Reinterpreting Schlemmer's Triadic Ballet: Interactive Costume for Unthinkable Movements

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ABSTRACT

In the 1920s, Oskar Schlemmer, artist in the Bauhaus movement, created the Triadic Ballet costumes. These restrict movement of dancers, creating new expressions. Inspired by this, we designed an interactive wire costume. It restricts lower body movements, and emphasizes arm movements spurring LED-light 'sparks' and 'waves' wired in a tutu-like costume. The Wire Costume was introduced to a dancer who found that an unusual bond emerged between her and the costume. We discuss how sensory alteration (sight, kinesthetic awareness and proprioception) and bodily training to adjust to the new soma, can result in novel, evocative forms of expression. The interactive costume can foster a certain mood, introduce feelings, and even embody a whole character - only revealed once worn and danced. We describe a design exploration combining cultural and historical research, interviews with experts and material explorations that culminated in a novel prototype.

Author Keywords

Costume Design; Design Research; Wearables; Theatrical Performance; Interdisciplinary Collaboration; Crafts.

ACM Classification Keywords

J.5. Computer Applications: ARTS AND HUMANITIES: Performing arts (e.g. dance, music).

INTRODUCTION

Wearable technologies come in many different shapes and forms. Many passively collect data from our bodies [5,18,34,47]. Others actively extend our senses [11,12,20,49,50,53]. Svanæs and Solheim developed mechanical tail and ears for the theater reifying Merleau-Ponty's concept of the lived body [46]. Bird et al developed Tactile Vision Sensory Substitution (TVSS) system for enabling 'skin vision' experience [3]. Mistry and Maes explored the possibilities of physical world augmentation via wearable gestural interfaces [31]. Most of these extensions of our bod-

CHI 2018, April 21–26, 2018, Montreal, QC, Canada

© 2018 Copyright is held by the owner/author(s). Publication rights licensed to ACM. ACM 978-1-4503-5620-6/18/04...\$15.00 https://doi.org/10.1145/3173574.3173635 ies aim to extend our senses, adding a novel body part or a new sense.

Here we took a slightly different route: we designed a wearable costume that restricts wearer's movements while adding interactive expressivity, and that kinesthetically affects the wearer and spurs new ways of moving and dancing. Wilde has previously shown how such an approach may affect movement, self-perception and human-space relation [50,53]. We describe our insights from a project that aimed to create a modern interpretation of a costume from Oskar Schlemmer's Triadic Ballet from the 1920s Bauhaus, an avant-garde abstract work that broke with dance traditions of the time (Figure 1).

Schlemmer's interest in *formalism, structuralism*, and the *absolute visual stage* [48], as well as the vigor and modern feel of his costumes attracted our interest. We believe that these aesthetic concepts from Bauhaus can inform design of interactive costumes and wearables more generally, creating new expressions, and help open a novel design space. This is very different from traditional approaches in designing wearables. The ballet facilitates a more open-ended design process encouraging aesthetics and creative endeavor.

We started by examining Schlemmer's work via a literature review alongside first-hand observations and expert interviews with members of professional troupes performing the



Figure 1. Left: Original Wire Costume (Oskar Schlemmer, Draht-Figur 1922). Photo © Staatsgalerie Stuttgart. Right: Our version of the costume.

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Triadic Ballet. This informed our re-interpretation of the costumes using interactive materials. Exploring alteration of dancers' movements led to the following insights: 1) restricting sight enabled new forms of feeling the space and communication, 2) adding unconventional weight distributions changed the momentum and therefore movement, 3) restricting movement helped create new aesthetic expressions, which, in turn, helps us 4) bring Bauhaus aesthetics into a new, interactive form. The characters in the play become embodied in the interactive costume, allowing the dancer to learn the story of the character kinesthetically by wearing the costume. Our design spurred "unthinkable movements", as expressed by the dancer who danced with our costume.

Our work provides a contribution in exploring and extending the design space for wearables by focusing on wearable's impact on movement and kinaesthetic-perception. With the advent and elaboration of IoT, shape-changing interfaces [40] and materials, the interaction paradigm is shifting towards movement-based interactions - introduced into HCI via concepts such as "implicit interaction" [22], "faceless interaction"[21] and commercial developments in IoT. Still, movement-based interactions are underexplored, and while some interactions are aesthetically interesting and inviting, others feel redundant and boring. Often, the body is seen just as an input device and the aesthetics is left out. The arts, ballet in this case, could serve as an inspiration. Not only the costume we created can be used on stage, but that the qualities of those interactions could be used more broadly in design work for a wide array of applications We here investigate firstperson felt experience in what is admittedly an 'extreme case' (similar to Beuthel's transfer of lived experiences of discomfort [2], Ljungblad's transfer scenarios [30] and Höök's analysis of horse-riding [15]). Our findings of sensory alteration, changing means of expression, immersion in a story/role/character, kinaesthetic awareness and proprioception can inform design of movement-based interaction in diverse IoT settings from homes, entertainment, to transportation and others, by highlighting factors and experiences that traditional user experience research and design has ignored.

