

# Investigating the efficacy of a virtual mirror box in treating phantom limb pain in a sample of chronic sufferers

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## ABSTRACT

This paper describes a pilot clinical study to evaluate the efficacy of using immersive virtual reality (IVR) as a rehabilitative technology for phantom limb pain experienced by amputees. This work builds upon prior research which has used simple devices such as the mirror box (where the amputee sees a mirror image of their remaining anatomical limb in the phenomenal space of their amputated limb) to induce vivid sensations of movement originating from the muscles and joints of their phantom limb and to relieve pain. The IVR system transposes movements of amputees' anatomical limbs into movements of a virtual limb which is presented in the phenomenal space of their phantom limb. The primary focus here is on a qualitative analysis of interview data with each participant throughout the study. We argue that the findings of this work make a case for proof of principle for this approach for phantom pain treatment.

## 1. INTRODUCTION

Phantom limb pain (PLP) is the chronic experience of pain in the residual impression of a limb which persists following amputation. Research has shown incidence rates as high as 85% with PLP sufficiently severe to require withdrawal from social or work environments for considerable periods of time (Sherman et al., 1984). The relationship between phantom limb pain (PLP), prosthesis use and psychological well-being is an intimate one. For instance, significant correlations have been observed between adjustment to amputation and pain (Katz, 1992), with adjustment to amputation less likely as levels of pain increase. Amputees with PLP are less likely to use a prosthetic limb (Dolezal et al., 1998). Non-prosthesis use often results in the restriction of normal activities (such as self-care, visiting friends and carrying out domestic work), and is associated with higher levels of depression (Williamson et al., 1994; Murray, 2005).

Phantom limb pain has thus far proved to respond poorly to the current range of pharmaceutical, surgical and psychological treatments. However, one promising development in this regard was Ramachandran's mirror-box (Ramachandran and Rogers-Ramachandran, 1996) which allowed amputees to view a reflection of their anatomical limb in the visual space occupied by their phantom limb. Ramachandran reported evidence that the box induced vivid sensations of movements originating from patients' phantom limbs and in some cases relieve their PLP. The mirror box has also been used with similar success in lower-limb amputees, where viewing a reflection of an anatomical limb in the phenomenal space of a phantom limb resulted in a reduction in phantom pain (MacLachlan, MacDonald and Waloch, 2004).

The mirror box presents a number of inherent limitations in treating PLP, highlighted previously by the authors (Murray et al., 2005). The illusion is tentative, relying on the patient maintaining attentional focus on the reflected image as opposed to the moving anatomical limb. If the patient were to move away from the mirror, or not to keep the mirror within visual range, the illusion would be compromised if not completely broken. It also operates within a narrow spatial dimension, relying on the patient remaining in a restricted, fixed position. Finally, the possible movements that can be induced in the phantom limb are constrained by the need for patients to imagine themselves carrying out two-handed tasks which are concordant with synchronous mirror-image movement; conducting with both hands, for example. Mirror-box work sometimes uses two-handed tasks so that the patient can focus on both limbs (intact and reflected). With single handed-tasks it becomes more difficult for the patient to ignore the visual information coming from their intact limb.

However, the mirror box work is promising and suggests that other visual therapies that work in similar ways, while overcoming some of its limitations, may also relieve PLP. In the present project we have implemented a similar phenomenon to the mirror-box using immersive virtual reality (IVR) (Murray et al., 2005; Murray et al., 2006a). This system transposes the movements made by their intact anatomical limb into movements of a virtual limb in the phenomenal space occupied by their phantom limb. Unlike the mirror-box, IVR allows the patient to perform tasks without having to remain visually and spatially fixed with a relatively narrow dimension. The tasks implemented in IVR can be more complex, and require a wider range of anatomical movements, than possible with the mirror-box. A further advantage is the ability of an IVR system to implement single-handed tasks, and there is the potential to implement tasks similar to those used in normal physical rehabilitation contexts. Therefore, the IVR system allows complex fine and gross motor movements and thereby the possibility for users to engage in tasks made impossible by the mirror box. In an earlier paper we presented initial findings regarding three patients (Murray et al., 2006b). In the remainder of this paper we outline the experiences of 5 patients 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 and to stimulate further work in this area.

