The Avatar Written upon My Body: Embodied Interfaces and User Experience

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Abstract. There is a growing consensus that the perception of our body is emergent and has a plasticity that can be affected through techniques such as the Rubber Hand Illusion (RHI). Alongside this we are seeing increased capabilities in technologies that track and represent our movements on screen. This paper will examine these issues through the RHI and conditions such as Complex Regional Pain Syndrome (CRPS) and consider the possibilities offered by these technologies for therapeutic use. It addition it will examine the issues raised for all users, asserting that we have reached a point where we can no longer afford assume that these are merely tools of representation.

Keywords: Avatar, Body Image, Complex Regional Pain Syndrome, Motion Sickness, Emergent.

1 Introduction

This paper will propose that advances in computational graphics and physical computing have reached a point where they are no longer merely tools of representation. Instead it will argue that because perception is increasingly understood as an emergent phenomenon, the representation and 'mapping' that computing now provides can affect bodily perception. This will draw upon work conducted to develop a tool to allow patients with Complex Regional Pain Syndrome (CRPS) to describe their perceptions of their body.

It will initially outline the nature of CRPS and the way the altered bodily perceptions problematizes the communication of the condition for patients. Having drawn attention to the fact that the body is not the given we often assume to be, the problem of motion sickness and virtual systems will be considered. This will focus on research asserting that motion sickness does not arise from sensory conflict but needs to be considered as ecological and emergent phenomena.

We will then consider the Rubber Hand Illusion (RHI) and the plasticity of bodily perception it highlights, looking at how the representation of the body might affect its perception. This will draw upon recent research concerning the RHI and patients with CRPS as well as work examining the affect that varying the representation of movement can have upon patients with Fibromyalgia. The paper will then return to examine these issues in relation to the discoveries made through the creation of a body

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image tool for use with patients with CRPS. The paper will then conclude by considering the opportunities and dangers that the combination of physical computing and representation present in therapeutic settings and normal use.

2 Complex Regional Pain Syndrome

Phantom Limb Syndrome (PLS) and Complex Regional Pain Syndrome (CRPS) were both identified by Dr Silas Weir Mitchell during the American civil war. Although now relatively well known, PLS had been thought to be an unusual phenomenon experienced by a limited number of amputees; often the condition was not reported as amputees feared they would not be believed or thought mentally affected. Now it's widely recognized as a common experience among amputees [1].

Similar circumstances appear to have affected our understanding of CRPS. CRPS is a chronic pain condition associated with the body's extremities affecting single or multiple limbs. The pain experienced often involves extreme and contradictory sensations of heat. There can also be the perception of the dramatic enlargement of parts of a limb, or that parts are missing or do not belong to their body [2, 3]. The affected region can possess heightened sensitivity and painful reactions to everyday sensations such as the touch of clothing, yet alongside this sensory discrimination in the affected region is reduced. The result is that patient's perception of their affected limb is different from its objective appearance and people with CRPS have reported they have found it hard to talk about their experiences of altered body perception. Indeed the frustration of trying to understand and convey their symptoms caused one of the patients we worked with to say that 'I really thought I was losing it.'

At present there are no objective tests for CRPS so diagnosis relies on signs and symptoms meeting a diagnostic checklist [4]. CRPS is defined as either CRPS-I or II dependent on the presence (II) or absence (I) of identifiable nerve damage. The condition is thought to be initially triggered by a peripheral insult but it rapidly evolves into a centrally driven condition for which there is currently no cure. Self-portrait sketches or drawings made by therapists are currently used to monitor changes in the condition, but this is limited by the individual's capacity to draw. As a result of this in 2010 a team at the UWE Bristol and the Royal National Hospital for Rheumatic Diseases in Bath instigated a project examining the use of tool utilizing a 3D avatar to monitor these changes. We will examine the results arising from testing the tool in a clinical setting; however prior to doing this we will challenge the assumptions that are often made concerning the perception of our own body.

3 Motion Sickness

Developers using the Oculus Rift have encountered significant problems with motion sickness. The source appears to be a problem present since the invention of immersive virtual reality (IVR) [5] deriving from the latency between the use of sensors to gain motion data and its use to update the users' view, resulting in motion that is felt but not immediately seen. Alongside this the use of virtual motion that does not possess a physical equivalent, results in 'movement' that is seen but not felt. It's thought that conflict between these perceptions of motion result in the body assuming it has absorbed a toxin, the sensation of nausea and the resulting 'desire' to evacuate it.

