Check for updates

RaveNET: Connecting People and Exploring Liminal Space through Wearable Networks in Music Performance

Rachel Freire
Sensorimotor Interaction,
Max Planck Institute for Informatics,
Saarland Informatics Campus
Saarbrücken, Germany
and CiTIUS,
University of Santiago de Compostela
Santiago de Compostela, Spain
rfreire@mpi-inf.mpg.de

Courtney N. Reed
Biomedical Engineering & Imaging Sciences
King's College London
London, United Kingdom *and*
Sensorimotor Interaction,
Max Planck Institute for Informatics,
Saarland Informatics Campus
Saarbrücken, Germany
creed@mpi-inf.mpg.de

Valentin Martinez-Missir
Sensorimotor Interaction,
Max Planck Institute for Informatics,
Saarland Informatics Campus
Saarbrücken, Germany
vmartine@mpi-inf.mpg.de

Paul Strohmeier
Sensorimotor Interaction,
Max Planck Institute for Informatics,
Saarland Informatics Campus
Saarbrücken, Germany
pastrohm@mpi-inf.mpg.de

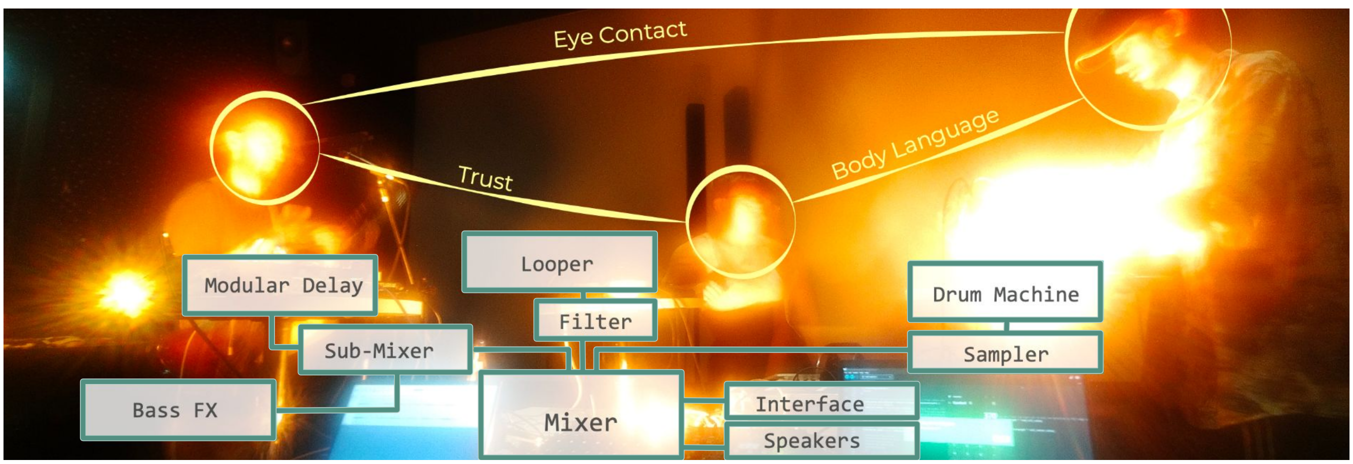

Figure 1: Inaugural RaveNET performance. A collaborative music improvisation consists of different types of networks. There is a network between people of shared sensemaking and communication (yellow). There is also a network of digital technologies and electrical signals (teal). In our design of RaveNET, we aim to create a network situated between these two.

ABSTRACT

RaveNET connects people to music, enabling musicians to modulate sound using signals produced by their own bodies or the bodies of others. We present three wearable prototype nodes in an inaugural RaveNET performance: *Bones*, an anti-corset, uses capacitive sensing to detect stretch as the singer breathes. *Tendons*, a half-glove, measures galvanic skin response, pulse, and movement of the bass player's hands. *Veins*, a cap with electrodes for surface electromyography, captures the facial expressions of the drum machine operator. These signals are filtered, normalized, and amplified to control voltage levels to modulate sound. Together, musicians and nodes form *RaveNET* and engage with shared liminal experiences. In designing these wearables and evaluating them in performance, we reflect on our creative processes, spaces between our different bodies, our presence and control within the network, and how this made us adapt our movements in order to be noticed and heard.

Permission to make digital or hard copies of part or all of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for third-party components of this work must be honored. For all other uses, contact the owner/author(s).
TEI '24, February 11–14, 2024, Cork, Ireland
© 2024 Copyright held by the owner/author(s).
ACM ISBN 979-8-4007-0402-4/24/02.
https://doi.org/10.1145/3623509.3635270

CCS CONCEPTS

• **Applied computing** → *Performing arts*; *Sound and music computing*; *Performing arts*; **Sound and music computing**; • **Human-centered computing** → **Interaction design**; **Gestural input**; **Interaction design process and methods**; *Interaction techniques*; **Interactive systems and tools**.

KEYWORDS

interaction networks, musical performance, wearable sensing, body-based control, biosignals

ACM Reference Format:
Rachel Freire, Courtney N. Reed, Valentin Martinez-Missir, and Paul Strohmeier. 2024. RaveNET: Connecting People and Exploring Liminal Space through Wearable Networks in Music Performance. In *Eighteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '24), February 11–14, 2024, Cork, Ireland*. ACM, New York, NY, USA, 8 pages. https://doi.org/10.1145/3623509.3635270

1 INTRODUCTION

Durkheim regarded the origin of language and culture to be placed in shared ritual [9]. The earliest documented rituals are known to us based on the artifacts involved; for example, the use of red ochre as body paint [38]. In today's culture, many rituals are technologically mediated. Such examples include raves and other electronic music events [36]. The artifacts supporting these rituals consist of networks of analog and digital technology. These technological networks facilitate interconnections between people – what Durkheim might have referred to as collective representation – or what we in the TEI community might describe as shared, embodied experience.

