Politics of Gear: Gender, innovation and live embodied composition

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Within computer-based and live electronic music, the values of competition, power, control and innovation dominate. Women continue to be under-represented in technical roles across production, management and software development. To address this imbalance, I examine how feminist frameworks and values can be applied to challenging the biases that influence uneven gender distribution within music technology development. Focusing on live embodied composition and computing where performative and design roles intersect, I explore the work of women composers who design or co-create bespoke systems that feature the body, reimagining the norms of music technology development while exposing insights about gender, race and body types in the sound and music industries. Referencing the work of Laetitia Sonami and Lauren Sarah Hayes, I argue that their embodied design practices constitute a type of activism that promote the feminist values of human computer interaction (HCI), including collaboration, transparency and empathy, countering dominant audio equipment and software design values oriented towards precise, perfected and disposable designs created in a hierarchical fashion.

1. INTRODUCTION

Within this article, I examine the culture and values surrounding music technology design. Reflecting on performance-based research in embodied musical interaction, I explore body-centred musical practice involving artist-designed instruments and motion-tracking systems that challenge existing tropes in digital musical instrument (DMI) and software design. Focusing specifically on the embodied approaches of performer-composers Lauren Sarah Hayes and Laetitia Sonami, I analyse how both artists repurpose and reimagine existing sensor technology for their own artistic ends, envisaging new types of uses and functions fed by diverse experiences and backgrounds. As part of their creative practice, Hayes and Sonami embrace collaborative methods, bypassing the centralised and hierarchical nature of commercial music technology development while challenging the myth of technological innovation as the domain of an individual lead designer or team (Constanza-Chock 2020: 14). Instead, they join a broader community of artists and collaborators who evaluate and recycle existing technology through real-world experimentation. Their user-led design practices also confront common values of precision, speed, low latency, slick production values and optimum control promoted in online discussions and marketing materials for commercial audio products. Through live embodied composition and improvisation, Hayes and Sonami adapt borrowed, repurposed and customised objects, interfaces and systems, refining and reshaping them through ongoing performances in vastly different performance environments to suit their artistic needs.

This article begins with an overview of how prevalent values underpinning commercial music hardware and software design influence audiotechnical discourse and workforce participation. A critique of dominant values prevalent in the field follows, accompanied by an exploration of how an emphasis on competition, innovation and fetishisation of equipment shapes technological invention. An analysis of musicians who contradict these norms through embodied reimagination of established values in music technology and sound art reveals approaches with a commitment to collaboration and transparency. Artists Hayes and Sonami, in their long-term engagement with embodied interfaces, embrace alternative values aligned with feminist human computer interaction (HCI), as outlined in the design agenda set out by Shaowen Bardzell (2010). Aligned with the central feminist tenets of cooperation, empathy, equity, diversity and inclusion, elements of Bardzell's vision can be found in the practical design approaches of both artists. These qualities are linked to a growing awareness of the social and cultural impact of HCI in feminist social science research, pursuing individual and social change while questioning the status quo (Bardzell and Bardzell 2011). The key aspect of this mission is to work openly and transparently with collaborators and to advocate for more diverse and equal representation of musicians of different abilities, genders, ages and cultural backgrounds in the new interfaces for musical expression (NIME) community (Hayes and Marquez-Borbon 2020).

The personal and subjective design methods adopted by Hayes and Sonami share similarities with

a range of related human-centred design approaches that draw on varied perspectives, including participatory design (PD), which emerged in Scandinavia in the 1960s and 1970s, and empathic user research (Wright and McCarthy 2008), where the scientific separation between researcher and subject is foregone to encourage designs informed by belonging, empathy, care and other aspects of human connection. In adopting the roles of researcher, designer and user, Hayes and Sonami create individualised performance systems influenced by embodied experience. Rather than simply channelling measurable physical movement and energy into gestural data, Hayes (2023: 29–30) integrates collaborative musicking and participatory instrument design scenarios in her recent work.