The supposition that motion sickness results from a conflict between visual and vestibular data has been unchallenged for over 100 years [6] even though blind people experience motion sickness [7]. Within the digital motion sickness is not limited to IVR and significant numbers experience it playing video games [8] and the cause has again been assumed to be a conflict between vision and the vestibular system. Whilst some are more prone than others, the recording of game play has allowed active and passive subjects to be exposed to the same visual and vestibular stimuli [9]. What was discovered was that the incidence of motion sickness was significantly increased in 'passive' subjects. If subjects significantly increase their chance of experiencing nausea simply due to the passive nature of the experience, discordance no longer appears to be a sufficient condition for motion sickness.

Work by Stroffregen [10] has shown suffers of motion sickness exhibit a postural instability prior to the onset of symptoms which is absent from those free of motion sickness. He has proposed that rather than arising from sensory incompatibility, motion sickness arises from an inability to maintain posture. The 'edge' players appear to have over those who passively experiencing virtual environments arises from their ability to anticipate and accommodate changes within the virtual environment, thereby lessening its impact upon their posture. The relationship between subject, environment and action is described by Stroffregen as the ecological approach to perception. Action is the fundamental 'unit of analysis' such that no one factor can be examined separately; the relationship between the body and its environment being central to maintaining stability. Focused as we are on tasks within an environment, environmental changes can impair our stability and affect our ability to act. We can use this instability to determine changes to the environment and adapt to them (such as when we gain 'sea legs'). As a result Stoffregen refers to sensory conflict as '*hypothetical; …an interpretation of facts, rather than a fact itself*'. Rather than possessing senses that have individual frames of reference that compete suggesting incompatible states, '*Patterns of intermodal stimulation make available information about properties of the environment that influence the control of behavior*' [10]. The information that arises between senses differs from that which is derived from individual senses, as such he asserts this as an emergent property.

The question this begs is that if an ecological approach to perception and action is the fundamental 'unit of analysis' and knowledge of the environment is an emergent process, as a part of this might not the body need to be considered in the same way?

4 The Rubber Hand Illusion and Representation

Through what has become known as the rubber hand illusion (RHI) cognitive neuroscience has demonstrated that there is plasticity in the perception of the body. Discovered by Botvinick and Cohen [11] the RHI results in participants perceiving a rubber hand belongs to their body. This was achieved by placing a life size rubber in front of a participant, whilst placing their own hand close but hidden from view behind a standing screen. Participants were asked to look at the rubber hand whilst their and the rubber hand were brushed simultaneously. All ten of the participants taking part in their study reported that at some stage they felt the sensation where they saw the rubber hand and many stated they felt that the rubber hand was their own. Participants were also exposed to the illusion for periods of up to half an hour. After they were asked to move their free hand along a straight edge under the table until it aligned with the position they perceived their other hand. It was found that this caused a shift in participants' perception between the perceived and actual position of their hand (referred to in later studies as a proprioceptive drift) dependent on duration of the illusion. Botvinick and Cohen proposed this was the result of the 'spurious reconciliation of visual and tactile inputs' distorting participants' sense of position. Like motion sickness notions of sensory conflict underpin this, but here a reconciliation of those sensations has been assumed, but what might allow this? Is, as is often assume, my body a given onto which sensation is mapped effectively shaping perception or is the body built from its sensations?

Tsakiris and Haggard [12] sought to examine this. To test if there was a top down influence, they investigated whether congruent and incongruent positioning of real and rubber hands would influence susceptibility to the illusion. In additions tests to see if a neutral object might be incorporated into the body were used. Incongruent positioning involved turning the rubber hand -900 so its fingertips pointed towards the hidden hand in what would be an anatomically improbable position. Although the RHI occurred using congruent positioning, incongruent positioning and the neutral object both led to its absence. Their use of a neutral object also resulted in a proprioceptive drift away from the object which they described as a 'perceptual repulsion'. This was contrary to the earlier results of Armel & Ramachandran [13] who appeared to show a neutral object (which in their tests was a table top) could become incorporated into the body schema. Tsakiris and Haggard proposed this repulsion was the outcome if self-attribution did not to occur.