In the spirit of playful exploration, we aim to further connect the artifacts of modern music rituals — the electrical network of power and audio-signals, speakers, mixers, drum-machines, and other electronic instruments — to the network of shared experiences and embodied sense-making between people participating in them (see Figure 1). We intend to design technology that lives inbetween the technological and the human. We do this by enabling human activity to modulate the technological network.

In this work-in-progress report, we present *RaveNET*, a system that quantifies aspects of bodily activities and uses these to manipulate live-audio performances. We designed three prototypes, or nodes for three specific musicians (the co-authors), which constitute the initial version of RaveNET: *Bones*, which measures the extension of Reed's torso as she sings, *Tendons*, which are half-gloves designed for Strohmeier, who uses these for capturing movement and biometric data while playing bass, and *Veins*, which measures Martinez-Missir's facial expressions, using these to modulate the output of a drum machine. For the sake of convenience and integration with systems already in use by the group, the non-wearable aspects of the hardware were made compatible to the popular eurorack format. All design files are open source (https://github.com/sensint/RaveNET) – we invite others to join us in our exploration of liminal spaces.

We share the following contributions: a) the three prototypes and their design process, b) supporting hardware for implementing RaveNET, and c) an examination of this shared network. In our reflection, we expand on one such exploration of how we each attempted to maintain our control and role within the network. We discuss our reactions to the experiential space and how we altered our behavior, sometimes to extremes, in order to create space for ourselves. We conclude with key takeaways from our work-in-progress and next steps to further explore these behaviors and re-implement body mappings for future versions of RaveNET.

2 RELATED WORK

Our ultimate goal is to engage with the experiential body on multiple levels by creating a liminal experience of connectedness; we take inspiration from ritualistic experiences at electronic music events. We also engage with bodies on a sensorimotor and morphological level by creating new sensorimotor couplings and expanding the perceived limits of our body. Finally, we engage with the body very directly in a material manner by designing bespoke wearable devices (cf. Strohmeier et al.'s discussion of the body in HCI [35]).

2.1 Experiential Bodies in Liminal Spaces

Humans organize experiences in a narrative form that requires distinctions or borders to be meaningful: me versus not-me, past versus future, etc. [25]. A liminal space is a space of change within this narrative, a semipermeable reality within which we have enough stability to retain a sense of self without the threat of chaos and disintegration, and, at the same time, enough openness to overcome such borders and distinctions [25]. Liminal spaces occur in different settings, ranging from religious rituals to modern secular shared practices, such as raves. For example, Takahashi and Olaveson discuss raving as a fundamental embodied experience and claim that ravers have an "overpowering sense of social connectedness," which is characteristic of ritual and liminal events [36]. While we argue that such experiences are emergent social phenomena, liminal experiences can also be induced through technological design. For instance, Glowacki et al. presented a VR system that induces a 'mystical-type' experience, characterized by a sense of connectedness, transcendence, and ineffability, in a manner associated with psychedelic drugs ([12], pp. 2).

In our own music practice, we view musical improvisation as a similar liminal space; once a certain flow state is reached, creating music becomes a fluid response to one another, transcending the individual ego. We designed RaveNET to explore the use of technology in manipulating such liminal experiences. We create this liminal space through mapping musicians' movements and biosignals, thus incorporating bodies into the interaction network. We not only use our bodies to manipulate sound physically through playing, but also digitally through modulation. We draw on other notable bio-signal sonification strategies [7, 18, 34] that have also worked to create liminal spaces and connections between humans, instruments, and bodies. Often, this results in experiencing a close connection to the musician or user whose data is being sonified. The presence of sonified bodies in socio-spatial interfaces can, for example, provide physical space to reflect on the privacy of our and others' bodies [18] and foster intimate interactions between strangers [13] and with physical surroundings [30]. A sonification strategy we find particularly interesting is the use of mapped [bio]data to modulate other sounds, rather than direct signal-to-audio sonification [27, 32]. Here, we are particularly inspired by Cyngler, who explored group and individual dynamics within a performance context using EEG

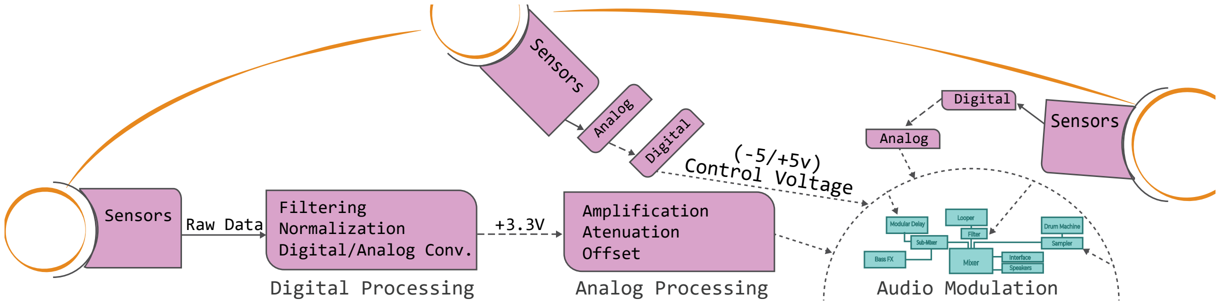

Figure 2: RaveNet (purple) is a network that is positioned between the network of shared experiences and embodied sense-making between people (yellow) and the existing technological network of electrical signals (teal) – see also Figure 1, which displays the human and technological networks in more detail.

[7]. Musicians have experienced such sonification of their own bodies represented through other sounds as coming from an additional entity; this can create a distinction between the self and the body that highlights unconscious behavior [32, 33]. Additionally, other agents are able to experience the physicality and effort in music-making as a way to drive connection between people [31].