## 2. METHODOLOGY

### 2.1 Design

Due to the relatively nascent approach of using IVR to treat PLP, the research is a pilot study to assess proof of principle for such systems. Participants used the system on a weekly basis, with the precise intervals between sessions determined by participant availability. This made it difficult to standardise the procedure precisely: however all participants used the system at least 7 times, with a maximum of 10 sessions. Each IVR session lasted 30 minutes. Participants completed four tasks in repetitions: placing the virtual representation of the phantom limb onto coloured 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. It was hypothesised that participants would experience phenomenological changes in their experience of their phantom limb which would lead to significant short-term and long-term reductions in the frequency and severity of PLP. The reduction of phantom limb pain was hypothesised to lead to significant positive changes in psychosocial issues, activity restriction, and satisfaction with a prosthetic limb.

### 2.2 Participants

Participant characteristics are shown in Table 1.

**Table 1.** Characteristics of Study Participants (N=5).

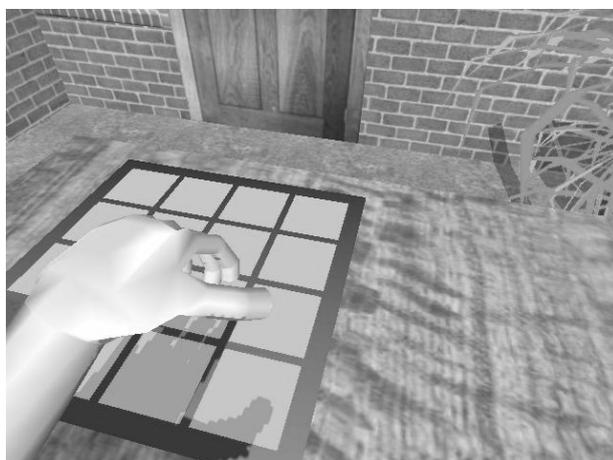
Name	Gender	Age	Site of Amputation	Time Since Amputation	Duration Suffering PLP	Prosthesis Wearer?
PK	Male	63	Left Arm Above Elbow	12yrs 10 months	12 yrs, 10 months	No
WW	Male	60	Right Leg Below Knee	12 yrs 3 months	12 yrs	Yes
BH	Male	56	Left Arm Below Elbow	39 yrs 8 months	39 yrs, 8 months	Yes
SM	Female	61	Right Leg Above Knee	11 yrs 8 months	11 yrs, 8 months	No
DT	Female	65	Left Arm Below Elbow	1yr 3 months	1 yr	Yes

Participants were recruited through Manchester's sub-regional Disablement Services Centre and contacted on the basis of having phantom limb pain and being adults without any major visual or cognitive deficits. For upper-limb amputees only left-arm amputees could be included (the equipment has a right-handed glove). Both left and right lower-limb amputees could be recruited. Participants were a minimum 12 months post-amputation to ensure the phantom pain experience was chronic in nature. Eight participants were recruited

after the inclusion criteria were exercised. Of these, three withdrew from the study after a maximum of 3 sessions. One participant was advised to withdraw participation by his physiotherapist due to weakness in the remaining anatomical active limb. The remaining two participants withdrew due to difficulties arising in transportation to and from the research site. All participants had undergone varied and extensive previous treatments for their phantom limb pain; in the case of PK, this included the implantation of a deep brain stimulator which had subsequently malfunctioned. Interestingly, a majority of participants (3 out of 5) had also been treated using the mirror box with no success. As such, the final sample comprised of participants suffering with particularly stubborn phantom limb pain.

### 2.3 Materials

A V6 virtual reality head-mounted display was used to present the computer-generated environments to participants and to facilitate immersion. In order to monitor and represent participants' arm/hand/fingers or leg/foot movements a 5DT-14 data glove and sensors were used for upper-limb amputees, while sensors were used for lower-limb amputees. Sensors attach to the elbow and wrist joints or the knee and ankle joints for upper- and lower-limb amputees respectively. A Polhemus Fastrak monitors head movements and arm/leg movements. A virtual environment represents the participant within a room, from an embodied point-of-view (see Figure 1). A full virtual body representation is provided for participants. A virtual representation of the phantom limb is made available by transposing the participant's opposite anatomical limb (e.g. their physical right arm) into the phenomenal space of their phantom limb (e.g. their virtual left arm – see Figure 2).