BACKGROUND: INTERACTIVE COSTUMES

Here we use the term *interactive costumes* defined as "*thea-tre costumes that are enhanced with computational components that can be controlled by their wearer*" [14]. Let us first introduce some of the history of interactive costumes used in dance performances, before we discuss what has been done in HCI and how this can contribute to the growing body of work on movement-based interactions [16].

Interactive Clothing for the Performing Arts

The use of digital technologies in the theater has a long history, tracing back to 1938, when Antonin Artaud foresaw future technologies for staging images [9]. Interactive technologies are often used for this purpose [10,20,37,47]. One of the first 'technological' costume was premiered on stage in 1956 with Atsuko Tanaka's Electric Dress [13]. Nowadays, interactive costumes are widely used in pop concerts (e.g. Lady Gaga, U2, Rihanna) and dance performances (e.g. 'The Brooklyn Nutcracker') [13]. In this context, the main purpose of an interactive costume is to create unique visual experiences for the audience.

But there is a bigger potential for interactive costumes. Birringer and Danjoux explored wearable technologies as instruments worn on the performing body [5]. They found that interactive dance costumes can go beyond a pure visual sensation for spectators' perception – they create a kinaesonic experience. The costume becomes a sensory medium between performer and environment, and the pre-defined choreography is replaced by psycho-physical (re)actions of the performer who becomes more musician than dancer. The authors further argue that the performer's proprioception of/with the garment interface is essential for successful interaction [4]. Similar, Schlemmer's untypical Triadic Ballet costumes force the dancers to open up to unusual kinaesthetic experiences and movements.

Interactive Costumes in HCI

In HCI, Honauer and Hornecker [14] share experience and insights from developing and staging interactive costumes. Wilde's Light Arrays I & II projects [51–53] dance costume with different configurations of LED and laser arrays allowed to experiment with non-observational relationship with space. In hipDisk [49,50] the costume took the role of musical instrument, encouraging exploration of sound through movements. These projects provide inspiration to us in how the costume alters and effects movement, self-perception and the human relation to space. In particular, Wilde's hipDisk shows how a wearable can engage its wearer in uncommon movements because the worn interface offers interesting and enjoyable interactions that are perceived as bodily extensions or enhanced expressiveness.

Some dresses explore social context. G(Hui) translates perpetual anxiety and fear of alienation from others into a wearable artifact [29]. The wear.x wearables materialize the abstracted experience of discomfort and transfer it to another person [2]. Venus garment demarcates the boundaries of the person's personal space [23]. The Laughing Dress, facilitates positive social interaction within the context of a public art installation [28]. Also related to our work is the design of Wo.Defy, which integrates cultural historical research into contemporary wearable design practice, and explores interaction semantics by mapping the wearer's breath to physical kinetic movement [42].

THE TRIADIC BALLET

The Triadic Ballet is an avant-garde dance performance created by influential Bauhaus artist Oskar Schlemmer in the 1920s [36]. This exploratory project broke with the prevailing dance traditions of its time. In opposition both to the free body movement propagated by New German Dance and the strict rules of classical ballet, Schlemmer wanted to explore movement possibilities of the dancer's body encased in the rigid form of his costumes [19].



Figure 2. Group photo of all figurines in Oskar Schlemmer's Triadic Ballett. (photo Ernst Schneider 1927) © Bauhaus-Archiv Berlin/ Museum für Gestaltung

The ballet consists of three parts, hence 'triadic', each with distinctive color, mood and appearance. While Schlemmer did not document the idea behind the three parts, Koss [26] interprets the Triadic Ballet as a reflection of dance history: starting with naturalism and traditional costumed dance in the first act (yellow, burlesque character) to the abstraction of pure movement of artificial organisms in the last act (black). The costumes are colorful three-dimensional objects, very different from traditional dancewear and made of various materials: metal, padded cloth, papier-maché. They represent abstractions of the human body, and their form and material properties determine the dancers' movements [19,43].

The piece remains significant, as costumes and performance still feel modern [7] and surprisingly novel. Four different groups have re-constructed or re-interpreted the Triadic Ballet and its costumes (only few survived in original) [7,38,55,56], starting in 1970. There are only few attempts to translate Schlemmer's ideas into contemporary performance art. Shallhorn [44] created a digital stage machine – a stage augmented with interactive real-time technology. Ka [24] aimed to achieve human body abstraction via an electroluminescent interactive costume. Both demonstrated novel approaches for digital technology use in performance.

METHOD

To enable a re-interpretation of the underlying concepts that remains true to its essence and intentions, we first familiarized ourselves with Schlemmer's artistic idea behind the Triadic Ballet and backstories, explanations and inspiration for the costumes via literature review. Furthermore, we engaged with two professional groups that currently perform the ballet, one of which remains as close to the original as possible (Bayerisches Staatsballett) and another that aims for a reinterpretation and has built their own costume versions (Theater der Klänge) in order to gain insight in the experience of constructing, wearing and dancing in the costumes and to see how these experts would react to the idea of adding technology to a new version of the costumes. We observed rehearsals and performances, and interviewed members of the ballet groups as well as supporting staff. The interview guide was based on a scheme previously developed for expert interviews with interactive costumes [13]. The Theater der Klänge group had some experience in adding technology to costumes, and the interviews also sought to clarify technical issues related to interactive costumes. In total 12 interviews with 13 participants were conducted. These include interviews with seven dancers and six 'experts' (two directors, choreographer, ballet mistress, producer, designer people with deep knowledge in the area, involved in the procostume of and choreography reconstruccess tion/interpretation). The interviews were coded inductively using thematic analysis [6].