Both Sonami and Hayes also blend the overlapping roles of performer, composer, sound engineer and software developer, challenging the prevailing division of labour in the music industry that sees a higher concentration of men in technical positions. Such vocalist-composers, according to Hannah Bosma (2013: 218), 'combine feminine cultural practices of singing and performance with the masculine cultural domains of avantgarde, authorship, composing, and technology'. This fluid movement between roles provides the inspiration for alternative speculative approaches to technological development instigated by artistic work founded on embodied musical interfaces. These ideas, underpinned by autoethnographic accounts that document and frame a range of embodied sensations and design concepts, are explored in the final section.

2. GENDERED AUDIO

Research into embodied musical systems has recently highlighted the social aspects of the design and creative practices underlying live performances. Intersecting body and gear politics, the technocentric field encompasses commercial, open source and do-it-yourself (DIY) technological development in DMI and software design. As in the related engineering and computer science realms, there is an increased focus on the under-representation of women, trans and non-binary individuals, as well as people of colour in electronic music, sound art and audio technology (Goh and Thompson 2021). Linda O'Keeffe and Isabel Nogueira (2023: 1) highlight how the cultures of racism, sexism and ableism shape practitioner bodily and professional experiences in sonic art, dance and music within the anthology *The Body in Sound, Music and Performance: Studies in Audio and Sonic Arts.* Women from diverse backgrounds who rarely receive keynote, speaking or book chapter invitations were invited to share their expertise in the edited collection (ibid.: 4), detailing the strategies they have devised to

overcome a sense of exclusion from the sound, music and performance practice areas.

Within the book, Hayes (2023: 24) reflects on her own embodied performance and improvisation practice with personalised instruments, moving beyond the 'individualistic formulations and hierarchical structures' of the music industry and academy. Questioning the dominance of 'able-bodied, white, cis-male bodies functioning in highly competitive – as opposed to collaborative domains,' Hayes (ibid.: 33), embraces collective approaches to music-making. Her practice-based research extends to developing instruments with a range of communities, including children, vulnerable adults and individuals with learning challenges (ibid.: 24). This work is explored further in section 5, which summarises the embodied research and creative workflows of both Hayes and Sonami.

To gain a deeper understanding of the context of their work, it is worthwhile outlining the sociopolitical aspects of the related audio software development, computer music and sound fields. Like the software industry in Silicon Valley, the predominant makeup of the design, leadership and executive workforce in audio software development remains primarily concentrated in specific areas of the northern hemisphere, including Berlin, Stockholm, Paris and the San Fransisco Bay area (Magnusson 2019: 229). The main research-based ACM Human Factors in Computing Systems (ACM) community also centres around Europe and the United States (Hayes and Marquez-Borbon 2020).

In their study of audio industry professionals, Brooks et al. (2021: 250) confirm lower participation levels among women and other marginalised groups in studio-based production, confronting critiques that individuals in these categories need to 'toughen up' to adapt to the rigours of a highly competitive industry where only the most meritorious and thick-skinned are deemed worthy of success. Brooks et al. (ibid.: 249) identify the presence of typically masculine workplace behaviours such as control, assertiveness, competitiveness and ruthlessness, which inhibit wider participation. Not only are women producers under-represented and under-researched (Wolfe 2019), but a pattern of inequity also extends to a range of groups, including trans-non-binary individuals, younger populations, Black, Indigenous and people of colour (BIPOC), people with disabilities and sexual minorities (Brooks et al. 2021: 249).

In the theoretical approach of intersectionality, the matrix of domination (Hill Collins 2000) refers to an overlap between different forms of power extending to race, gender, class, sexuality and ability. Dedicated to dismantling these structural inequities through community-led technological development processes, researcher and designer Sasha Constanza-Chock

(2020: 110) argues that 'access to key jobs in the information economy is structured by linked white supremacy, heteropatriarchy, class inequality, ableism, and other aspects of the matrix of domination'. A spokesperson for design justice, Constanza-Chock promotes collaborative and creative approaches to design that address the exclusion and under-representation of certain groups based on a range of factors including race, class, gender identity, disability and age in product design, evolution and manufacturing. Elevating the contributions of marginalised groups, the design justice movement targets normative assumptions and stereotypes behind everyday technology.

