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Personalising prosthetics: digital interventions in disability and dance

Sarah Whatley[a], Steve Benford[b], Kate Marsh[a], Feng Zhou[b], Ian Ashcroft[b], Paul Tennent[b], Welly O'Brien[c] and Tanja Erhart[c]

[a]Centre for Dance Research, Coventry University, Coventry, UK; [b]Computing Science, University of Nottingham, Nottingham, UK; [c]Independent, Brighton, UK

ABSTRACT

This paper emerges from an interdisciplinary collaboration between prosthesis-using disabled dance artists, computer scientists, dance researchers and engineers to explore the transformative potential of digital technologies to co-create aesthetically personalised prosthetics from dance movements. Beginning with the dancers performing improvised movement sequences in motion capture suits, which drove a computational design algorithm, an 'aesthetic seed' for each dancer was generated: a kind of personal signature from their movement. These seeds were then algorithmically mapped onto the shapes of prosthetic limb covers that could be 3D printed in a variety of materials. The paper will share some of the reflections from the dancers on how the process generated questions about agency, appropriation, ownership and the political implications of disability as a site of resistance. It will suggest some ways in which digital methods can offer disabled artists different routes towards making and sharing work, whilst foregrounding the importance of inclusion to challenge normative thinking around what 'connection' and 'access' means in the context of digital innovation.

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Introduction

The pandemic had a major impact on artists and for disabled artists the impact was particularly difficult. A survey conducted by the UK Disability Arts Alliance suggests there are significant threats to the continued participation of Deaf and disabled people in the arts and culture sector as a result of the fallout from the COVID-19 crisis (Pring 2021). Despite digital streaming and conferencing technologies allowing live performance to continue in some form, disabled artists voiced their concerns about being 'left behind' in a time of post-pandemic reconstruction: Musician and activist John Kelly, said: 'The pandemic has just amplified our experience of discrimination (Pring 2020)'. However, the pandemic also provided an opportunity to turn our gaze inwards, which for disabled dancers meant a chance to reassess their bodily practices, including relationships to their prostheses.

CONTACT Sarah Whatley s.whatley@coventry.ac.uk Centre for Dance Research, Institute for Creative Cultures, Coventry University, Priory Street, Coventry, CV1 5FB, UK

This background formed the basis for an interdisciplinary collaboration, enabling us to explore the potential intersections and links between prosthesis-using disabled dance artists, computer scientists, dance researchers and engineers to explore the transformative potential of digital technologies to co-create aesthetically personalised prosthetics from dance movements. Early experiments were designed to challenge the ways in which technologies intervene in the recording and visualisation of human motion. Then during Covid-19 we continued to find some time to meet and over a series of primarily online co-design-focused workshops, experiments were designed to challenge the ways in which technologies intervene in the recording and visualisation of human motion. Covid-19 meant having to rethink our terms of engagement but continuing was important to ensure that disabled artists were not 'left behind' and that our commitment to inclusion informed our working methods. Kate Marsh, together with Welly O'Brien and Tanja Erhart, who are all experienced disabled dance artists, brought an individual experience of, and relationship with prosthetics, based on their own body and dance practice. As an iterative, co-design process, moving through cycles of planning, analysis, testing and reflecting, we shared our questions around how normative design methods can be challenged through the expertise of prosthesis-using dance artists. The experiments revealed insights to the dancers' own artistic decisions, and for O'Brien and Ehrhart, their relationship with their prosthesis, and the potential for digital processes and the emerging designs to be collaborating partners in sustaining and developing their practice. Whilst this project specifically focused on dancers who have experience of using prostheses and how their professional practice is shaped by their prosthesis use, we acknowledge that the field of prosthetics is not confined to artificial limbs. In the context of disability, wheelchairs and other assistive devices could be considered prostheses. However, our project was designed to work collaboratively and intensively with professional dancers who have a deep experience of using prostheses and can bring that expert knowledge into the creative process. In other words, whilst non-dancers who are prosthesis users would doubtless also have insights to improving the design of prostheses, our project was specifically focused on the interface between prosthetic design and dance making, and which depended on expert dance knowledge.

Beginning with the process of motion capture, we first explored how diverse bodies require new ways to mark up, track and measure motion. Improvised movement sequences captured from individual dancers then drove a computational design algorithm which, inspired by the layering of natural rock formations, generated a distinct visual design or 'aesthetic seed' for each dancer: a kind of personal signature from their movement. These seeds were shared with the dancers as a source for generating new movement responses. They were then algorithmically mapped onto the shapes of prosthetic limb covers that could be 3D printed in a variety of materials. The resulting designs were presented back to the dancers as a stimulus for further discussion.