Based on our understanding of Schlemmer's intentions and the interviews we decided on one costume to recreate and modernize: Wire Costume (Draht-Kostüm), a costume with a large bell-shaped skirt made of wire loops. This features in the final part of the performance, depicting Schlemmer's vision of the future, allows for interaction with other characters on stage and is subject of various interpretations [32,36,45], thereby opening a broad design space for us. During the process of costume design and development, numerous sketches of costume appearance, component arrangement, and interactions were made. Three physical prototypes were created before the final version. Also, the Wire Costume choreography from Bayerisches Staatsballett was analysed and sketched as a storyboard.

After the costume was constructed, it was tested with a local semi-professional dancer, who had no previous experience with the Triadic Ballet. She was provided with video recordings of the Bayerische Staatsballett reconstruction and the storyboard of the dance. She was asked to learn the choreography, but to feel free to experiment and improvise. She then performed her vision of the piece in the new interactive costume to us (which was video recorded and analyzed), and was then interviewed.

DESIGN EXPLORATION

Here we present the results of the initial steps of our design exploration. We start with a summary of our interpretation of Schlemmers's aims and concepts based on his own writing and related literature, followed by the results of the interviews with members of professional dance troupes about their experience with Schlemmer's costumes.

A review of Schlemmer's aims and concepts

No recordings of Schlemmer's historical performances exist and the original choreography is lost. Nine original costumes, photos, his sketches (Figure 3) and manuscripts are all that is left. Seven original costumes are currently exhibited in Staatsgalerie Stuttgart. Nevertheless, Schlemmer's general vision of theater, his interpretation of space and dancer-stage relation is well explained in his essay "Man and art figure" [43], which gives hints on how to interpret the aesthetics of the Triadic Ballet. In short, human body and stage obey different laws. The abstract stage is a cubic space, pierced by the invisible lines of planimetric and stereometric relationships, while the human body is a biological organism, whose



Figure 3. The laws of cubic space. Inherent mathematic of the human body. Figure 4 A-D. Transformation of the human body in terms of stage costume. In: Oskar Schlemmer, László Moholy-Nagy, Farkas Molnár: Die Bühne im Bauhaus. Munich: Albert Langen Verlag, 1924 [Bauhausbücher 4]. First edition. © Bauhaus-Universität Weimar Universitätsbibliothek

movements are determined biomechanically and rationally (Figure 3).

stage work was a "magic of transforming dancers and actors into moving architecture" [43].

When dancers perform, they are exposed to the laws of cubic space, functional laws of the human body in relation to space, laws of motion of the human body and metaphysical forms of expressionism. The costume acts as connecting element. Via the costume, the dancer is transformed into four different forms (Figure 4): A. walking architecture (following laws of cubic space, head, torso, arms, legs are transformed into cubical form), B. a marionette (using the laws of the human body in relation to space, bodily forms are stereotyped: an egg-shape head, vase-shaped torso, club-shaped arms and legs), C. a technical organism (emphasizing rotation, directionality, intersection of space: a spinning top, spiral, disk), or D. dematerialized (metaphysical forms of expression symbolize parts of the body: the cross of spine and shoulders, the ∞ sign of folded arms). [43]

Schlemmer's correspondence with critic Artur Michel [25] reveals his intent for the costumes to limit dancer movements. This is reflected in reports on the experience of the original costumes: "The costumes wear the dancer rather than the other way around" [19]. He also described the costumes as worn sculptures that influence body perception; when the dancer becomes deeply entangled with the costume, their body achieves new forms of dance expression [27]. Paret believes that the costumes' form determines their motion, so some tend to move diagonally, whereas others remain within a grid [35]. Reinhild Hoffmann, in her memories of the Triadic Ballet, recalls that "the heavy skirt would swing round to its own laws" and she had to "learn to act in opposition to it". The costumes can be considered as sculptural extensions, which add or subtract qualities to the body. They emphasize a human body underneath the costume, but the movements become new and strange [33].

Schlemmer only hinted at possible interpretations of the costumes in his manuscripts: "Precision machinery, scientific apparatus of glass and metal, artificial limbs developed by surgery, the fantastic costumes of deep-sea diver and a modern soldier" [43]. His costumes have been described as human-machine hybrids or robots, marionettes, to crippled soldiers and prosthesis – concepts at the core of the Bauhaus concerns at the time [8,19,36] as well as reflecting early industrialism. Gropius' personal impression of Schlemmer's Dancers' experience of the original costumes

Despite all the above, most of the literature on the Triadic Ballett comes from art history or media theory. Thus, while much is known about Schlemmer's intentions, and there is anecdotal evidence he achieved these, to our knowledge there has so far been no empirical investigation of how this comes to be and the range of effects this has on dancers' movements, bodily awareness and experience.