2.2 Interactive Garment Design

Interactive garment design is a way to measure and extend our movements and actions [22], for example by augmenting artistic expression [34]. Data expressions can be outward facing and performative [16], used to communicate the movement of others' bodies between people [20], or be more inward facing and reflective [4, 5]. The garment itself often becomes a character within the story or performance [17, 19]. As such, garments are a part of social expression and interaction with others; similar work in wearable data externalization explored how users alter their behavior and how design can be refined iteratively using to social interaction as a guide [15]. Each of these systems requires similar cycles of iteration and refinement to unify garment with technologies.

Bridging concept design and fabrication, pattern-making draws on a lineage of notation and craftsmanship and a constant communication and refinement of techniques. Foundational 'blocks' and subsequent patterns are a "mathematical extraction of a spatial knowledge that is systematized so it can be reproducible and shared" [26]. Such patterns now extend into notations for circuit design [10, 23] to create maps and methods [21] for new technological garment hybrids. In this process, the subtlety of material properties and their influence on the experience of wearing technology cannot be separated [21]. Considerations such as user fit and aesthetic language all contribute to how a design is approached. The garment must be designed sympathetically to potential influences or restrictions on the wearer [19].

Gestural musical interfaces such as the MiMU gloves focus on precision, system reliability, and error minimization [3]. In contrast, the wearables to comprise RaveNET require a robust output but were approached with the aim to explore a more open-ended ambiguity and the potential for meaning-making and interpretation — as Gaver says "evocative rather than didactic, and mysterious rather than explicit" [11] — for both the self and others within the network.

2.3 Networked & New Instruments

While RaveNET is a network, it is explicitly designed for in-person co-located interaction. Other research in networked music performance has been centered around geographically distant artists [1, 40], but similarly explores tension between the communicative, aesthetic qualities of musical interaction and technical constraints [39] and new ritualistic behaviors [37].

Individual RaveNET nodes build upon a strong tradition of experimentation with sensors and digital technology to create new musical instruments. We trace our ideas back to the seminal *Hands* by Waisfisz [24], followed by instruments such as *Midi Conductor*, played by van der Heide in Sensorband [2], and *Lady's Glove*, played by Sonami. The use of interactive gloves as music controllers gained mainstream attention with Imogen Heap's *MiMU* gloves [28]. Our *Tendons* prototype builds directly upon these. Tendons uses the original MiMU open-source glove pattern designed by Freire and Perner-Wilson [14]. Similarly, *Bones* builds on previous work to capture vocalists' body movements in performance, notably the Body Electric [6], Corsetto [20], and the Singing Knit [34]. However, the intended *use* of the RaveNET nodes differs from much of the previous work. RaveNET is not primarily designed as an instrument but rather as a source of signals for modulating music created with more traditional instruments.

3 IMPLEMENTING RAVENET

RaveNET consists of *nodes*, which are wearable sensing elements, each with a digital and analog signal processing component. These nodes are constructed using inherent elements of garment technology as a second skin [10]. We use the nodes to encourage a more fluid understanding of these partial garments as part of a wider system, rather than individual wearable technologies. A node enables the connecting of biometric or movement data as a modulation source for audio-effects or audio-synthesis. In our implementation, the analog signal processing is always co-located with the audio-source that is being manipulated (Figure 2). Multiple nodes can connect to audio in various topologies depending on the network between musicians, other performers, or even audience members. In this simplest case, a musician might modulate their own instrument's output; for instance, controlling an analog voltage-controlled low-pass filter with their movement. One might also imagine a centralized network, in which one performer uses

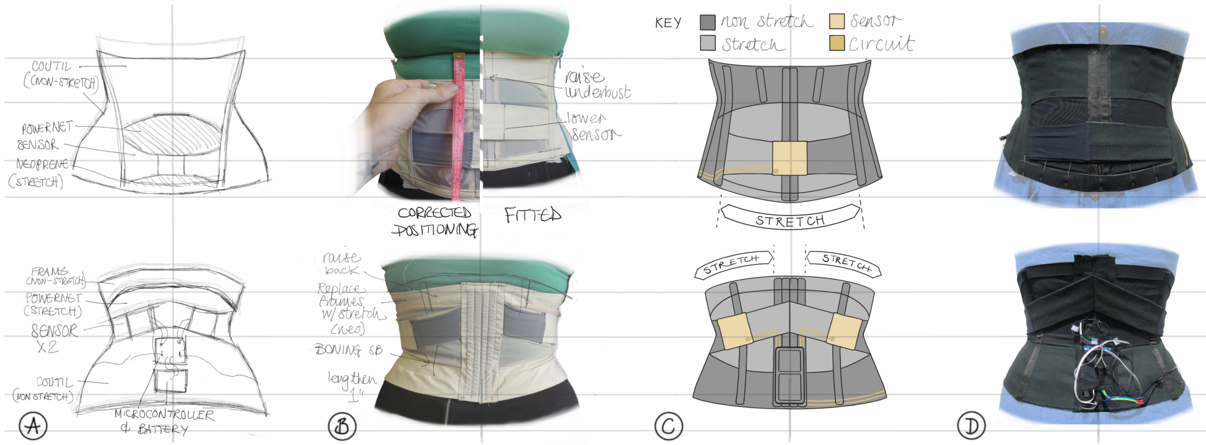

Figure 3: Overview of BONES. A: Initial design sketch. B: Toile. C: Revised Design. D: Prototype

the movements of others, for instance their bandmates or a wider audience, to modulate their instruments in a many-to-one mapping. Another scenario might involve a soloist or dancer's movements connected to a band (one to many), or, in a band, each member's instrument might be connected to each other member (fully connected). RaveNET supports such arbitrary network topologies.