**Figure 1.** One possible view participants may see when taking part in the experiment.



**Figure 2.** A person with a left-arm amputation taking part in the study.

Transferring movement from an anatomical limb into movement of a virtual limb on the opposite side of the body is possible due to joint angles parameterization. For example, once the joint angles are recovered from the right physical arm, applying these joints angles to the left virtual arm results in mirroring the movement. This method of transferral as well as other implemented software generates responsive, fluent, real-time motion, allowing virtual limbs to move in synchrony with anatomical limbs. The representation of the virtual

body gives realistic results at a gross level, which the authors and participants found to be satisfactory for successful immersion. However, in an attempt to reduce discrepancy, the interface on start-up does allow the colour of skin and clothes to be altered to approximate those of the participant (see Murray et al., 2005, 2006a for more details).

## 2.4 Data Collection

The small sample size in the study reported here precludes a meaningful quantitative analysis. Therefore 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. The broad approach here is a phenomenological one; with the aim of understanding patients' own embodied experiences (see Murray, 2004). This is achieved through semi-structured interviews carried out at each session (lasting about 15 minutes each). Alongside this qualitative data the below quantitative information was also collected and is reported where appropriate in the results to contextualize the qualitative findings.

Measures of PLP were monitored over the course of the study period through a number of questionnaires: The McGill Pain Questionnaire (MPQ) (Melzack, 1975) which was completed on the first visit and a follow-up 2 weeks after completion of participation in the project; The Short-Form MPQ which was administered following each interim session; and Pain Diaries were also completed daily throughout the course of the intervention to allow a contextualised analysis of participant's phantom pain experience. The Trinity Amputation and Prosthetic Experience Scales (TAPES) (Gallagher and MacLachlan, 2000) is a multidimensional self-report instrument designed to help understand adjustment to an artificial limb and was administered on the first visit and at the 2-week follow-up. Finally, the Amputee Body Image Scale (ABIS) (Breakey, 1997) assesses how an amputee perceives and feels about his or her body experience and was administered at the same time interval as the TAPES. These additional measures were completed in order to assess any secondary benefits that may have occurred alongside pain reduction.

## 3. RESULTS

### 3.1 DT

DT had no volitional control over her phantom arm and her phantom pain was localized to the phantom hand. She described the pain in her fingers as, "almost as if they're trapped. My fingers are trapped. The knuckles hurt." The phantom hand remained paralysed in a fist: "The palm of my hand hurts, I think because it is as if they're [fingers] sticking into it." Her phantom pain was "there all the time" and often interrupted her sleep and everyday life. Her initial scores on the MPQ, using weighted rank values were 37.25 (out of a possible 88.21). DT reported vivid sensations of phantom limb movement during the tasks and, after just one session, that her index phantom finger had been somewhat freed: "It's funny... one of my fingers is coming out." It is unlikely that DT's self-reports were confabulation since she expressed extreme surprise at this new experience, "It's weird... I know that it can't be and your brain's telling you it is and you know damn well that the brain's wrong and it can't be! The brain's weird!" After the fourth session the phantom pain was reported to have eased overall: "the pain has gone down a bit and the [pain] flashes have gone down a bit... so it's been quite good for the last few days."

One negative aspect associated with DT's participation was that she usually experienced slightly more intense phantom pain for a period immediately after sessions. When asked how long this would tend to last, DT stated, "about 24 hours. Yes, it spiked a lot and goes up but then it improves slowly". This verbal report was confirmed through observation of DT's pain diaries. Despite the negative aspects of DT's experience, the trend of improvement continued over the study period. By the final session both the phantom thumb and index finger had been released and DT reported having some voluntary control over these digits. DT surmised that this had a positive affect on the phantom pain in general: "I think the fact that it's brought my fingers out – at least some of them out – has helped the pain considerably. It feels more comfortable." DT did not complete follow up measures; in lieu of the full MPQ follow-up evaluation, it is interesting to note that the Short Form MPQ, showed an overall evaluative decrease in phantom pain following the first and last sessions from 'Discomforting' to 'Mild'.