Our interviewees told us that sometimes, despite the missing documentation of the original choreography, how the story is revealed by the costumes: "the costumes themselves, they carry a character". A costume can uncover its story in various ways: "the 'Spiral', for example, the costume goes like a spiral. So, this character is also turning a lot". Others argued that the costume only communicates its character once they dance and develop movements with it: "And there was a point she <a dancer> was so tired because of the weight. She sat on the floor and everybody then, I thought, look at this, it looks like a toy". A central way to deliver a message to the dancers was through the limitations posed by the costumes. While these could be viewed as severe usability problems from a traditional HCI perspective, the experts and dancers considered these limitations a source of inspiration. In particular, three main themes reoccurred in the interviews: (1) restricting movement, (2) adding or re-distributing weight, and (3) restricting sight.

Restricting movement to create new emotional expressions

All dancers mentioned the physical limitations experienced when dancing in the Triadic Ballet costumes, but 'limited movement' does not suffice to describe what they experienced. One of the ballet reconstructors mentioned that the costume does not limit movements as much as it helps dancers to depart from the strict formula of classical ballet. The costumes also force them to be slow. One of the ballet directors looked upon this not so much as a restriction but as *reduction*, a possibility for new expressions, harmonizing with the choreography that sets the adequate amount of movements given the costumes.

Besides rather obvious physical limitations, the costumes limit dancer's emotions, expression and communication. One dancer claimed that wearing the costume changed her mood, and triggered different feelings. Dancers' expressiveness and communication, in turn, is altered by the physical limitation of movement and by wearing masks that hide their faces. Yet other expressions became possible and necessary. A reoccurring theme in the interviews concerned the opportunity to develop movements from the costumes, where the costume guides the dancer by limiting some movements, reducing or making impossible other ballet elements: *"because they would guide me, or they would tell me: you cannot do this, or it doesn't look correct in the choreography, if you are not in dialogue with the costume. Dialogue means you cannot do everything" and "Zylindermann and Glockenfrau, they are like little puppets. I mean, he could not really move, he is really prisoned in this! So it already gives you a lot of inspiration how to move".*

One of the experts thinks this was how Schlemmer developed the original choreography – the costumes provided the character that in turn lead to the choreography. The choreographer of the Munich reconstruction, Gerhard Bohner, followed this approach: the ballet dancers were initially given many possible movements, and these were subsequently "*reduced*" to adjust to the costumes' characteristics.

Weight, Momentum and Shape of the Costumes

Almost all the dancers and experts mentioned the weight of the costumes. Their excessive weight was considered one of their drawbacks, but if the dancer accepts and overcomes this, a different expression can be achieved.

The heaviest costume, referred to as 'Big Skirt' (Großer Rock) weights around 10 kilos. The dancer for this role said that its weight is not evenly distributed and primarily "goes to the back". One dancer mentioned that weight was not the biggest issue, but rather losing her normal, well-grounded feeling for her own weight and resulting control over its momentum. Jumping, turning and other demanding movements. are altered and more difficult to perform. Apparently, the original costumes were even heavier: "In Bauhaus Dessau, they have the original costume of the 'Diver', which is made of wood. They told us, if we give it to you, one person can't carry it".

Some of the costumes make it hard to find and keep balance. The dancer of 'Großer Rock' acknowledged that it takes time at the beginning of a performance to find balance and then is challenging to keep it. When a dancer wears the Golden Sphere costume (Figure 5), he cannot move his hands, as they *"are blocked inside the ball"*. Free hand and arm movements play an important role in keeping balance for a dancer; with locked hands there is always a risk of falling, especially considering that the Golden Sphere character spins a lot. 'Harlekin in Weiß' sets an interesting challenge: *"one side is heavier than the other and you have to shift your whole body to be just straight."* So, when the dancer is a little off-balance, he falls.

The weight of the costumes creates an interesting phenomenon – inertial motion. The dancers have to think about and be meticulous in movement. Großer Rock costume is a good example. With its big weight and inertia momentum, the dancer has to be very careful, avoiding any extra movements, as sometimes it is not the dancer who is spinning the skirt, but rather the skirt that "brings you around".

Some parts of the costume can extend a person's arms or legs, which, besides stunning visual effect, can create difficulties. A spectacular example is Großer Rock "*I couldn't reach the table, because the skirt is longer than my arms. I couldn't have a break, I couldn't sit down*". The skirt also limited physical contact with other dancers. But the choreography of the Triadic Ballet is aware of and adapted to these limitations; there are no complicated lifts and other challenging dance partnering techniques.

Restricting Sight: A Different Relationship with the Stage, Audience and Other Dancers

Another limitation experienced by the dancers was restricted sight, in to two causes. They were wearing masks as part of some costumes. Here the dancer predominantly mentioned the 'Diver' (Taucher), which has a big head mask. Since the character also spins a lot, this easily results in a dancer losing orientation in space. The second sight restriction comes from the lack of illumination in some scenes and in the theatre. In some of the scenes, dancers look directly at the audience, they cannot turn their heads and cannot see anything in front of them.