They examined whether the RHI involved a bottom up association of sensation by stimulating individual fingers and asking participants to indicate the perceived position of an adjacent digit. If the illusion involved a bottom up process the test might demonstrate significant differences in the perceived relative positions of digits following stimulation. The outcome was that although there was some drift, it was not significant and broadly relative to the fingers receiving the stimulation. Given that the RHI did not occur with incongruent positioning and adjacent fingers 'followed' stimulated ones, Tsakiris and Haggard asserted that the illusion resulted from the integration of visual input with a pre-existing representation of the body; a bottom up combination of visual and tactile data was a necessary, but not sufficient condition in the creation of the illusion. However this already appears to make the assumption that perception results from one or the other; what if this were considered similarly to Stroffregen's ecological approach to motion sickness? What if the perception of our body is an emergent phenomenon that possesses a plasticity, but one where intermodal sensation reaches its 'own' perceptual limits?

Ehrsson, Holmes and Passingham [14] felt it was … *important to find out whether an illusory feeling of ownership can be induced in the absence of visual input…* Blindfolding participants, they moved the subjects own hand to touch the rubber hand whilst simultaneously touching the participants remaining hand in the 'same' place and discovered the RHI could be generated using synchronous touch *without* the involvement of vision. Contrary to Tsakiris and Haggard's assertion that visual and tactile data is a *necessary* condition for the RHI, the discovery that the RHI can be created without the active involvement of vision means this may not be the case.

Further research by Petkova, Zetterberg and Ehrsson [15] has shown that although the direct involvement of vision is not required in itself, vision appears to influence our capacity to experience the RHI. Referring to Ehrsson's earlier work as the "somatic" RHI they describe how it was used "to compare the multisensory representation of the body in blind and sighted individuals." This involved a comparison between participants who had been blind since birth and a group of aged matched sighted participants. Their outcomes were remarkably clear in that only 10% of blind compared to 67% of sighted participants experienced the illusion in any way. Additionally blind participants stated the illusion was "totally absurd" or that "they could not even imagine the illusion".

As possible explanation for the lack of the RHI in the blind group they noted behavioral studies showing those who have been blind since birth do not appear to map somatosensory sensation in external co-ordinates the way the sighted do [16, 17, 18, 19]. The lack of visual experience appears to effect the way other sensations work together, influencing the way the body is perceived. The phenomenologist Edmund Husserl stated that "The Body is in the first place the medium of all perception...the zero point of orientation... "[20]. Although the body is an object with parts that can be perceived "just like other things" [21] Husserl notes this only applies to visual appearances and that visual perception of our own body is not the same as tactile sensation, something touching which is touched [22]. In fact Husserl asserted that a "subject whose only sense was the sense of vision could not at all have an appearing body" [23]. What is interesting about Petkova's work is that that the sensation of the touching which is touched appears to only occur in those who have had sight, here there is a mapping of two sensations so they become one. The RHI appears to be the result of the hand touching and the one which is touched being 'pulled' into the same space.

But does any of this apply to virtual or augmented reality? Ehrsson et al [24] explored whether the illusion could be generated using a virtual limb. Computer graphics were used to provide users with a stereoscopic 3D view of a virtual arm extended in front of them. The outcome was that participants' sense of possession of the virtual arm was broadly similar to those demonstrated in the RHI. Yuan and Steed [25] took this further by testing whether this might be experienced within IVR and "an illusion very similar to the rubber hand illusion is "automatically" induced by active use of the virtual body in an IVR." Their use of a head mounted display provided a first person perspective that occluded participants' views of the physical environment and their body. Asserting a weakness of prior RHI studies to have been the passivity of participants, users were asked to undertake a series of tasks using their right hand to hold a wand to control virtual tasks such as placing 'balls' through 'holes' in a 'table'. Their left was immobile to enable the placement of galvanic skin response (GSR) sensors and avoid any movement that might introduce unwanted variability to the data. Since participants were seated at a table, this also enabled the use of the wand to judge the position of the user's arm using inverse kinematics and to appropriately 'map' the position of the avatar's arm to the user's. Using questions broadly similar to Botvinick and Cohen's their results showed participants experiencing a similar sense of ownership as seen in the RHI, as well as a rejection of the illusion when using a neutral 'object'. The GSR demonstrated that threat to the virtual body produced a positive response. As a result Yuan and Steed claimed they had 'shown that an "IVR arm ownership illusion" exists'. Given the work of Ehrsson and Steed we can see that the effect of the RHI can be extended from the physical into the virtual worlds.