The paper will describe the methods developed through the project, and some of the outcomes and findings based on the experiences and reflections of the disabled dancers involved: Erhart and O'Brien. The method has been developed at Nottingham's Mixed Reality Lab, led by PhD candidate Feng Zhou under the supervision of Steve Benford, Paul Terrent and Ian Ashcroft. Workshops took place at the Coventry University's Centre for Dance Research, with researchers Sarah Whatley and Kate Marsh. Our research to date seeks to draw attention to the need to challenge normative methods and power

structures whereby dancers are central to the research design, analysis and outcomes and not simply 'objects of study' in research focused on innovations in design and technology.

Materials and methods

Our research draws on two key bodies of theory, the first concerning the aesthetics of prosthetics, and the second exploring the potential of generative design algorithms to help co-design personalised products.

Aesthetic prostheses. Many have recognised that the appearance of prostheses is important to their acceptability (Bhuvaneswar, Epstein, and Stern 2007; Cairns et al. 2014; Law et al. 2016; Pohjolainen, Alaranta, and Kärkäinen 1990; Profita et al. 2016). But what should that appearance be? The traditional aesthetic for prostheses emphasised notions of realism and 'embodied wholeness' (Donovan-Hall, Yardley, and Watts 2002). Murray (Murray 2009) for example, found that a realistic-looking passive limb pleased female participants more than a less realistic but functional prosthetic limb, while Sousa et al. propose that prostheses that give the appearance of a healthy physique improve aesthetic appeal as the individual believes they conform to the socially acceptable body image (Sousa, Corredeira, and Pereira 2009). Others, however, have proposed that prostheses need not be realistic, and that alternative designs can assist the wearer in promoting their own distinctive identity (Hart 2021; Labarre 2010; Summit 2016; Vlachaki et al. 2020). Elite athletes and the Paralympic movement have done much to promote a positive image of disability and of a stylish and 'sporty', but clearly non-realistic, aesthetic for prostheses (Tamari 2017). Hall & Orzada argue that the wearers of distinctive non-realistic prostheses are reclaiming and reframing the disability identity by fostering pride and positivity of the non-normative body (Hall and Orzada 2013). There is an evolving relationship between prostheses and fashion, with arguments that medical engineering should draw on fashion design (Pullin 2009) and that fashion generates new visual languages that break the barriers of invisibility traditionally associated with disabled bodies (Vainshtein 2011). Hall and Orzada argue that expressive prosthetic limbs can reduce stigmatisation and increase self-confidence (Hall and Orzada 2013) while Vlachaki et al assert that customised prostheses can increase self-confidence (Vlachaki et al. 2020). In practice, pioneering design companies have been responding to such ideas through the creation of bespoke designer prostheses and prostheses covers (Hart 2021; Labarre 2010; Summit 2016). Blom explored the importance of co-design in establishing artisanship in prosthetic aesthetics (Blom 2018). Finally, in introducing the concept of disability aesthetics, Siebers' assets that 'disability intercedes to make the difference between good art and bad art' (Siebers 2010).

Generative design. Employing an artisan designer to personalise a prosthesis is beyond the means of many people. We therefore explore the alternative approach of generative design algorithms which have previously been applied to the design of architecture (Chase 2005; Gu and Behbahani 2018; Rodrigues et al. 2015; Shea, Aish, and Gourtovaia 2005; Singh and Gu 2012), graphic layout (Cleveland 2010), consumer electronics (Lin and Lee 2013), jewelry (Kielarova, Pradujphongphet, and Bohez 2013), interface design (Troiano and Birtolo 2014) and the shapes for everyday products (Alcaide-Marzal, Diego-Mas, and Acosta-Zazueta 2020). Such algorithms are able to quickly explore thousands of design variants, often by imitating nature's evolutionary process (such as

Flocking, Fractal, Metacelluar Automata), potentially delivering improved performance, reduced development time and also customised product development (McKnight 2017). Sanders consider generative tools to be a form of participatory design language that can support non-designers early in a design project (Sanders 1999). Stones and Cassidy propose that such approaches can enable human designers to explore beyond what they might normally imagine (Stones and Cassidy 2010) while Mitchell proposes 'digitally mediated design' where the computer is neither a replacement for the designer nor traditional passive tool (Mitchell 2005). We note that there has been considerable interest in applying additive manufacturing (often referred to as 3D printing) to replace the traditional plaster moulding of prostheses which is widely seen as being laborious and time-consuming (Jin, He, and Fu 2015). For our process, we chose the physical forms of the prostheses for the practical work but we did not use the dancers' existing prostheses. The ensuing conversations with the dancers revealed a desire for a much broader range of possibilities for ways to personalise their prostheses based on their own unique body features. The strategy was therefore to achieve an overall prosthesis designed by their personal data by scanning and mirroring their corporeal limb.