### 3.2 SM

SM suffered violent phantom pains on a regular basis which often left her: "passed the screaming stage... you end up crying." Her phantom pain at its worst was described as, "electric shocks" which travelled down the leg and across her foot. This sensation would build up until, "as one if firing off, another one's

following.” She had good voluntary control over the movement of her phantom leg and foot and found that sometimes movement would “interrupt the pain.” Her phantom pain often interrupted her sleep and everyday life and initial scores on the MPQ were 77.84 (out of a possible 88.21). SM reported a lowering of PLP during the IVR sessions: “It kind of diverts the mind away from the pain,” and a transferral of sensations into her phantom leg throughout the tasks: “I was moving the limb itself and trying to get into the position you would actually use it – you know, to kick the ball.” She enjoyed the experience of using the system: “the right leg was trying to do it for me. I think it’s a good exercise”. However, her PLP increased following sessions for a period of up to 48 hours, which she attributed to the “stimulation of phantom nerves”.

Whilst SM enjoyed using the system and “exercising” her leg, in general, both qualitative and quantitative reports of her levels of PLP did not seem to alter much throughout the period of the study. SM’s follow up questionnaires were not returned so comparative MPQ scores are not available. However, the Short-Form MPQ which was completed at each visit showed an overall evaluative decrease in phantom pain from ‘Distressing’ at the first session, to ‘Discomforting’ at the last session.

### 3.3 PK

PK suffered severe phantom pain “twenty-four seven. I’m never, ever out of pain” in 12 years and 3 months since amputation. He experienced his pain as a “burning, cutting pain – like someone cutting me with a hot knife.” He also had a vivid experience of a strap around his wrist that was “pulled really tight” and his hand was paralysed in a cup position with the fingers always being very painful. Initial scores on the MPQ were 46.41 with ABIS scores at 33 (out of a possible 95). (TAPES Scores are not reported here as PK did not wear a prosthetic limb and therefore could not complete this questionnaire.) PK had little to no volitional control over movement in his phantom limb and could only swing it side to side with movement of the stump.

PK reported vivid sensations of a transferral of kinaesthetic sensations into his phantom limb whilst using the equipment which “allowed me to forget that my [phantom] arm was actually in a fixed position.” After the 3<sup>rd</sup> session, the use of the system felt “more like reality than virtual reality”. PK also reported that, whilst using the system, “it took away a lot of my phantom pain.” For the first few sessions, PK – like DT and SM - reported increased levels of phantom pain after sessions. However, PK attributed this to the pain returning after a lull which increased subjective experience of the pain: “having had nothing (*during sessions*) and then having the pain, it feels stronger.”

After 4 weeks of using the system, PK was very surprised to report his phantom limb moving of its own accord for a period of 1 hour whilst he was at home. During this time, he was “virtually pain free.” It is unlikely that this report is due to confabulation since PK telephoned the experimenter whilst this was occurring to share his extreme surprise. Towards the end of his involvement PK reported, with some surprise, a number of changes in the phenomenal experience of his phantom limb which improved his phantom pain. The strap around his wrist had loosened: “before, the strap was so tight that my fingers felt swollen up and really, really painful. Now that strap seems to be not as tight, it feels as if I’ve got circulation.” He could make very small volitional movements of his phantom fingers and had some control over the orientation of his wrist. Finally, he reported the experience of telescoping in his phantom arm which had a beneficial effect on the pain: “My limb actually seems shorter... I don’t know why, it just seems to be shrinking.” PK’s follow-up MPQ scores fell to 32.76, with the ABIS scores also decreasing to 25.

### 3.4 WW

WW has suffered with severe PLP for 12 years and 10 months and experienced intense pain in the sole of his phantom foot on a regular basis, “as if someone’s ramming a knife in”. WW also reported experiencing many different kinds of pain in the phantom foot which he could attribute to previous pain experience in the right foot before amputation including: a broken ankle; a burn to the top of the foot, and even the memory of his toes being tightly squeezed when he was a child due to small shoes, amongst other things. WW’s initial MPQ score was 44.54. The ABIS evaluation showed a body image disturbance score of 57. The TAPES measures of psychosocial adjustment, activity restriction and prosthesis satisfaction were 42, 20 and 40.

WW suffered with simulator sickness which meant the first session was 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.” Asked to try and elaborate on this, WW mentioned his PLP had increased slightly during this period. This is consistent with research which sites sensory-motor incongruence as a possible source for painful sensations (McCabe et al., 2005). WW chose to remove his prosthesis during subsequent sessions to avoid this situation and consequently, he engaged more and reported decreased feelings of nausea.