Recent work by Reinersmann has examined the susepticablity of those with CRPS to the RHI [26]. The expectation was that patients with CRPS would not experience the illusion due to the disruption to cortical plasticity assumed to exist as a result of the condition [27]. Contrary to expectations those with CRPS experienced the RHI illusion to the same extent as healthy participants. However it was found that patients who felt strongly that their affected limb did not belong to them experienced a weaker form of the illusion. However understanding a 'normalized' perception of the body as intact and CRPS as something that breaks this representation may be problematic. If bodily perception is emergent, rather than being broken, what we may be seeing is a comples system that is being expressed differently. What is particulary interesting is the reduced level of the RHI in those who did not feel their own limb belonged to them. Given that the RHI occurs within CRPS, we should perhaps first consider whether factors that affect the creation of the RHI in other groups might be at work within CRPS. Given that CRPS patients experience their limb to be different to its visual appearance, the 'perceptual repulsion' a neutral object has been shown to generate in the work of Tsakiris and Haggard might be the underlying cause of this.

As Yuan and Steed noted many of the studies involving the RHI have not included activity. Here it is interesting to note a study involving Fibromyalgia (FMS). FMS is a condition similar to CRPS with symptoms including widespread pain, hypersensitivity to sensory stimuli, phantom swelling of limbs, reduced sensitivity to the position of limbs and motor abnormalities such as tremors or slowness in movement. Investigating whether these symptoms might be the result of a dysfunctional relationship between motor and sensory systems McCabe et al [28] conducted tests using a mirror/whiteboard to create varying degrees of sensory conflict through the representation of congruent/incongruent limb movements. The outcome was that 89.7% (26 out of 29) of patients with FMS reported changes in perception compared with 48% of a healthy control group. The sensations included "… disorientation, pain, perceived changes in temperature, limb weight or body image. Subjects described how these symptoms were similar to those they experienced in a "flare" of their FMS. This led us to conclude that some sensory disturbances in FMS may be perpetuated by a mismatch between motor output and sensory feedback." Whilst appearing to play a role within FMS, we should note that healthy participants also reported changes in perception. Rather than being a phenomena linked to the pathology of FMS, the results appear to indicate the underlying 'structure' of sensation is such that incongruent representation of movement can also affect body perception in healthy subjects. The impact of FMS appears to make those who suffer from the condition all the more vulnerable to new anomalies. Clearly results such as these ought to be of concern to anybody making use of systems that track and represent the movements of users.

5 Unseen Truths

The contradictory sensations experiences resulting from CRPS make it difficult for patients to talk about their condition. As one noted of their experiences prior to diagnosis "*…it's a very strange thing ... I really thought I was losing it.*" Following a diagnosis of CRPS, self-portrait sketches or drawings made by clinicians are used in its assessment. This can be revealing because patients often haven't fully engaged with these sensations, appearing to keep these contradictions at a distance rather than 'inhabit' the sensation. As one patient noted "*...it's quite new to me because I hadn't really thought about this until I came in* here." In addition the differences between sensation and appearance was often commented upon *The right side of my whole body actually feels quite normal, there no problem with that I don't have any difference in perception to what I see with that...*

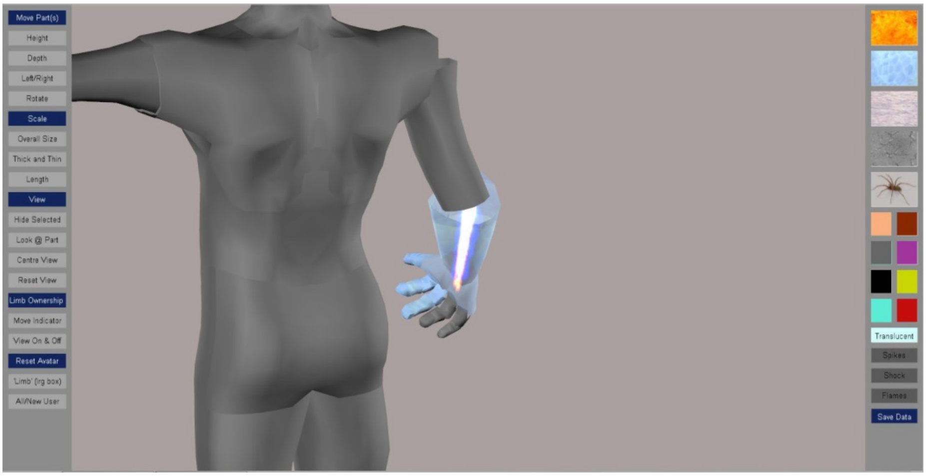

Fig. 1. Image Created of CRPS affected limb using the second version of the tool which added the ability to use particle effects to depict sensations