Generative algorithms might potentially produce designs in the future that could directly drive the additive manufacturing process by generating new 3D shapes. In our implementation, it has involved layering one 3D shape (aesthetic seed) onto another (basic prosthetic shape) to create a new 3D form.

By not only slicing the 3D models into contours for 3D printing (like the most conventional slicing software), but also optimising these layers for improving manufacturing efficiency, e.g. modifying the contours to avoid overhanging, which requires printing supporting structure and consume significant manufacturing time and materials.

Our design process. We integrated these techniques into the seven-stage process for dancers to personalise prostheses covers by dancing shown in Figure 1.

The first stage was to choose a generative design algorithm with an appropriate design style from among the many that might be possible. Inspired by naturally occurring forms such as wind-sculpted rock canyons, we implemented an algorithm called Mogrow that could sculpt wrinkly and organic looking 3D forms. Technically, Mogrow is based on an interactive spring-forces simulation in which a closed chain of virtual particles can be perturbed in various ways to generate wrinkly shapes, which over time can be freeze-framed and stack to grow a 3D shape. The key perturbations were to inject or remove particles with different levels of simulated friction which would result in more or less wrinkles.

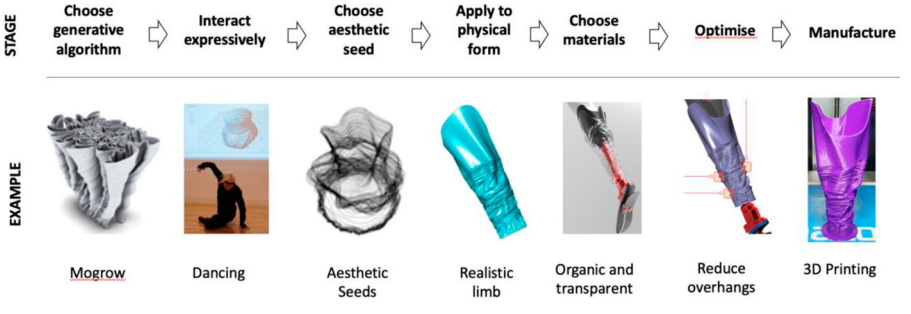

Figure 1. Our seven-stage process for personalising prosthetic covers.

The second stage was to decide how to interact with the algorithm. Rather than require the dancers to use buttons and sliders on a conventional interface, we implemented a technique where they could control the algorithm through their trained (aesthetic) practice of dance. We invited them to don a ROKOKO motion capture suit which can capture the movements of up to 17 points on the body. Tilting their bodies one way of the other (technically realigning the two axes running between their shoulders and hips) would inject or remove particles, while their overall rate of movement would control friction. Motion capture enabled a real-time interactive dialogue between dancer and algorithm so they could drive it using their dancing skills. A video-based motion capture system might also work, but the suit was the easiest technical route. However, offline (not real time) texture mapping would not have worked and it is not only texture mapping; we are adapting the shape of the limb here.

We then captured the distinctive 3D forms generated by different dances as 'aesthetic seeds', concrete instantiations of an otherwise ephemeral personal moment of interaction with the algorithm. The third stage was then to choose a particular aesthetic seed from among potentially many based upon its aesthetic qualities, including what was meaningful to the dancer.

Stage four involved applying the chosen aesthetic seed as a decoration to the form of a prosthesis cover. Such covers might assume a range of shapes according to the tastes of the wearer. We opted for a shape that tried to realistically approximate the shape of a human leg. Ideally, we would have obtained this by scanning the dancers' legs, but as this was not possible due to COVID restrictions, we had to instead work with an existing model, editing this to the appropriate size, before algorithmically applying the chosen aesthetic seed to transform its shape (in this case wrinkling it). We primarily focused on aesthetics, but much more than simply visual decoration, reflecting aesthetics within HCI as arising from shared agency between user and system; entangling appearance and functionality; arising from making sense of experiences; being embodied; and potentially (in this case) being staged.

We then offered the dancers a choice of materials in which the designs could be manufactured, including various organic-looking textures and also a transparent material that partially revealed the inner structure of the prosthesis. Before the resulting design could be additively manufactured, it first had to be optimised to reduce both printing time and materials consumed. This involved reducing some overhanging elements that would have required printing large supporting structures in the additive manufacturing process, ideally without compromising the visual aesthetic and identity of the aesthetic seed. At this point, the design was ready for the final stage of 3D printing, noting that further research could explore ways to increase the strength of 3D printed prostheses. At present, it is better to add a cover to an existing string structure, noting the increasing popularity of prosthetic covers as an expression of individual identity.