Nevertheless, our interviewees reported an interesting phenomenon, which helped overcome this. One of the dancers said: "You feel the stage. You, we, you normally saw that, after a little, know where exactly to go". We found further evidence that 'feeling the stage' goes far beyond just helping dancers to find their way when sight is restricted. Dancers also gain a sense of the physical presence of other dancers ("know that you are with the other person on the stage and feel that you are together") and regard this as a pleasant experience. 'Feeling the stage' is especially relevant for the last, abstract part of the piece, where it helped dancers to synchronize even without eye contact: "Once you get that sense of feeling each other on stage, without having like a direct connection... I think like once it was a really cool feeling, like there wasn't direct eye contact, but we were together on the stage and were harmonious".



Figure 5. Dancer wearing Golden Sphere during rehearsals.

RE-INTERPRETING THE WIRE COSTUME

Let us now turn to our re-interpretation of Bauhaus aesthetics through the creation of a new interactive design. Our aim was a re-interpretation that remains true to Schlemmer's original intentions, to the idea of 'limiting' movement, and that retains the qualities of the costumes, in particular their impact on experience. As such, rather than departing dramatically from the original design, we opted for a subtle modernization, adding new materials and contemporary technologies. This also addresses concerns of the interviewed experts that significant changes in appearance of the costumes and/or heavy electronic augmentation may break the uniqueness of the piece. At the same time, our interviewees supported the view that if Schlemmer had been alive today, he would certainly try out modern materials.

We chose to re-design the Wire Costume. In line with the Bauhaus aesthetics of modernism and utopia, it is an artifact reflecting the imagination of future at Schlemmer's time. The beginning of the 20th century was the time of electricity, electrical wires and appliances entering everyday life of ordinary citizens. In 1837, the telegraph was invented, and in 1895 the radio. Wires, in a sense, became transmitters of information. In the scene with Wire Costume and Golden Spheres (Goldkugeln), one can have the impression of a power line, with a wire running between two line isolators, or of a wire connecting two inductors (Figure 6). Murgia [32] described the costume as a personification of electricity, due to the reliance on wire and metal and the reflections on these elements under stage lighting.

In the augmented costume design, we replaced the original copper wire with fiber optics, thereby adding novel interactive capabilities, but staying true to the original ideas of Schlemmer on electricity and industrialism and what those enabled. The installation of the undersea telegraph cable was one of the marvels of engineering of the late 19th century. In 1887, all five continents were linked by thick copper wire, nowadays replaced by fiber optics. Thus, the use of this material allows us to reflect the modern age, similar to Schlemmer's original intentions. In the original scene, the stage is dark and the dancer lit up by a spotlight from the ceiling. When reflected by the metal wires, this light creates an unusual effect, a so-called *counterpoint*: the traces of light are set against the black box of the theater. Therefore, using light as material picks up on these aesthetic qualities and allows developing them further.



Figure 6. Wire Costume dancing with two Golden Spheres. Image from Tanzfonds Erbe © DIEHL+RITTER gUG

We started by examining a recording of the performance by Bayerisches Staatsballett [55] in order to determine the movements of the dancer and the interaction with the other dancers in the scene. Movements were represented in form of a storyboard (Figure 7) with one view from the audience perspective, and another from overhead, with timestamp added for each frame. The first view highlights the dancers' movements and body parts; the second shows the relative position of dancers to each other and movements on stage.



Figure 7. Storyboard with choreography of Wire Costume dance from Bayerisches Staatsballett highlighting relative dancers' positions.

Material qualities of the costume

During construction, two prototype iterations were built to explore different materials, their qualities and ability to integrate novel technology. In both, we sought to preserve visual aesthetics from the audience perspective for two reasons. In our interviews with dancers, the costumes were praised for their original design, which, despite being almost one hundred years old, remains novel and different from traditional ballet costume design. The dancers considered the color, material and shape of the costumes a "very strong element" when presented in the black box of the theater. The individuality of each costume and the potential to create a unique picture in every single act were considered a big advantage. The other factor we wanted to preserve were physical properties in order to maintain a similar experience for the dancer: shape, limitations, and weight. In the final version of the prototype, the frame of the costume was built using the same materials as in the original.

During prototyping, different materials were tested. First, we attempted to create fiber optics hoops without a supporting construction (Figure 8, left). The result indicated that a rigid frame is required to achieve a stable circular shape for elastic material. In the second iteration, two competing designs were created. As first variant, a rigid skeleton of leather and metal was formed following the approach of Schlemmer (Figure 8, center). The skeleton was complemented with elastic PVC pipes resembling fiber optic wires. Another variant explored the use of Plexiglas as light conductor, combing rigidity and glow. Nevertheless, heat treatment and bending significantly decreased the luminous transition of Plexiglas



Figure 8. Left: Experimenting with elastic materials. Center: Leather/metal belt prototype. Right: Testing Plexiglas ring with one LED.

(Figure 8, right), making the leather/metal prototype a viable basis for the final version of the costume.

All in all, the weight of the original costume was preserved by the use of metal wire as base material for the hoops. The hoop sizes and their placement on the belt were determined by analyzing photos and sketches of the original costume. Besides maintaining the authentic look, it also preserved the limitation of the original costume – the dancer was unable to lower her hands and perform classical ballet leg movements.