WW reported vivid sensations of movement in his phantom leg during sessions: "It's a queer sensation...I'm doing the games with my right leg" and expressed pleasure at feeling as though he was "achieving" something with his phantom limb. After 3 sessions, WW used his experience of the IVR system to begin self-hypnosis; a technique which he had once previously used to aid pain control. He would be "imagining myself on this machine and it seems to help a bit that I can look down and see my leg." It seemed the virtual representation of the body helped WW to focus his concentration. He began self-hypnosis sessions 3 times a day using this technique; a factor which may confound the findings of this research.

WW reported that the use of IVR system was helping his PLP: "the burning pain is abating a little bit. So it's improved a little bit." When reflecting on the experience at his final session, WW referred to an easing in the various different types of pain he experienced: "it seems to have taken the edge off them. You know, they're not as severe." However, quantitative measures at follow up would suggest that the PLP has worsened rather than improved. The follow-up MPQ score increased to 61.79, with ABIS increasing to 62. The TAPES measures of psychosocial adjustment, activity restriction and prosthesis satisfaction remained largely the same at 45, 20 and 40 respectively. It is difficult to consolidate WW's verbal reports with these findings. WW's pain did appear to be the most inconsistent of all participants since he did not suffer with just one type of phantom limb pain; the pain memories would come and go at random intervals, making it difficult for him to comment on his pain over any extended period of time as it would fluctuate so greatly. This highlights a difficulty in comparing pain scores obtained at one point in a study with another point (when either of these particular data collection times may not be typical of the person's pain level).

### 3.5 BH

BH self-reported that his phantom pain: "doesn't bother me regularly", but it was particularly stubborn in that it had persisted for almost 40 years. The pain he experienced was severe cramping in the phantom hand and his initial MPQ score was 21.72. The ABIS evaluation showed a body image disturbance score of 56. The TAPES measures of psychosocial adjustment, activity restriction and prosthesis satisfaction were 48, 18 and 39 respectively. BH had very good voluntary control over his phantom limb before use of the system but reported highly unexpected sensations in the experience of his physical body whilst using the equipment: "It felt like I was leaning over to do it." He reported vivid sensations of feeling as though his right physical arm was leaning over his body towards the left hand side in order to make the virtual left, or phantom arm, move. This was a highly unexpected experience since his physical right arm would always remain on the right hand side of his body. It is highly unlikely that this self-report was due to confabulation since he continued to report this experience even after he knew that this was not possible: "I feel like I'm reaching right over but I can't possibly be because it's like a mirror so my arm should physically be going that way!" Interestingly, he also had strong impression of his physical phantom arm moving whilst carrying out the tasks and found it difficult to accept the contrary: "it feels like I'm moving my left arm. But according to you, I'm not!"

In the last 3 weeks of involvement, BH reported no experience of PLP (previous reports and diaries had shown at least 2 episodes per week). Whilst BH could not conclusively attribute this improvement to use of the system, he did comment: "I'm not doing anything different from what I've always done... and I've not had the cramp since." The follow up questionnaires showed improvements on all measured scales apart from the TAPES prosthesis satisfaction. MPQ scores dropped to 11.89 and ABIS to 46. The TAPES psychosocial adjustment subscale improved to 52, with a small decrease in perceived activity restriction to 11.

## 4. DISCUSSION

Analysis of the qualitative data does provide opportunities for tentative conclusions to be proposed that are beyond the scope of quantitative statistical tests. All participants made some reference to a transferral of sensations into their phantom limbs during testing. This is a particularly interesting finding when we consider the proportion of paralysed phantom limbs which could not be moved voluntarily. It may be, in fact, that this treatment would be most beneficial for those with paralysed phantom limbs as some phantom pain can be directly attributed to the inability to move paralysed phantoms into comfortable positions.

The reporting of sensations of movement in phantom limbs appeared to be more vivid for upper limb amputees. This finding could reflect the greater degree of movement afforded by the virtual hand and fingers as opposed to the virtual foot. The very nature of feet is less dexterous than hands so that authors feel this is a situation that is difficult to avoid in virtual reality systems. It would however, be possible to develop specific tasks using virtual lower limbs which encourage the user to manipulate the foot in a more detailed way. For example, tasks could be made more difficult to force participants to use their feet in more dextrous ways. It would also be interesting to use a virtual representation of a foot, as opposed to a shoe, which may make the

lower virtual limbs more analogous to the upper virtual limbs and reduce any discrepancy between the experiences of lower-limb and upper-limb amputees when using the system.