Reflections insights and dance principles

The exploratory nature of the project has generated interest in pursuing how to not only extend this particular research but to take the research into new directions, which is currently in development. Core to extending this work is knowing more about how the dancers experienced the research. The dancers' insights to how the exploration may

impact on their practice and on their relationship with prosthetics were captured during a number of discussion sessions during and following the practical workshops at which the dancers were able to reflect on their experiences of the design process and the outcomes. The quotes that are included in the following section are all taken from these discussions, which were recorded for analysis purposes, and attributed accordingly. These sessions were important for acknowledging that different disciplines assume particular knowledge and expertise, which need to be discussed to gain the most from each other's perspectives and a sense of 'ownership'. Underpinning the workshops and discussions was the principle of co-design. It was important that the disabled body was not used as a site for experimentation. The open nature of the discussions promoted a sense of equity. As Marsh observed:

> What is fascinating from my perspective, is how Tanja and Welly have experienced [the] workshop differently: as someone who wears a prosthetic leg and someone who has one leg and does not wear a prosthetic leg. What is the different relationship to that? What is it for me as someone with a missing limb to observe this, who does not wear prosthetics? But watching [the] workshop makes me think: 'oh I could design something'. This is actually powerful. It is really interesting that this idea of an alternative prosthetic that is not functional but is maybe a costume that is not even for dance: that it becomes about body augmentation.

The workshops drew on a number of dance principles as a way of providing a baseline of possible movement explorations. These principles, drawn from a project that Whatley had worked on Cisneros et al. (2019) and which were generated from rethinking a number of Laban principles (Raheb, Whatley, and Camurri 2018) were discussed in relation to this project. Marsh noted that it is worth considering that for the disabled dancer, normative dancing principles often don't relate to or fit the body. What access means is very different for a 'non-conforming' body, which feels like an opportunity rather than having to adapt to normative dancing principles. Marsh also recalled Erhart's 'three body' reference (Whatley 2018)' and how each may have its own identity and relationship to dance principles. Erhart responded, saying how:

> I want to work with my shoulders to work with velocity. When I talk about my three different bodies, I would actually really try the axis and those two hip and shoulder parts. Because they move really differently when I'm using the wheelchair or when I use crutches or when I use none of the tools. Because in the wheelchair I'm sitting down and I have my shoulders mobile. Whereas when I use my crutches it's different how I use my shoulders and my hips, and I wonder what that brings different observations or patterns, or designs.

The opportunity to be directly involved in designing their prostheses was of interest to the dancers, who were also intrigued by the idea of the prosthetic being something to wear. As O'Brien commented 'So it's like wearing this jacket or this jumper or glasses, or anything you have actually designed yourself. And you don't ever have that chance, especially in the disabled world. Like designing your own crutches or designing your own wheelchair'.

Considering the different experiences of using prostheses, questions of how prosthetics might thus prioritise function or design were raised. Erhart was also excited by the possibilities of 3D printed prosthetics and how it can be customised, commenting:

> We all have different bodies. I had a prosthetic once, but it's also quite based on a normative body and my body was not normative. So I decided not to use a prosthetic because it doesn't

> work with my body. And this could be a real chance to exactly make it work for my body. And it's not just a leg, but it's my leg or it's my crutches. And my crutches would have a spring because they are important to take off the pressure in my shoulders so I can walk and not get pain.

Zhou pointed out that prosthetics don't have to simulate human limbs: it can be any form, depending on the application. He posited that the artificial leg for a ballet dancer doesn't have to include a foot shape, it could be a tip shape (An 2018) O'Brien is aware that younger women are wearing different prostheses, moving away from the aesthetic of the normative body to what works for them. But comfort is also essential. Erhart offered that where the prosthesis attaches to her flesh and bones where trouble can happen and where it can be painful. And for Marsh, she can't wear a prosthetic because she has 'too much arm', but in any case, would not want a hand and would opt for something 'functional, but also beautiful'. O'Brien shared how she has to go to the limb centre hundreds of times, backwards and forwards, saying 'People can't feel it, whereas you could feel it. So you can try something (and notice) that needs to be a bit more, and you can do it yourself rather than having to rely on somebody taking it away, coming back wrong, taking it away [again]'. Both O'Brien and Erhart describe the impact on their work and their mental health, and would rather take more control of the process themselves, so they can get the prosthesis fitting right.