Nevertheless, one of the characteristics of the original costumes was left out – they were designed for one person and couldn't be adjusted. The lack of different sizes and inability to adjust not only affects performance on the stage, but also makes the process of dressing complicated. Even the dancers, who fit in their costumes, easily bruise from protruding parts of the costumes. It was thus decided to provide a high level of adjustability by using modularity, a backpack-like mounting system and polyurethane foam cushion on the inside of the costume's belt.

The final version of the costume (Figure 9) consists of a belt with mounting system, unitard and sensors. This modular approach allows keeping the majority of electronic components and wires on the belt and its mounting system, leaving unitard almost untouched, allowing for easy maintenance and cleaning.

Interactive capabilities

Analysis of Bayerisches Staatsballett's choreography led to two possible approaches for augmenting the costume. The first was to build on relative positioning and proximity to the other dancers on stage, realized by e.g. attaching RFID tags to all costumes. This was discarded, as it would require changing several costumes or altering the stage. Given the choreography involves considerable arm and hand movement, an alternative was to track arm positioning and movements with an accelerometer and/or gyroscope and to reflect these in the glow of the fiber optics rings. We chose the second approach, and used two LilyPad accelerometers as sensors. These are attached to the dancer's wrists with Velcro wrist straps and connected to an Arduino unit.

For the light effects, we looked at the recording of a Bayerische Staatsballett performance and noted the color palette appearing in the relevant scenes, in costumes, stage lighting and in combination: gold, silver, white and dark blue (cp. Fig. 6). To maintain the original aesthetics, it was decided that the costume should have a constant golden glow, and



Figure 9. The final look of the costume

white and blue lighting. Finally, two 'effects' were implemented:

- "Spark". A single blue light going from the point in the belt under the dancer's arm from left to right or right to left clockwise and counterclockwise simultaneously. This is triggered on raising the left or right hand.
- 2. "Wave". A streak of white light going from the front to the back of the costume clockwise and counterclockwise simultaneously. The effect is triggered when the dancer stretches her hands out to the front.

TRIAL EVALUATION OF RE-INTERPRETED COSTUME

The new costume was evaluated with the help of a local semi-professional dancer. She performed the dance of the Wire-Costume character and was subsequently interviewed. Many of her responses confirmed or mirrored the findings from our prior interview study with the two professional ballet troupes that perform the Triadic Ballet.

She experienced similar issues in how the weight and momentum of the costume affected her own movements due to inertia: "When turning around, for example, or changing the direction of walking". She experienced this as one of the challenges of the costume. She was also unable to lower her arms; however, this did not cause discomfort when performing. Most limitations in the costume were experienced regarding movement. The dance experience was described as "different" as she had to "get used to the fact that there is something that you feel all the time" and to "find out which movements are possible". Another complication was finding her body center for keeping balance while rotating, as the wobbling movement of the rings in the belt was unpredictable and affected performance. This made standard ballet movements rather complicated "I felt limitations in performing different standard ballet movements as for example a pirouette on pointe shoes due to the compounded feeling of balance". Nevertheless, she could get used to these limitations, as well as to the weight of the costume and even noted that it "was guiding me to the movement by restricting me in movements I can't do". This aligns with the interview findings from the dancers we interviewed before.

The costume did not encourage the dancer to try out new moves, as some of the moves initially planned were not possible. However, she thought that if she wore it more often, she would try something new: "at first you face the restrictions, and then you think: ok - what is possible now?" When asked about the story of the character, she gave a rather abstract description: "I felt like a person coping with a restriction, but feeling precious at the same time".

The dancer appreciated the original costume and our new interpretation, as a "*mixture of a very classical tutu-like ballet costume, but still absolutely not, because it was just made of wire*". She liked how the costume looked on the body. She further mentioned the reactions she experienced to her own dance movements and the feeling of connection between costume and body: "*I don't know if my body is connected to the costume or the costume is connected to my body*", she said: "...we were bonded somehow". As for expressiveness, she was not sure whether the costume really limited her regular means of expression, instead, it gave her "*the possibility to change my expression into a new one that wouldn't be the same when I wouldn't wear the costume*".

We now move to the feedback gathered from the dancer that relate to the new interactive features of the costume. Her vision was not obstructed by the light effect. But she concentrated on directing her gaze to "*see if the costume reacts as it should*". That happened in key moments, when she knew the costume should react to her moves. She considered this somewhat distracting. However, she thought that if she would perform the piece regularly, she would not be concentrating on the effect anymore.

The dancer did not think she had full control over the costume: "sometimes it was just doing whatever it wants to do". Nevertheless, controlling the costume was not considered difficult. Its reaction was responsive but sometimes lagged, when the dancer did a 'swimming' motion. All in all, interaction with the costume was considered intuitive and it took the dancer five or six attempts to adjust the movements to the "right pressure of going forward with my hands or the right speed of going forward". Placing sensors on her wrists had the dancer experiment more with arm movement, exploring options that would have been less desirable without the sensors and creating bi-directional interaction with the costume.