A specification for the tool was established using data from a previous study of body perception [29] and consultation with a person with CRPS. It was decided the tool should allow the manipulation of the scale, position and surface texture of body segments whilst allowing these to be removed if desired. Scaling would include the length and making parts thicker and thinner. The movement of parts was to allow their separation as well as their placement in anatomically impossible positions. Colors and textures were to aim to provide an opportunity to represent feelings of burning, cold, rough, smooth and lack of substance. Finally the tool should allow the camera to orbit the 'avatar'. A prototype was created that fulfilled these criteria and the research was approved by the Local NHS Research Ethics Committee and the tool was tested with consenting patients.

Ten participants used the first version of the application in a single consultation with the research nurse. Audio recordings were made of the participants using the application allowing immediate reactions to the tool to be captured. Immediately after using the tool participants were asked to complete a structured questionnaire with the research nurse with questions to ascertain their views and experience of using the tool. When asked ‘Did you find using the body perception application an acceptable way to communicate how you view or feel about your limb or body parts?’ all participants reported that it was a good method; for themselves and to help clinicians understand their perceptions of their body. They were also unanimous in the view that the tool was better than the standard interview undertaken earlier in their admission and was much more adaptable than a clinician’s sketch and found it easy to use in consultation with the research nurse. Because discussing their condition can raise their levels of pain participants were also asked whether using the tool caused increased pain and distress. In most cases this was not an issue but in some instances increased pain was experienced, but what was surprising was that benefits were also expressed “It wasn’t that I disliked using it, it’s just... for me as I say to visualize that how I feel I felt a bit emotional, but the more I’m looking at it, it’s only because I’m sitting here thinking that is exactly how in my mind’s eye what I look like so it was a bit of a shock I suppose.” One patient who had previously commented “I don’t like looking at it” when talking of their limb described the experience of the Body Image Tool and the image they created differently…

> **Patient:** Seeing something and knowing that it’s your hand is errm how can I put that into words, its erm, I don’t know it I suppose accepting now that it’s there, it’s happened, I’ve got it..
> **Interviewer:** Does this help you accept it?
> **Patient:** *Yeah*, because you can see it...

If we revisit Reinersmann’s findings that patients with a stronger rejection of an affected limb experienced a diminished form of the RHI, the comments made by patients during testing of the body image tool may provide an insight. What is noticable in the comments made by those who used the body image tool are the moments of recognition and acceptance that occured through its use. Here we should consider the observations made by Tsakiris and Haggard concerning the ‘perceptual repulsion’ that occurred if self-attribution of the rubber hand did not to occur. Patients often commented upon the difference they preceived between the sensation and appearance of their limb. Often these are not ‘minor’ contradictions, the disparity between experience and appearance is often marked “I know there are fingers there and I even move them, I can’t see fingers when I try closing my eyes to see it, I don’t see anything, I just see a big blob…” One patient commented that when they saw their physical limb “There is a sense now of repulsion, I think is the word, I don’t like looking at it.” Given this it seems that the lack of the RHI in those who felt that their limb didn’t belong to them could plausablily result from the sense that the limb didn’t belong to them.Nevertheless it is also important to note that overall the discovery was that those with CRPS experienced the RHI, as a result it may be that those who did not experience it had reached the kind of intersensory limit that prevented its formation. In relation to these instances it would be interesting to know if a more accurate depiction of the affected limb, perhaps using the combination of the body image tool and an augmented reality system such as that used by Ehrsson et al [24] would alter the veracity of the illusion.