Zhou was keen to point out that the practical workshop activity was based on only one algorithm (Mogrow) and its design 'language' of the wrinkle. He asked if the designs reflect the dancers' dancing motions. The dancers responded very positively to the idea of the wrinkle and how, as O'Brien observed, 'something is created directly from the body moving'. Erhart described how 'it seems to have its own brain on how the wrinkles work. And where they are going to bend or not. I don't want something sleek because that's also not what I am'. And later: 'They remind me very much of myself in many ways so I like that and that they had their own mind'. O'Brien remarked on how she thought they were 'really organic and human'. 'Wrinkles' thereby offered an image for the dancers which enabled them to respond to and build upon the unexpected or the accidental in their improvisations, and produced some unexpected rhythmic structures, breaking up otherwise 'smooth' or 'flowing' pathways. Whilst there was amusement at the thought of the wrinkles (Erhart and O'Brien agreed that they are 'wrinkling' and 'wrinkles') there seemed to be something important about the relationship with an aesthetic that had movement implicit within the design, and that appeared to eschew 'perfection' as an antidote to some of the non-human aspects of technical processes.

Aesthetic seeds; physicalising the 'image'

The relationship between what was termed the aesthetic seed and the designs emerged as a core part of the research. The dancers felt that their movement was more recognisable in the aesthetic seeds than in the prosthetic covers so were able to identify more clearly with them, potentially because they felt a greater connection with the image (aesthetic seed) when they were doing it: 'we were seeing that image coming up on the screen, so we could sort of see what we were doing and it was on the screen' (O'Brien). So, the dancers generated it, they saw that image and that led to recognition that it was 'me dancing', but not when it's been transformed again (Benford). The dancer

chose their favourite aesthetic seed, producing a greater emotional connection to it. The same point is likely relevant for all dancers moving in relation with their digital image, when it is reflecting back what is being captured. The dancer moves the way they like, so the dancer likes what they see, so they move more in that way, and so it generates more of what the dancer likes.

A continuous cycle is created based on personal preference but the screen is also a powerful force, hard to ignore as it draws the dancer's attention towards what is being produced. Moreover, with the thought that what is being created could be a prosthesis, there is awareness of a certain level of the need for functionality, which may limit some possibilities. There is a play between the visualisations producing the potential for movement in abstract forms, and the transformation of the visualisation into something more tangible and recognisable as a limb, which has a functional property but may lose some of the potential to be something else. For artists, the potential for the 'net yet formed' and the possibilities rather than the product is what is attractive (Whatley). But making something concrete 'can lose something aesthetically' (Bedford). It is acknowledged, however, that the emphasis on occularism produced by the lure of the screen and privileging of visualisation over other modes of engagement could be limiting in terms of response. Further, for the dancers this environment was in many ways novel for them so it produced curiosity as well as pleasure in seeing and responding to their own image as it was rendered through the visualisations.

The naming of 'aesthetic seeds' was thus one of the major outcomes of the research and provided a basis for the prosthetic design. Benford described the importance of the 'aesthetic seed' as part of the visual design but is also important to the final stage, for manufacturing with a focus on what the dancer requires as well as performance functionality, which includes strength, durability, muscle force, pressure on joints and other biomechanical considerations. Marsh asked if there is an actual resistance to aesthetics for those with disabilities. For O'Brien, perhaps functionality is all that is needed because of not using the prosthetic in performance. It does raise the question of how the dancer might comprehend their relationship with their dance differently: dance as an embodied practice has no material remains so having a physical object emerge as a materialisation of the dance can be both troubling and illuminating. Marsh admitted that as an observer of O'Brien and Erhart's designs, she can

> remember the way [they] were moving and even if I am making it up for myself, I can kind of create a narrative around: 'Oh they were doing this kind of movement and I think I am seeing that in this thing'. I wonder whether that is the same for the dancers.

Agency in co-design

Erhart referred to her sense of agency when she could see the result of her movement very quickly, saying 'When I spiral, it creates, I can see it spiraling. Or when I go faster, I can see it, you know, growing the points and there, I felt very much ownership of what I create'. However, discussions also focused on how the dancers' moods and emotions whilst dancing may affect the designs as they emerge. Marsh observed that it could be revealing to explore the relationship between how we verbalize what's happening in the body, in the moment that it's happening. For O'Brien, there is something interesting

in being prompted to move a body part, and she moves but doesn't see what is being created, but then she does in the designs. Marsh observed two scenarios are thus possible, saying:

> There's this one scenario where you are making the disabled body hyper- autonomous and totally powerful. But also, there's the potential to make it completely passive to make it a vehicle for someone else, to 'do this move like that', or 'do that more', or even be mimicking someone else's movement.

Erhart admitted a frustration of 'wanting to create this on the screen, but it didn't work. I very much felt like I have to produce, I have to be productive. I have to produce something here'. This observation is likely to be an experience of others who perform in these digital environments and is thus not unique to disabled dancers.