While we imagine bespoke nodes which adapt to the individual musician and their practice, they all share a common processing pipeline. Sensors are sampled digitally, signals are normalized and filtered, before being passed to a set of analog processing modules. This analog stage enables amplification to CV level, but also shaping of the signal so that it corresponds to both the artistic intent of the musician and the signal requirements of the target device. From there it connects to any voltage controllable component of the technological network.

We intend for the RaveNET nodes to serve as the artifacts which support future ritual music practices. In the following section we introduce the first three nodes created for RaveNET, which we designed around our (the authors) existing practice. We have worked and performed together for the last year and a half and have built the nodes with our group, existing relationships, and individual instruments in mind. Reed is a vocalist, Strohmeier a guitarist/bassist, and Martinez-Missir a drum machine operator. We utilize an existing network of various music technology in our performances (Figure 1); Reed uses a looper to layer her voice and add effects processing, Strohmeier uses a variety of pedals and modular synthesizers, and Martinez-Missir uses a combination of digital drum machine and eurorack sound processor setup. We perform in an improvisatory setting, without clear structure, and generally follow whoever wants to lead. This results in a variety of performances, but they are often led by one of us, with the others supporting. The nodes were created to fit into this existing context.

3.1 Node Implementation

Each node was implemented through a garment design process by Freire, an expert in textiles, costumes, and electronic garments, in conversation with Reed, Strohmeier, and Martinez-Missir. Each node was co-designed to the unique requirements of the musician via an iterative toiling process. A *toile* is a term used in garment making to describe a textile shell used for physical design development, creating an accurate pattern which fits the garment to the body. The final design is then fabricated using the information from the toile. Construction aspects, such as seams, must be considered when routing wires and often become structural functional features. For the nodes' functionality and aesthetics, our aim was simplicity and stability during performance [17, 34]. A well-integrated design leverages the features of textile engineering harmoniously with the electronics design and sensor placement [41].

3.1.1 Bones. A corset-like wearable for Reed to measure the expansion and contraction of her abdomen while she sings:

Requirements: Reed is a classically trained vocalist and wanted to measure how their body changes shape while singing, specifically the abdomen and back with breathing. Reed explained the anatomy of controlled breathing so we could identify the parts of the garment that would need to move. We focused on the expansion of the diaphragm; the movement is located in her lower belly at hip height and her mid back, immediately below her rib cage. We devised a structured garment with both practical and aesthetic considerations. The design and restriction of a corset seems antithetical to the freedom of movement required by a singer, but we discussed the nature of a powerful visual silhouette and the collaborative notion of a support garment with physical parameters to 'push' against to feel the body.

Implementation: While a corset is typically engineered to reduce the waist, flatten the stomach and compress/lift the breast, we designed Bones as an "anti-corset" inversion – a garment which maximizes stretch and movement in these areas. We designed a capacitive sensing solution to measure the extension of Reed's torso. Integrated, overlapping sheets of conductive material are superimposed when Reed has fully exhaled; when she inhales, they are offset from one another. We infer the extent of overlap by measuring the capacitance between the two conductive sheets. The controlled structural engineering of a corset can constrain certain parts of the body to maximize movement in the locations where we intended to place the sensors. The sensors are located on top

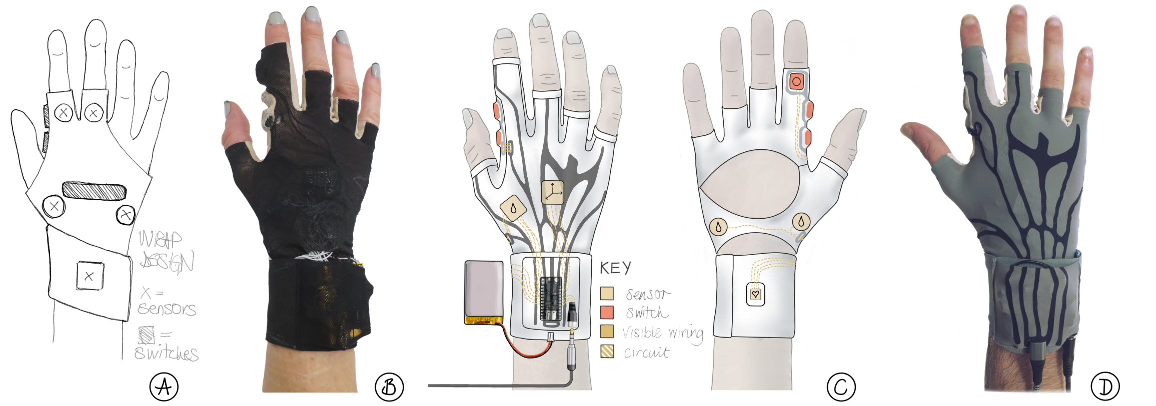

Figure 4: Overview of TENDONS. A: Initial design sketch. B: Toile. C: Revised Design. D: Prototype

of stretch panels at the front hip and mid back (Figure 3), with non-stretch control' panels to maximize movement in the active areas.

We used a hybrid design approach with highly structured, non-stretch side panels and a fixed waist measurement, combined with softer elements - similar to a stretchy supportive medical corset - using 4-way technical knit materials with high tensile strength and stable stretch recovery. These panels create a balance of tension in the overall garment while allowing the sensors a controlled range of movement. The design uses powernet and a neoprene-like rubber to allow controlled stretch at the lower front abdomen and upper back panels where pairs of conductive pads are placed. When Reed breathes, the amount of overlap between the pad changes. We measure this change for inferring expansion of the abdomen. The current prototype reliably produces at least 7mm change in overlap. The non-stretch side panels are made from coutil, a dense, low profile herringbone weave used in traditional corsetry.