The treatment of CRPS and PLS has also involved the use of Graded Motor Imagery (GMI). GMS is a development of a technique used by Ramachandran to treat PLS [30]. It uses a series of graded steps to treat the pain associated with a range of conditions related to the nervous system. Patients suffering from these conditions often exhibit a diminished ability to be able to discriminate between images of the part affected from the left and right hand side of the body. The first step of the treatment involves showing patients a series of images asking them to identify which side of the body they belong, with the exercises being aimed at increasing the ability to discriminate through changes achieved via perceptual plasticity. The next step is to ask patients to imagine moving their affected limb with the aim being that the activity exercises mirror neurons associated with the effected limb. Finally the use of mirror box is employed to see the affected limb moving (which in Ramachandran's work led to a reduction in the painful clenching felt within the phantom limb) and within conditions such as CRPS to gradually encourage actual movement of the affected limb alongside the one being mirrored. Moseley has achieved a noticeable reduction of the pain suffered by patients with CRPS and PLS [31] however this has so far not been something that has been reproduced in clinical settings [32]. Indeed was noted that

> "As GMI is now recommended practice, it is important to understand that treatment failure is not necessarily a patient's or a therapist's fault, but may reflect that we do not yet fully understand what the active ingredients of this complex intervention are, and how it interacts with other therapeutic strategies."

As we have seen if it is the case that patients with CRPS may not experience the RHI due to a 'repulsion' based on an incompatibility between the felt experience and appearance of a limb this might also affect the capacity of GMI as an intervention. In fact incongruent motions might have a negative effect. Once again a starting point might be the use of a virtual limb attuned to the perceived experience of the patient might achieve outcomes where they are able to identify with the image more immediately.

6 Conclusion

Stroffregen has noted that improvements in technology are leading to an increase in the reports of its side effects [32]. The effects go beyond those of motion sickness and include changes in users' movements after the use of these systems. He notes that

> "Enactive interface systems, such as Wii and Kinect, are associated with widespread anecdotal reports of motion sickness.
>
> Ignoring this problem is not likely to make it go away. Similarly, the use of disclaimers (e.g., "use of this product may lead to motion sickness") is a legal rather than a practical solution."

Indeed he goes on to note that

> "Rather than relying on brute technological development, a meaningful solution to the problem of interface side effects will need to emerge from a better understanding of the perceptual-motor dynamics of human movement."

Given that work by McCabe [28] has demonstrated that the use of the incongruent representation of limb movements can create symptoms similar to FMS in healthy participants, the perceptual dynamics to which Stroffregen goes beyond the relationship that exists between the body and the environment. What we now have to address are the perceptual dynamics that inform the perception of the body itself. At present most tracking technologies are simply applied to avatars with idealized proportions. In some instances the disparity between the ideal and the real may be such that it will affect the user's perception of their body (beyond those pressures we usually associate with ideal physical forms).

Paradoxically we have also seen that the use of these technologies may provide more effective means to therapeutically track and address conditions such as CRPS. As a result of her findings Reinersmann notes that treatments should now include "interventions that address the distorted body image which appears to affect sensory functions in a top-down manner". In some ways this might first include the recognition and representation of the sensations experienced by those with CRPS. This might also be addressed in such a way that these are mapped onto an avatar which they move through motion tracking. Interestingly one possible (although not favored) reasons for the greater level of success achieved by Moseley's use of GMI was that "Reducing Pain related fear in CRPS may actually reduce pain and perhaps the clinicians in the RCTs better captured this effect" [32]. The spatial awareness of those with CRPS is affected by the condition and often limbs are held out of harm's way; it may be the case that representing the proportions of the limb as it is perceived might allow a greater confidence in moving the limb. Given that no references are made to the range of movement made using the affected limb by the participants in either the RDC or clinical use of GMI the 'active ingredients of' a 'complex intervention' might involve tracking the movements of both limbs involved. It is also the case that the use of tracking technology and the use a virtual mirror might also allow the appropriate differentiation in motion between limbs to be shown to participants as they enter the third stage of their treatment.

Stroffregen has noted that one solution to motion sickness might be to "design interfaces that are deliberately different form the relevant real-world situations." Anyone who has suffered motion sickness due to the head bob used in games such as Call-of-Duty will probably prefer a first person view that does not do this. What is interesting is that a simpler approach does not diminish an interface but makes it more effective. For a very long time the activity of artists has focused on stripping out unwanted sensation in order to drive at the heart of a matter. Although we might use the phrase 'less is more' when talking about such activity achieving less requires a greater insight into the matter at hand. Gaining an understanding of how representations of the body and its movements will allow us to achieve this in such a way it benefits users and will allow the development of new therapeutic techniques and systems.

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