The motion capture suits raised questions about how the dancers felt about wearing a suit for a body that wasn't like their own, and were asked whether putting on a suit that assumes a body with four limbs means it felt like becoming someone or something else. As with many technological processes, the motion capture suit is created on a normative design principle. The dancers then found inventive (and sometimes humorous) ways of tying up the material for the extra limb. Erhart commented that whilst it didn't make a difference to how she moved, it certainly made a difference to how she felt, commenting:

> Seeing these four limbs on screen, where I have three. It's like, what is this? It's an interesting aspect to even play with, I do not know how to have that activated as a limb that is not there, but actually, there it is, when I swing my left side, where I don't have my left leg, I could create a speed that I couldn't with a leg.

When O'Brien, who uses a prosthetic leg, but dances without wearing it, was wearing the motion capture suit and sensors, we had improvised an adaptation to the two-legged body suit, so it might fit better. The result of this on the avatar on the screen was of an 'impossible' body, twisted and distorted. As Marsh observed, 'it was neither a 'normative' body nor Welly's body'.

The conversation also considered how a particular prosthesis (such as wearing a very heavy leg) would inform how the dancer would create particular movement, and then a different leg, or hand, could be 'put on' for another activity. Erhart reflected on her own mobility aids, assistive tools and crutches, sharing that she has been thinking about glass material or see-through material to provide her with 'invisible crutches'. She described researching 3D printing and finding a material where her crutches could be printed and she could use them but they are not visible as crutches, but Erhart also raised the tension between visibility and invisibility for disabled dancers. She continued:

> I'm really interested in the way I walk with my crutches and making the mobility aids invisible. It already lets the body appear in a different way. If you would like to let this disappear in a way, on stage and in a performance setting, I think you could do amazing things with that and to play with this idea of making things visible or it being invisible. Recently I was thinking more and more about how the concept of invisible disability is actually a very ableist one. Because for me as having that invisible disability, it's very visible. It's very visceral. It's very there for me, but for someone who is not having it, it's not visible. And yeah, so I'm really interested in that play of making things visible or not, or having them invisible and making them visible. I think it's actually really important, but to make it visible in my terms.

Erhart is pointing towards the importance of dancer agency in technology/arts research. Co-design can overcome how dancers may have negative feelings towards their assistive tools and avoid having a part of your body determined by others (O'Brien). Recent developments have allowed prosthetic users to have more control (for example, O'Brien is now able to take parts of her leg home to adjust herself) but historically, the prosthesis is not owned by the user: there is a sticker stating that the limb is the property of a particular limb centre. Erhart shares how she talks with fellow crutch users about the brand, or names of the crutches, and how naming is quite a personal thing, but emerges over time when a relationship with a prosthesis has developed. But discussion focused on how good it would be able to access different styles and designs in the same way as selecting glasses to wear. The same naming strategy might emerge for the designs made with Mogrow.

Reflecting on the materials that were drawn on for the different prosthetic designs, Erhart comments:

> I was very intrigued by the see-through or the glass one, because it reshapes even the metal within … and what the leg looks like as in the various sleek lines, breaking it, breaking it up again, and it makes it even more fluid and moving. I think how it breaks up the sleek line of the red metal, I really liked that, how it seems it's moving differently in itself. Then I can imagine when the light breaks in, you can play so much with that, especially in a performance. (see Figure 2)

Marsh raised the possibility that it may feel important that

> you can, if not fully see, sense the workings, the functionality of what's happening in the prosthetic leg. So, it's not pretending to be a normal leg, but you also have a sense of the functionality because you can see the workings.

O'Brien reiterated that she observes that younger women quite like having the metal showing on the leg, so it seems to be 'where people's aesthetic is at the moment'. Marsh agreed, noting how women now might wear a hook or a functional metal-looking prosthetic hand and how attitudes towards prosthetics really give a picture of attitudes towards disability, particularly limb-based disability. However, O'Brien describes

Figure 2. Prosthetic cover with see-through material.

her preference is to avoid the shiny metal trend, preferring organic, natural materials. However, she notes that:

> I would love to have a wooden leg, like a proper wooden leg, but I just wouldn't be able to walk with it, because it's just too heavy but you could make different materials that look like wood. I like the idea that you can create different kinds of patterns, different textures and different looks in that algorithm.

Prosthetics, politics and ethics

Marsh raised the political dimensions of the research. A prosthetic could mean taking up space very differently, which would be a fundamentally political action. Having a missing limb could be perceived as traumatic but having a prosthesis that invites looks is a political act, so could play on the perceived difference by exaggerating through creating 'ginormous crutches' (O'Brien). Erhart asked

> how does that prosthetic leg or whatever I've created now, move me rather than how I can move it? What appears as a massively long stage, makes me want to move a certain way and it's choreography. And for me, that's crip choreography. It's beautiful.