3.1.2 Tendons. A sensorized glove for Strohmeier to measure incidental movements, arousal, and pulse while playing bass guitar:

Requirements: One of Strohmeier's goals in his personal setup is creating as much sound as possible, using creative signal routing to create multiple sounds concurrently with his singular instrument. Because Strohmeier uses his hands to play, he argued that these implicit movements would already be meaningfully connected to his music making. Similar in functionality to effects pedals, he requested 'switches' to change states easily whilst playing. Strohmeier wanted to use his hand to both explicitly and implicitly manipulate sound and use his more abstract physiological data to create broader atmospheric sound and distortion. The glove should also not occlude his fingertips or interfere with the bass' strings.

Implementation: Tendons is a form fitting glove with sensors at the fingers, palm, wrist, and back of Strohmeier's hand. It is made from layers of thin, stretchy high performance sportswear materials. The multi-layered textile is designed to sandwich and protect the electronics as well as route the connecting wires around the hand without limiting movement whilst he plays. The glove is the most intricate of the three garments due to scale and the placing of the sensors on the complex surfaces of the hand. It also contains the most sensors: pulse, galvanic skin response (GSR), an IMU and three buttons.

A rough placement of sensors was physically mapped onto Strohmeier's hand whilst holding his bass, to better understand the small affordances of gloves and which parts of the hands could not be obstructed whilst playing. An initial toile used a single piece wraparound cuff design to tension sensors at the wrist and palm. This proved too bulky for Strohmeier, influencing his ability to play his instrument. This toile provided information for sensor placement and a more traditional glove and cuff pattern was created. This toile was fitted and the textile annotated to finalize sensor placement. The optimum recommended placement of some sensors (on the inner index or middle fingers) did not allow enough freedom of movement while Strohmeier played bass, so they were adapted, miniaturized and re-fitted. The GSR electrodes became customized dry electrodes mounted in a mesh strap on the glove's palm. The pulse sensor moved from finger to wrist. Buttons were mounted on the side and inner index finger, to be easily pressed by Strohmeier using his thumb. The IMU was placed between the layers of fabric on the back of the hand.

Tendons is made from 4-way stretch technical knit fabrics selected for breathability and good stretch recovery. The cuff is made from Yulex Airprene, a natural rubber with the same tensile strength as neoprene. Yulex has a cushioning property which acts as a barrier between hard electronics and the skin, giving protection for the electronics and comfort for the wearer. The pattern used for Tendon's is based on the pattern Freire designed for the MiMU glove (cf. [28]).

This iteration process focused on the glove feeling as invisible as possible. An enjoyable contrast to this was Strohmeier's request to 'make it look cool'. Aesthetics and color were curated by available materials, which were ultimately selected for their specific functionality. Within these constraints, the visual detailing on the glove fuses a visual and practical aesthetic, blending the shapes of the tendons of the human hand with the structural reinforcement required to support the electronics and route the cables.

3.1.3 Veins. A head-worn device to capture Martinez-Missir's subtle facial movements and expressions while obscuring his face:

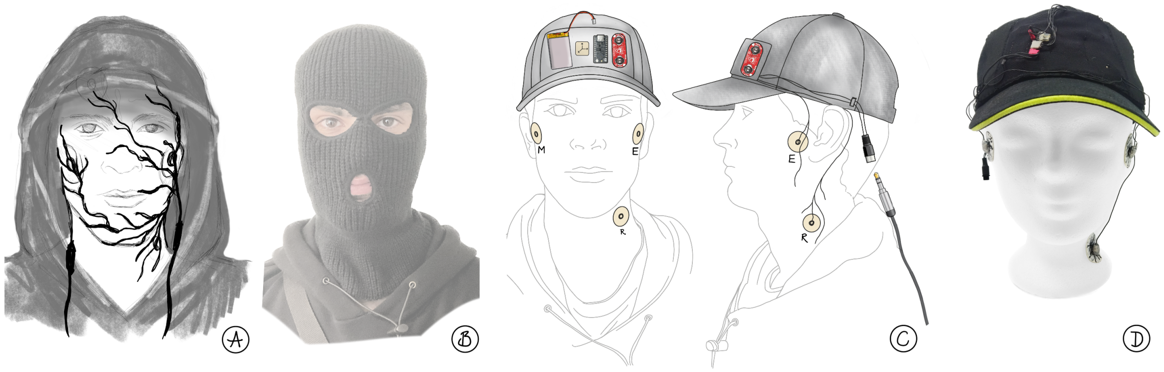

Figure 5: Overview of VEINS. A: Initial design sketch. B: Toile. C: Revised Design. D: Prototype

Requirements: Martinez-Missir uses modular synthesizers and drum machines to produce and perform electronic music. He is most familiar with solo composition, but expressed a wish to become more accustomed to live performance. He noted that his musical practice can feel more mediated and externalized, compared to more "traditional" instruments, and wanted to augment the format of knobs and switches to include something more intuitive and unusual. Martinez-Missir describes himself as a "music practitioner", viewing his live creation from a technical rather than performative perspective. This distinction frames his initial request of a mask to obscure the face and sensing which is subtle and not 'too gimmicky'.

The cultural reference point was both activism and anonymity at raves and parties, while the conceptual aim was to create a controlled disconnection between his music and other parts of his identity. His desire for anonymity was expressed from both external and internal perspectives; to obfuscate himself from the audience but also to facilitate an internal sense of detachment that can be used as a tool: "It disconnects you from the audience, you from yourself." Testing various sensors helped to decide what data capture felt most natural and unobtrusive. We decided on the use of electromyography (EMG) to capture subtle facial movements using electrodes on his cheek muscles.

Implementation: The conversation began with visual references to visceral organic body-horror aesthetics such as Cronenberg and Carpenter, in stark contrast to the more subtle and non-theatrical aspects of the design brief. Through sensor placement tests, observing signal output and physical movement, the design concept progressed from a full mask or balaclava to a partial mask and eventually to a hat with extended tentacles. The brim of a cap creates shadow on the face without completely obscuring the features. This design made more stylistic sense; the cap also provided a stable physical base for the electronics, which did not restrict the neck.