The dancer did not notice any difference in bodily experience for whether the costume was turned on or off, besides the lighting effect. Nevertheless, she preferred dancing with the costume turned on. From the two available light effects, she favored blue sparkle. When asked, she could describe both; however, she did not know "which movements provoke what light". However, it seemed that the interactivity affected how the dancer experimented with the costume. "My means of expression were also restricted – not because of the wire costume itself but because of the attached electronics and their intention of making the costume glow." We noticed that she was more inventive and tried out more moves when the costume was switched off, however, in the interview, she was not able to explain why. This may indicate a risk with interactive effects that dancers may begin to focus only on those movements that the costume reacts to, and do not explore as much what else they can do.

The dancer thought that the augmented costume might be beneficial for the Triadic Ballet due to the expanded mutual relation between dancer and costume: "the original costume was affecting only the dancer, but now the dancer can also affect the costume". The experience of wearing the costume was regarded as inspirational due to the light effects and the challenges caused by the costume: "you have this very uncomfortable, I would say, maybe even senseless costume, because why would a dancer wear wire around your hips? But then I ask myself, yeah but why not?" Nevertheless, inspiration by the light effect was considered more influential due to its novelty: "for me that is something very new, that a costume or clothing could react to the body wearing the costume."

All in all, the dancer considers the limitations introduced by the costume as both advantageous and disadvantageous. For example, being "forced" to move in a special way can be considered a disadvantage. Since conventional movements and means of expressions are restricted, it provokes a dancer and a choreographer to try out new moves, they have never thought before. "While ordinary dancers' costumes are created in a way to give a dancer all possibilities of all thinkable movements this wire costume gives the dancer all possibilities of all unthinkable movements".

DISCUSSION

Our investigation into the impact of the Triadic Ballet costumes on dancer's movements, perception, and embodied awareness reveals previously unknown qualities. We show via this extreme case how costumes can result in sensory al-



Figure 10. Wave effect in action

teration, affecting kinaesthetic awareness and proprioception, altering means of expression, and how this should not be interpreted in terms of 'bad usability' (i.e. negative limitations posed on the wearer) but instead can inform design (cf. estrangement methods [54]) leading to novel sensory awareness and engagement, spurring creativity.

Restrictions

Wilde [50] has shown that wearables can lead to uncommon performative movements, and our investigations confirm this. Further, we found that restrictions through wearables can lead to new ways of proprioception and this then forces the wearer to focus on certain movements while avoiding unintended ones.

Movement restriction. As expected, the dancers experience different limitations when dancing in the Triadic Ballet costumes, including our re-interpreted Wire Costume, where the most obvious is movement limitation. This was reported by all the interviewed dancers to a greater or lesser extent. However, this not really 'limits' movements – it appears more adequate to speak of 'altered movement', with changed tempo or reduced amplitude. Most interestingly, this does not have major negative impact on dancers, as the current choreography implies a sufficient range of movement. The choreography developed for the reconstructions of the piece was apparently already driven by costumes' limitations. This is in d'accord with the 'story, embedded in the costume' principle described.

Sight restriction. Another limitation experienced by the dancers is restricted sight, often due to wearing masks or acting in low-light scenes. This, however, led to an interesting phenomenon, reported as 'feeling the stage': the ability of the dancers to understand their position in relation to the stage and other dancers, and to synchronize their movements in a duet. Besides the above-mentioned limitations, the dancers' mood, their abilities to express themselves and communicate with other dancers on-stage were also affected by the costumes.

Disturbed proprioception. The costume appeared to be an interesting 'thing in itself' from the physical perspective. While aspects such as a costume's weight, size and shape seem to be banal and insipid findings, they lead to more sophisticated consequences. For example, the heavy weight of a costume and its uneven distribution make a dancer lose the feeling of the weight of their own body. The costume weight and having a dancer's hands obstructed by costumes of certain shape create additional difficulties for a dancer in finding and keeping balance. The inertial movement of a costume's weight and its distribution forces dancers to think through the movements in advance and concentrate on not doing anything further which might interfere with it. Parts of the costume alter the reach of the dancer, limiting physical contact with other dancers and make lifts and other advanced dance partnering techniques impossible.

All of these restrictions raise the bar for dancers, introducing them to new challenges and providing a completely new experience. The experiences with and without Triadic Ballet costumes (in unitard) can hardly be compared due to the different degree of freedom. The experience in the costumes is not pleasant, though. The dancers have to learn not to resist these difficulties, but rather to accept the inconvenience of the costume. For some of the dancers, the beautiful image that the Triadic Ballet creates for the audience outweigh the downsides. Others see it as an opportunity to test the capabilities of their bodies.

Communicating character, story and concepts through costume design

Our aim for the modernized costume was a subtle reinterpretation that remains true to the original intentions of Schlemmer, that is, connecting the ideas of electricity & industrialism and what this enabled at the time – but now with a parallel to digital developments and interactivity everywhere: switching from copper wire to fiber optics. At the same time we wanted to retain its essence to experience. Both the earlier historical and empirical analyses were necessary for our re-interpretation, remaining true to the idea of "limiting" movement, which was confirmed by the final user study. The interactivity, for example, adds a demand to make the costume "glow" – adding yet another restriction on movement, thriving off the interactive properties.