The political then also calls into question the involvement of other stakeholders in the process, such as choreographers, costume designers and set designers. For disabled dancers, it is important to be included in conversations with designers or costume makers, 'particularly if you occupy a disabled body' (Marsh). For dancers with different disabilities, design, including costume, can sometimes neglect the lived experience of the dancer, acknowledging that not all disabilities are visible. For dancers with physical disabilities, Marsh observes how important it is to have 'those conversations about how a particular costume works for your body, versus someone just layering stuff on'. This reflects back on the relationships created within the research between the dancers and the algorithmic process of creating visualisations, raising complex questions about the 'self' and how the individual is tied to or disconnected from the visualisation in its transformation into prosthesis. Erhart links this tension to 'the discussions around appropriation and who is allowed to wear a prosthetic or create a prosthetic and then use it in art and make lots of money out of it'. She asks: 'Is it part of disability culture that we create here? Or is it an art piece? To whom does it belong to?'

Ethical issues arise because we are not used to the idea that we don't own our bodies and performance. Prostheses are rarely owned by the individual, they are 'issued' to them by a health authority, so even if felt to be 'part of the body' they remain in ownership of another. Unlike a general sense of 'owning' our corporeal bodies, a prosthesis-user may find the 'me but not me' status uncomfortable and may be amplified for dancers who are experts in bodily movement. It follows then that the ethics of ownership of prostheses can be complicated if the action of a prosthesis is determined by who has made it or who claims its ownership. The visualisation process illuminates broader questions of whether the prosthesis is an entity that exists independent of the user, and whether it cannot become itself until it is worn.

Our final reflections returned to aesthetics and the complex idea of how digital aesthetics played a role in the research (see Figure 3). O'Brien was clear that her preference is for the organic designs (the silk, wood, stone). Marsh notes that the organic may be