A classic baseball cap was customized, attaching electronics to the brim and front to visibly integrate it into the design, in place of a logo or decoration. We then added customized electrodes extending through the brim which could be applied to the face as an extension of the garment. To visually integrate the electrodes, the wires and snaps were encased in clear DragonSkin prosthetic silicone. Extra fine decoration was added with a tattoo gun to give the impression of branching veins'. This served to visually diffuse the bulkier electrode wires and help integrate the sensors into the face, creating some visual disruption. The veins connecting the electrodes are secured to the face with a body-safe glue. A standard jack connector is broken out from the electronics on the brim and run around the edge of the cap to the back of the head to connect to the rest of the network.

4 REFLECTIONS & DISCUSSION

As a group, we discussed our perspectives using our respective nodes after an inaugural performance (see Figure 1 and video-figure in this paper's Supplemental Material). We utilized an auto-biographical framing and reflected on the design as it functioned in our existing performance practice [29]. From a purely physical design perspective, each of the prototypes was successful in that they allowed us to interact and modulate sound; the nodes themselves functioned and were stable. One main subjective thread in this shared experience was our awareness of our control and role within the network through the nodes. We found that each of us was worried about our presence in the group; although we internally felt our action and presence through our own node, there was a level of insecurity about how we were externally understood by the others to be contributing to the shared experience.

We each tried to make things as explicit as possible within our own performance; still, it was sometimes hard to tell how the movements and mapped signals were functioning across the group. We found at times that, when we knew our own signal was being used, an onlooker was not able to understand the connection or contribution to the network, even when we could clearly understand the connection and felt in control. For example, in testing the final iteration of Veins, Martinez-Missir very excitedly described that it was working, but Strohmeier and Freire were not able to hear it. Externally, the non-obvious movement and resulting action-sound link proved to be troublesome in testing and interaction. Utilizing "middle" movements — not pushing our bodies to their extreme points — was difficult; although felt strongly within each body, outside of that body the interaction became less obvious. Reed similarly described how she felt covered over at points because her breathing-based interaction was more externally subtle than the other controllers. Strohmeier noted a mismatch between the movement range Tendons was calibrated for and the movement range he wanted to use. To better understand how they effected the music, he even stopped playing the bass and instead used the glove as his main instrument.

We discussed as a group how easy it was to overextend ourselves for the sake of creating space and bringing attention to ourselves — Reed reported feeling lightheaded at points from exaggerated breathing while Martinez-Missir had jaw pain following one of the performances. From Reed and Martinez-Missir's perspectives, Strohmeier's hand movements appeared to offer an advantage because they could be more overt; however, Strohmeier noted that this type of movement was actually not what he and Freire were going for throughout the design, but in the performance he felt the need to move in this way to make sense of and understand if and how Tendons was working. We noted that, while scaling our outputs to a noticeable level could have been done computationally, we unintentionally scaled up our body movements.

The original intention was that the nodes should vanish and become part of the background of the performance; instead, they became instruments and we played them with with these unexpected, deliberate actions. Each of us felt in this context that the nodes were very chaotic and we needed to physically learn to use them, rather than the intended behavior of utilizing existing movements in our musical practice. Within the performance context and the existing network between us, finding meaningful ways of using the signals was unexpectedly difficult. This tension between intention and in-context reaction to the nodes presents an opportunity to explore ways to fully integrate the presence of our bodies.

4.1 Future Work & Conclusion

As Martinez-Missir noted, "I wanted the nodes to vanish, to just be part of the background. Instead they became instruments, I played them with intention. Even though we played them deliberately and with intention, they were very chaotic, and it felt like I needed to learn to use them." Similar sentiments were shared by the rest of the group. A positive result of this interaction was that the overwhelming presence of the nodes made us focus on our music in a new way: struggling with the performance made us create something unlike the music we had played before. The initial experiments creating music within the network as an ensemble were more fragile, trance-like, and poetic than previous music improvisations.

In further development of RaveNET and these particular nodes, our learning will continue to shape this liminal space and our experience of it. For instance, we can leverage existing frameworks for evaluating the design of social wearables, such as that presented by Dagan et al. [8]. Such frameworks focusing on augmenting and not detracting from the interaction would provide grounding to address issues of control, over-extension, and insecurities related to not being seen in the performance. Eventually, the network could also be extended beyond our immediate musicking bodies to incorporate the presence and impact of other co-located agents, such as the audience or environment itself, in the network [13, 37]. The most immediate steps will involve further iterations of the wearables, centered on these larger implications of our interaction as presented here and opening the integration of such a system to potential non-hardware setups for facilitating a broader audience of performers. Overall, we are excited by this project and the design reflections it has driven so far. We aim to engage and share our process and the current state of this with the TEI community – for example by providing all patterns, code & schematics in our GitHub Repository (https://github.com/sensint/RaveNET) – while looking forward to continued exploration of RaveNET.

ACKNOWLEDGMENTS

Courtney N. Reed is supported by the European Research Council Advanced Grant (AdG) project "COSMOS: Computational Shaping and Modeling of Musical Structures" (No. 788960).

REFERENCES

[1] Álvaro Barbosa. 2003. Displaced Soundscapes: A Survey of Network Systems for Music and Sonic Art Creation. *Leonardo Music Journal* 13 (Dec. 2003), 53–59. https://doi.org/10.1162/096112104322750791

[2] Bert Bongers and Sensorband. 1998. An Interview with Sensorband. *Computer Music Journal* 22, 1 (1998), 13–24.

[3] Dominic Brown. 2020. *End-user action-sound mapping design for mid-air music performance.* Ph. D. Dissertation.

