When we consider that one of the vivid sensations experienced by DT was that of nails digging into her palm, if this phenomenological change continues, it has the potential to alleviate this pain. DT has also reported vivid sensations of her phantom hand carrying out the tasks and she unconsciously moves the stump of her left arm around whilst carrying out the tasks: “My left arm felt if it was moving… which was quite an odd sensation”. She also reports she is tired after sessions and that her left (phantom) arm aches significantly more than her right (the labour intensive arm) after the IVR sessions.

3. Discussion

All participants made some reference to a transferral of sensations into the muscles and joints of the phantom limb. PK and DT support this more vividly than WW and this may indicate the system could potentially be of greater benefit to upper- than lower-limb amputees. This is a tentative claim, however it could be supported by the larger degree of movement afforded by the virtual hand over the virtual foot (i.e. all the fingers move separately whilst for the foot there are no toes – it is represented as if it is wearing a shoe).

DT reports the most drastic change in her phantom limb after just one session. This may indicate that this kind of treatment is more effective for more recent amputees. A speculative hypothesis could explain this in terms of a greater plasticity in the brain for recent amputees as it has had less time to re-define the internal model of the body.

All three participants report a decrease in phantom pain during at least one of the sessions. However, another common factor is that they all comment on how they are based on the tasks which may suggest they are simply distracted from the pain. This evidence stresses the importance of further research using control trials to assess the efficacy of this system over and above any pain relief caused purely by the novelty of the tasks and the concentration required.

Most importantly, the results appear to highlight the necessity for a more intense intervention since the interim pain diaries suggest there is little effect of the sessions beyond a day or two. This is understandable, especially for PK and WW who have suffered with this pain for over 12 years: it would be unreasonable to expect any treatment to have a dramatic effect in such a short space of time.

The authors conclude that these preliminary qualitative findings show sufficient proof of principle to justify further testing with the IVR system using control trials, more intense intervention and a greater number of participants.
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References