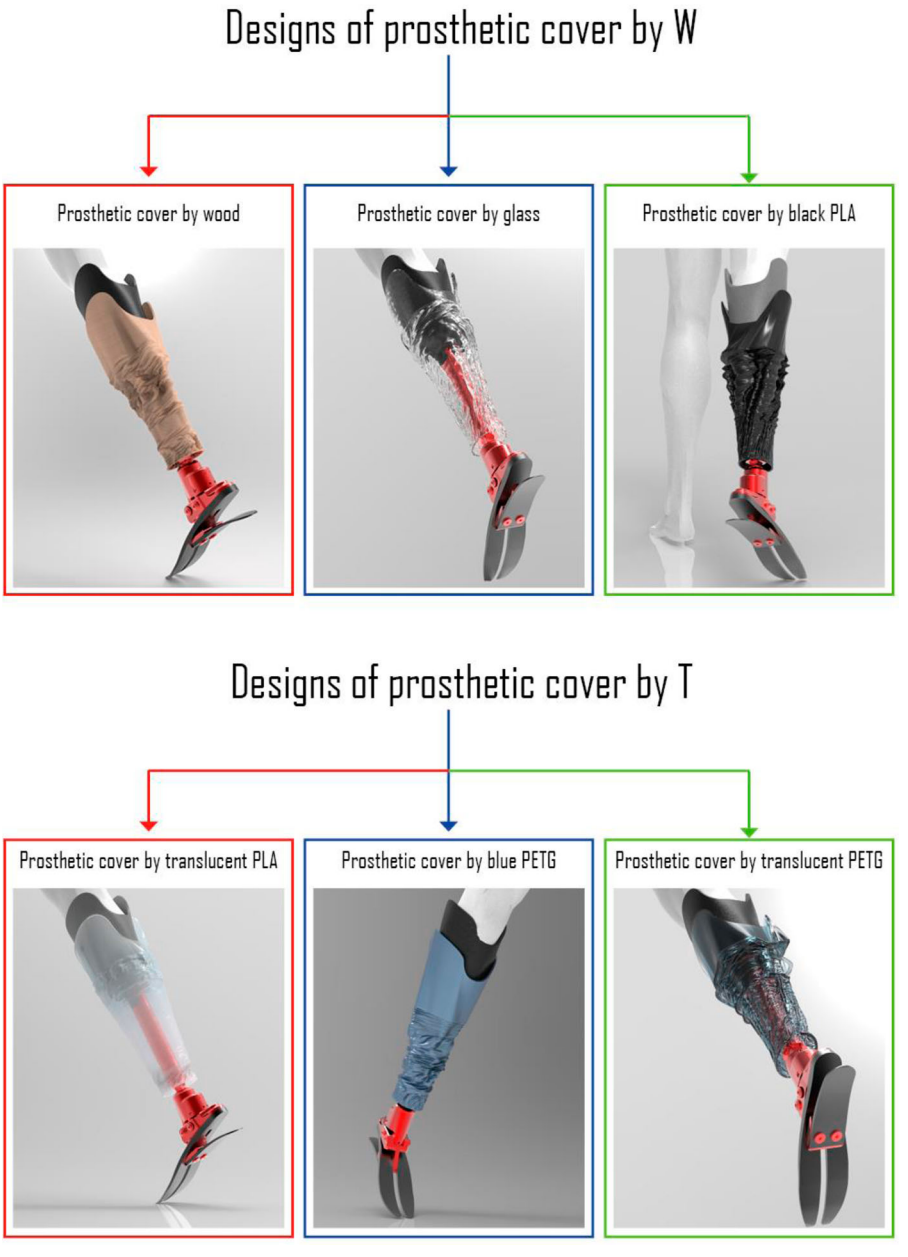

Figure 3. Designs of prosthesis covers by the dancers.

preferred because 'they seem like a really good balance of having some agency and some design'. Zhou's inspiration for the algorithm was also the natural world and took the team back to pictures of canyons and rock formations, but the natural world is external to the human body so there appeared to a rejection of 'a sort of very artificial, digital, completely man-made aesthetic' (Benford) and yet not a full rejection but the 'uncanny valley' (Mori 2012) of trying to replicate the human organic material. The posthuman is more visible now in prosthesis design, looking towards the cyborg and the increase in the human

interest in putting bits of different machines in the body, for example in the work of Victoria Modesta.

Discussion

The research has revealed the benefits and challenges of collaboration and co-design, leading to concepts that were meaningful for all involved, such as 'aesthetic seeds'. But the project showed that work is still needed to ensure that technological processes do not reproduce assumptions about bodies and how bodies move. It is important to directly involve those who have lived experience of different ways of moving due to disability, age or other characteristics that challenge normative working methods (Figure 4). The research posed a number of important questions, such as how do autonomous disabled bodies interacting with these systems disrupt assumptions about normative bodies in dance and technology? Marsh reflected that:

> As soon as we (Welly, Tanja and myself) entered the studio and the equipment was being set up, we began to ask questions about what we could do and how it worked. I noticed a space being created for discourse, rather than one where the bodies in the room were simply there as vehicles for using technology, the dancers were in negotiation all the time, with each other, with Feng and with the equipment. This reminds me of the everyday requirement to adapt and negotiate a world set up for normative body minds when you don't fit.

The dancers used their improvised movement to create designs which they could see changing as they moved; the more they saw the designs reflect their actions the more they experimented with growing confidence in their movement. What became clear is that the presence of disabled bodies in product design might impact on prosthetic design, and this engagement could then have a positive impact on a user's relationship to their prosthesis. Diverse bodies draw attention to how normative methods and traditional power structures in the dance/technology interface might be challenged and rethought. Whilst our own project involved disabled dance artists/researchers and non-

Figure 4. Tanya Erhart in rehearsal for the project.

disabled computing scientists and engineers, and reproduced what might be regarded as a familiar gender divide between disciplines, we recognise that a commitment to diversity means we are mindful of challenging and resisting binary distinctions as our research develops. Our research has thus aimed to draw attention to the importance of considering what inclusion means to challenge normative thinking around 'connection' and 'access' in the context of digital innovation in artistic practice.

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Notes on contributors

Sarah Whatley is Director, Centre for Dance Research, Coventry University. Her research includes exploring the interface between dance, disability and digital technologies.

Steve Benford is Dunford Professor of Computer Science where he co-founded the Mixed Reality Laboratory. His research lies in HCI with a focus on creative applications of emerging technologies.

Kate Marsh is Assistant Professor at the Centre for Dance Research, Coventry University, and has a practice as a disabled dancer/choreographer. Her research is broadly focused on leadership in the field of dance and disability.

Feng Zhou recently completed his PhD on the topic of using motion capture and generative algorithms to enable disabled dancers to aesthetically personalise their prostheses.

Ian Ashcroft is member of the Additive Manufacturing and 3D Printing Research Group and Head of Department of Mechanical Materials and Manufacturing Engineering at Nottingham University.

Paul Tennent in Assistant Professor in Computer Science at Nottingham University specialising in the design of immersive experiences, including applications of motion capture technologies.

Welly O'Brien is an independent disabled dance artist. She performs and teaches nationally and internationally with a number of major dance companies and collaborators.

Tanja Erhart is a crip dance artist and cultural anthropologist. She creates her own work, teaches and choreographs, and has performed in pieces by artists and companies worldwide.

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