[4] Sophia Brueckner and Rachel Freire. 2018. Embodisuit: A Wearable Platform for Embodied Knowledge. In *Proceedings of the 2018 ACM International Symposium on Wearable Computers* (Singapore, Singapore) *(ISWC '18)*. Association for Computing Machinery, New York, NY, USA, 242–247. https://doi.org/10.1145/3267242.3267297

[5] Kelsey Cotton, Pedro Sanches, Vasiliki Tsaknaki, and Pavel Karpashevich. 2021. The Body Electric: A NIME designed through and with the somatic experience of singing. In *Proceedings of the International Conference on New Interfaces for Musical Expression*. Shanghai, China, Article 27. https://doi.org/10.21428/92fbeb44.ec9f8fdd

[6] Kelsey Cotton, Pedro Sanches, Vasiliki Tsaknaki, and Pavel Karpashevich. 2021. The Body Electric: A NIME designed through and with the somatic experience of singing. In *Proceedings of the International Conference on New Interfaces for Musical Expression*. Shanghai, China, Article 27. https://doi.org/10.21428/92fbeb44.ec9f8fdd

[7] Richie Cyngler. 2017. Music for Various Groups of Performers (After Lucier): An Improvised Electroencephalographic Group Performance. In *Proceedings of the 2017 ACM SIGCHI Conference on Creativity and Cognition* (Singapore, Singapore) *(C&C '17)*. Association for Computing Machinery, New York, NY, USA, 462–465. https://doi.org/10.1145/3059454.3073725

[8] Ella Dagan, Elena Márquez Segura, Ferran Altarriba Bertran, Miguel Flores, Robb Mitchell, and Katherine Isbister. 2019. Design Framework for Social Wearables. In *Proceedings of the 2019 on Designing Interactive Systems Conference (DIS '19)*. ACM. https://doi.org/10.1145/3322276.3322291

[9] Lorenzo D'Orsi and Fabio Dei. 2018. What is a rite? Émile Durkheim, a hundred years later. *Open Information Science* 2, 1 (2018), 115–126. https://doi.org/doi:10.1515/opis-2018-0009

[10] Rachel Freire, Cedric Honnet, and Paul Strohmeier. 2017. Second Skin: An Exploration of ETextile Stretch Circuits on the Body. In *Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction* (Yokohama, Japan) *(TEI '17)*. Association for Computing Machinery, New York, NY, USA, 653–658. https://doi.org/10.1145/3024969.3025054

[11] William W. Gaver, Jacob Beaver, and Steve Benford. 2003. Ambiguity as a Resource for Design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Ft. Lauderdale, Florida, USA) *(CHI '03)*. Association for Computing Machinery, New York, NY, USA, 233–240. https://doi.org/10.1145/642611.642653

[12] David R. Glowacki, Mark D. Wonnacott, Rachel Freire, Becca R. Glowacki, Ella M. Gale, James E. Pike, Tiu de Haan, Mike Chatziapostolou, and Oussama Metatla. 2020. Isness: Using Multi-Person VR to Design Peak Mystical Type Experiences Comparable to Psychedelics. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3313831.3376649

[13] Ge Guo, Gilly Leshed, and Keith Evan Green. 2023. "I normally wouldn't talk with strangers": Introducing a Socio-Spatial Interface for Fostering Togetherness Between Strangers. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23)*. ACM. https://doi.org/10.1145/3544548.3581325

[14] Hannah Perner-Wilson. Accessed: 2023-11-23. The Gloves Project. https://theglovesproject.com/.

[15] Kate Hartman, Boris Kourtoukov, Izzie Colpitts-Campbell, and Erin Lewis. 2020. Monarch V2: An Iterative Design Approach to Prototyping a Wearable Electronics Project. In *Proceedings of the 2020 ACM Designing Interactive Systems Conference (DIS '20)*. ACM. https://doi.org/10.1145/3357236.3395573

[16] Kate Hartman, Jackson McConnell, Boris Kourtoukov, Hillary Predko, and Izzie Colpitts-Campbell. 2015. Monarch: Self-Expression Through Wearable Kinetic Textiles. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction* (Stanford, California, USA) *(TEI '15)*. Association for Computing Machinery, New York, NY, USA, 413–414. https://doi.org/10.1145/2677199.2690875

[17] Kate Hartman, Nick Puckett, and Adam Tindale. 2023. Designing Wearable Technology for Opera. In *Proceedings of the 2023 ACM Designing Interactive Systems Conference (DIS '23)*. ACM. https://doi.org/10.1145/3563657.3596113

[18] Noura Howell, Greg Niemeyer, and Kimiko Ryokai. 2019. Life-Affirming Biosensing in Public: Sounding Heartbeats on a Red Bench. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–16. https://doi.org/10.1145/3290605.3300910

[19] Pavel Karpashevich, Eva Hornecker, Michaela Honauer, and Pedro Sanches. 2018. Reinterpreting Schlemmer's Triadic Ballet: Interactive Costume for Unthinkable Movements. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal, QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3173574.3173635

[20] Ozgun Kilic Afsar, Yoav Luft, Kelsey Cotton, Ekaterina R. Stepanova, Claudia Núñez Pacheco, Rebecca Kleinberger, Fehmi Ben Abdesslem, Hiroshi Ishii, and Kristina Höök. 2023. Corsetto: A Kinesthetic Garment for Designing, Composing for, and Experiencing an Intersubjective Haptic Voice. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 181, 23 pages. https://doi.org/10.1145/3544548.3581294

[21] Jarrod Knibbe, Rachel Freire, Marion Koelle, and Paul Strohmeier. 2021. Skill-Sleeves: Designing Electrode Garments for Wearability. In *Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction* (Salzburg, Austria) *(TEI '21)*. Association for Computing Machinery, New York, NY, USA, Article 33, 16 pages. https://doi.org/10.1145/3430524.3440652

[22] Jarrod Knibbe, Paul Strohmeier, Sebastian Boring, and Kasper Hornbæk. 2017. Automatic Calibration of High Density Electric Muscle Stimulation. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 1, 3, Article 68 (sep 2017), 17 pages. https://doi.org/10.1145/3130933

[23] Kobakant. Accessed: 2023-10-06. How To Get What You Want. https://www.kobakant.at/DIY/?cat=179.