The findings of the augmented costume evaluation correlate with those from our earlier engagement with both dance troupes. For example, the dancer noted the ambiguity of perception of her body connected to the costume or the costume connected to her body. The same was stated in the literature regarding experience of the original costumes [19]. Our dancer remarked on the costume's weight and related factors: momentum of inertia and difficulty to find and keep balance. The same was reported multiple times by the other dancers. During costume testing, the dancer mentioned that the costume helped to find out which moves were possible by restricting some movements. We learned previously that the same strategy was used by Gerhard Bohner and Jacqueline Fischer (choreographer of Theater der Klänge group) when developing the choreography for their reinterpretations of the Triadic Ballet. Despite all limitations, the dancer was getting used to and even overlooking them when performing the piece. She believed the costume limited her regular means of expression, but gave her other possibilities in return. The same opinion was expressed by the dancers from Bayerische Staatsballett. Similar to them, our dancer also saw the costume as a challenge and a proof of her skills. She was able to come up with a story for her character, finding 'the story embedded in the costume'.

To sum it up, the augmented costume probably did not provide exactly the same experience as previous versions, but we can constitute that it is very similar. Moreover, novel findings were made. The main source of inspiration for the dancers in the 'traditional' Triadic Ballet costumes was the costume shape. For our new version, this is still important, but it interaction with light plays the main role in inspiring the dancer. The dancer also expressed that the light effect expands the relation between the dancer and the costume by allowing the dancer to affect the costume back, while in the original piece this relation was only unidirectional. This may serve as a logical progression to the Triadic Ballet.

Shifting dancer's attention to arm movements via interactive light patterns around their hips is coherent with the concept of 'subtle guidance' [17] - interaction that guides and directs a person's focus and attention towards specific bodily or sensory sensations without compelling it explicitly. In the costume, it serves as a logical extension of the original design concept, for the arms are not affected by the costume's physical limitations and allow a broader range of movements, which can be explored by the dancer.

Implications for design

The theme of restriction, applied to wearables, can result in new forms of "being" in the world, combining your own bodily movements with that of the interactive costume (cf. [49,50]). Our study results relate to the physical design of wearables, showing how restricting movements can be considered a kind an estrangement method [49] that may unveil underlying properties of relevance to different application domains. For example, it could inform design for body awareness, which can be applied in physical therapy and stress treatments [41]. It could also be a tool for empathy in the design process by supporting co-discovery of fears and limitations in each other's bodies (cf. [1]). If applied to interactive performance art [3] and design of pervasive games, it can be used to enrich and convey characteristics of a character. It can also be used to inform design of interactions that enable bodies to connect in novel ways with their environment, be it with smart objects [39] or nature [1].

Our findings also have implications for how to engage with new interactive design materials such as e-textiles that change shape, weight and size [40]. By building on movement explorations and proprioception, we can support careful reflection during the design process and imagine novel, interesting types of interactions. Shape-change and weightshifting wearables may utilize the effects we have found to new purposes, e.g. as a form of 'slow design'.

CONCLUSION

Sensory alteration appears to be crucial for novel forms of dancer's expression. Obstruction of vision, metamorphosis of body shape and weight distribution, restriction of movements and means of expression opens a dancer for the new experience. Traditional ways of moving, expressing, communicating are disabled or made too complex to perform, providing a dancer and choreographer with a "tabula rasa", a starting point to experiment with new forms of movement and expression, having an opportunity to create something new, which has not been performed before. At the same time, the restrictions literally "put" the dancer inside of the body of the character, telling its story, temperament, behavior kinesthetically, which is one of the most powerful catalysts of immersion. By affecting kinesthetic awareness and proprioception of the dancers, the costumes contribute to which movements are possible and desirable, therefore having an active role in the construction of the choreography.

Our work provides the first empirical investigation into the effect of the Triadic Ballett's costumes on dancer's experience of movement, perception and embodied awareness. Furthermore, based on the gained understanding of the costumes' 'essence' for experience, we developed a reinterpretation using interactive technology and tested this. Our modernized version manages to preserve the aesthetics of the original costume and, even more important, the experience inside it. In addition, the interactivity of the costume adds another degree of freedom in the dialog between the dancer and the costume. While the costume alters the soma of the dancer, the dancer is affecting back, by controlling the lighting effects of the costume.

We believe that the HCI community can find inspiration from this 'extreme case study' of wearables and costumes, which highlights the costumes impact on bodily awareness and movement and shows how design choices (restrictions and limitations on movement) that could be discounted as 'bad usability' can be functional and might inspire new uses for wearables.

ACKNOWLEDGMENTS

We thank the Theater der Klänge for the interviews: director Jörg Udo Lensing; choreographer Jacqueline Fischer; dancers Phaedra Pisimisi and Camila Scholtbach. We also want to thank The Bayerisches Staatsballett II and its members, in particular director Ivan Liška for the opportunity to observe, visit live performances and conduct interviews. We are thoroughly grateful to the Textile Workshop of the Bauhaus University for assistance with costume component layout development and answers to other product design-related questions. Our sincere thanks go to Sophia Kluge for dancing in the electronic costume and providing us with rich feedback. We furthermore thank Kristina Höök for discussions and active support in writing. Our sincere gratitude goes to the respective image copyright owners. This work has been supported by AffecTech: Personal Technologies for Affective Health, Innovative Training Network funded by the H2020 People Programme under Marie Skłodowska-Curie grant agreement No 722022.

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