DT reported the most drastic change in phenomenological experience of her phantom limb. After the first session, changes in the once paralysed phantom limb began to help relieve aspects of her phantom pain experience, as recorded in qualitative reports. A speculative hypothesis could explain this in terms of a greater plasticity in the brain for more recent amputees as it has had less time to re-define the internal model of the body and to cortically reorganise, which is strongly correlated with phantom limb pain (Flor et al, 1995). As such, it is possible that this system may be of more benefit for more recent amputees. However, PK also reported surprising changes in his experience of his phantom limb after over 12 years of paralysis so this could suggest that any potential improvements may be caused by some other factor than time since amputation. It would be interesting to couple this research with some form of function brain imaging technique to help establish if and how much normalisation is occurring through use of the system.

Another common finding between many participants was the experience of an increase in the level of phantom pain which followed sessions. This is difficult to consolidate with existing research on phantom limbs. As PK pointed out, it may be that the easing in pain during sessions, that almost all participants commented on, means any subsequent pain feels more severe. All pain experiences are relative and subjective and a constant level of pain may be easier to overcome than fluctuating levels of pain, as is the case when pain levels were unexpectedly lowered during use of the system. It could also be that the increased concentration required to carry out the novel tasks actually have some temporarily detrimental affect on absolute phantom pain. This is an issue that would be closely monitored in future research.

As mentioned above, all participants did make reference to a decrease in experienced phantom limb pain whilst immersed in the virtual environment. This is a positive result which should be investigated further. SM specifically used the word “distraction” when reporting this reduction, which leads us to the conclusion that the novelty of the tasks may provide an easy, temporary escape from the phantom pain. It is important to carry out further testing, not only with a larger sample size, but with a control condition in order to assess any placebo affects of pain reduction caused by the novelty of the task. A suitable control condition for this research would be the use of the IVR system without any transposition of movement in the virtual world i.e. physical right leg movements would correspond to virtual right leg movements (see Murray et al., 2006a).

There are also practical issues to consider with this research. Two participants withdrew from the study due to difficulties in travelling to research site. If this equipment were to be disseminated, it would require dedicated disablement service centres running regular, intensive trials with participants. This may present some difficulties for certain patients and is a factor to consider when planning dissemination if justified through further research. One participant dropped out due to pre-existing weakness in his remaining anatomical which meant he found using the IVR system difficult. Whilst the virtual tasks themselves were not judged to be particularly strenuous by this participant, the novelty of the tasks meant he was using his limbs in a way they were not used to. Obviously, it is crucial that use of this system does not exacerbate pain of any kind in any way. To ensure this is the case, it would be simple to introduce parameters which control the difficulty and nature of the tasks to accommodate users of varying ability. A larger database of tasks would also provide the flexibility required when treating amputees of all ages and levels of health.

Finally, a crucial factor to be addressed in future research would be the intensity of the intervention. Previous work with the mirror box has used regular intervention sessions of up to twice daily (MacLachlan et al, 2004; Ramachandran, and Rogers-Ramachandran, 1996). Using this protocol, participants came for sessions on a weekly basis which may be insufficient to facilitate change. This is understandable given that the majority of participants had suffered with phantom pain for over eleven years; it may be unrealistic to expect a weekly intervention for less than 3 months to have any dramatic effect on phantom pain. This is especially the case with this kind of intervention which is not only novel for participants to get used to but also novel in terms of how IVR has been used in rehabilitation in general. Two participants (DT and PK) expressed an interest in coming for testing more often as they felt that it would be of more benefit to them. Such decisions to decrease (or increase) intervals between interventions may impact on the practical issues of the general reliability and availability of participants and would require consideration of these factors.

Overall, the majority of participants report some kind of positive impact on their phantom limb pain throughout testing. The authors feel that the initial qualitative analysis coupled with the positive trends in the quantitative data show sufficient proof of principle to justify further research with the system. Future work would first require some adaptations to the system to accommodate the various changes specified above. Randomised controlled trials with a larger sample size would be crucial to assess the efficacy of this system in treating phantom limb pain, not only over and above any placebo effects but also in order to extrapolate to the wider amputee population.

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