[24] Volker Krefeld and Michel Waisvisz. 1990. The Hand in the Web: An Interview with Michel Waisvisz. *Computer Music Journal* 14, 2 (1990), 28–33.

[25] Johan Liedgren, Pieter Desmet, and Andrea Gaggioli. 2023. Liminal design: A conceptual framework and three-step approach for developing technology that delivers transcendence and deeper experiences. *Frontiers in Psychology* 14 (02 2023), 1043170. https://doi.org/10.3389/fpsyg.2023.1043170

[26] Rickard Lindqvist. 2015. *Kinetic garment construction: Remarks on the foundations of pattern cutting*. Vol. 13. Rickard Lindqvist.

[27] Mary Mainsbridge. 2022. Feeling Movement in Live Electronic Music: An Embodied Autoethnography. In *Proceedings of the 8th International Conference on Movement and Computing* (Chicago, IL, USA) *(MOCO '22)*. Association for Computing Machinery, New York, NY, USA, Article 13, 7 pages. https://doi.org/10.1145/3537972.3537989

[28] Thomas J Mitchell, Sebastian Madgwick, and Imogen Heap. 2012. Musical interaction with hand posture and orientation: A toolbox of gestural control mechanisms. (2012).

[29] Carman Neustaedter and Phoebe Sengers. 2012. Autobiographical Design in HCI Research: Designing and Learning through Use-It-Yourself. In *Proceedings of the Designing Interactive Systems Conference* (Newcastle Upon Tyne, United Kingdom) *(DIS '12)*. Association for Computing Machinery, New York, NY, USA, 514–523. https://doi.org/10.1145/2317956.2318034

[30] Binh Vinh Duc Nguyen, Jihae Han, Maarten Houben, Yssmin Bayoumi, and Andrew Vande Moere. 2023. Engaging Passers-by with Rhythm: Applying Feedforward Learning to a Xylophonic Media Architecture Facade. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23)*. ACM. https://doi.org/10.1145/3544548.3580761

[31] Aura Pon, Eric Pattison, Lawrence Fyfe, Laurie Radford, and Sheelagh Carpendale. 2017. Torrent: Integrating Embodiment, Physicalization and Musification in Music-Making. In *Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction* (Yokohama, Japan) *(TEI '17)*. Association for Computing Machinery, New York, NY, USA, 209–216. https://doi.org/10.1145/3024969.3024974

[32] Courtney N. Reed and Andrew P. McPherson. 2021. Surface Electromyography for Sensing Performance Intention and Musical Imagery in Vocalists. In *Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction* (Salzburg, Austria) *(TEI '21)*. Association for Computing Machinery, New York, NY, USA, Article 22, 11 pages. https://doi.org/10.1145/3430524.3440641

[33] Courtney N. Reed and Andrew P. McPherson. 2023. The Body as Sound: Unpacking Vocal Embodiment through Auditory Biofeedback. In *Proceedings of the Seventeenth International Conference on Tangible, Embedded, and Embodied Interaction* (Warsaw, Poland) *(TEI '23)*. Association for Computing Machinery, New York, NY, USA, Article 7, 15 pages. https://doi.org/10.1145/3569009.3572738

[34] Courtney N. Reed, Sophie Skach, Paul Strohmeier, and Andrew P. McPherson. 2022. Singing Knit: Soft Knit Biosensing for Augmenting Vocal Performances. In *Proceedings of the Augmented Humans International Conference 2022* (Kashiwa, Chiba, Japan) *(AHs '22)*. Association for Computing Machinery, New York, NY, USA, 170–183. https://doi.org/10.1145/3519391.3519412

[35] Paul Strohmeier, Henning Pohl, Jess Mcintosh, Aske Mottelson, Jarrod Knibbe, Yvonne Jansen, Joanna Bergström, and Kasper Hornbæk. 2022. *Body-Based User Interfaces* (1 ed.). Vol. 1. Routledge, 478.

[36] Melanie Takahashi and Tim Olaveson. 2003. MUSIC, DANCE AND RAVING BODIES: RAVING AS SPIRITUALITY IN THE CENTRAL CANADIAN RAVE SCENE. *Journal of Ritual Studies* 17, 2 (2003), 72–96. http://www.jstor.org/stable/44368995

[37] Femke Vandenberg, Michaël Berghman, and Julian Schaap. 2020. The 'lonely raver': music livestreams during COVID-19 as a hotline to collective consciousness? *European Societies* 23, sup1 (Sept. 2020), S141–S152. https://doi.org/10.1080/14616696.2020.1818271

[38] Ian Watts. 2009. *Red ochre, body-painting, and language: interpreting the Blombos ochre*. 62–92.

[39] Gil Weinberg. 2005. Interconnected Musical Networks: Toward a Theoretical Framework. *Computer Music Journal* 29, 2 (June 2005), 23–39. https://doi.org/10.1162/0148926054094350

[40] Rebekah Wilson. 2020. Aesthetic and technical strategies for networked music performance. *AI & SOCIETY* 38, 5 (Nov. 2020), 1871–1884. https://doi.org/10.1007/s00146-020-01099-4

[41] Clint Zeagler. 2017. Where to wear it: functional, technical, and social considerations in on-body location for wearable technology 20 years of designing for wearability. In *Proceedings of the 2017 ACM International Symposium on Wearable Computers (UbiComp '17)*. ACM. https://doi.org/10.1145/3123021.3123042