Examples of ableism, sexism and racial inequity in technological development are increasingly being identified in areas such as artificial intelligence (AI). Katta Spiel (2021) exposes the implementation of societal norms across a range of applications including algorithms behind airport security systems that treat trans individuals as deviant bodies because they do not fit neatly into male/female anatomical classifications. In motion tracking, fitness devices calibrated to light skin tones (Spiel et al. 2018) and motion capture systems that use black markers draw on the assumption that all users are white-skinned, reflecting racial biases (Spiel 2021). A growing movement of disability, racial and gender activists are mobilising around the need to achieve greater representation of marginalised groups in leadership and key decision-making roles to insure the wider relevance of emerging systems.

Within the academic sphere, gender disparities in music technology and sound art have become more recognised in the past two decades, including an initial review of the topic by George Essl (2003) published in *Organised Sound*. A special issue of *Contemporary Music Review* in 2006 covers the subject from multiple angles. Subsequent research into the gender balance within electronic music and the NIME community by Tara Rodgers (2010), Hannah Bosma (2016), Kristina Warren (2018), Anna Xambó (2018), and Emma Frid (2021) have exposed the persistence of the imbalance.

While much of the existing literature has focused on gender inequality within audio production, electroacoustic composition and performance, there is less reporting on the demographic makeup of music software developers and equipment designers. In a global software developer survey conducted by Stack Overflow (2022), 92% of respondents identified as men. Women, who account for a third of the global technology company workforce, assume one in four senior leadership positions. Although less is known about women's representation in music software development, research into the gender gap within computer music demonstrates that women are under-represented at key conferences, including the

International Conference of Computer Music (ICMC) (Frid 2021).

In her book *Design Justice: Community-Led Practices to Build the Worlds We Need*, Constanza-Chock (2020: 79) asserts that dominant social groups in design and engineering firms lead to product specifications that mirror the interests and priorities of those groups. The predominantly male software engineering research community is also characterised by Georgina Born (2020) as WEIRD (white, educated, industrialised, rich, operating within democracies), an acronym adopted from Joseph Henrich et al. (2010). Born (2020: 196) stresses the necessity to diversify engineering roles and research groups in the related area of Music Information Retrieval (MIR) by incorporating contributions beyond this specific demographic and addressing the preferences of multiple types of users. She views the MIR field, which is a subset of the science and engineering areas, as fertile ground for embracing 'politics of diversity' (ibid.: 196). Yet for too long, these spheres have been considered immune to social forces, she argues.

Accompanying this dominance of particular social groups in design research is a promotion of specific sets of values based on individualism, neoliberalism and entrepreneurialism that will be explored in the next section. Building on Constanza-Chock's work in amplifying structural inequalities that expose 'the ways that race, class, gender, and disability structure both information asymmetries and variance in user product needs' (2020: 73), I accent the need to broaden current priorities regulating audiotechnical discourse.

3. DOMINANT DESIGN VALUES: CONTINUOUS INNOVATION AND PRECISION

Common values underpinning technological development include greater ease, control and mastery, resulting in a polished and refined final product for mass commercialisation. Within electronic music and audio engineering there is a strong focus on continual and rapid innovation. Artists and producers who promote and engage with new technologies for each composition or project are recognised and rewarded in experimental art music. Novelty and innovation are frequently used as criteria to assess artistic and technical submissions at the ICMC, Live Interfaces, Tangible and Embodied Interaction (TEI) and NIME communities. NIME research commonly involves the invention and evaluation of systems through performance or in labs (Hayes and Marquez-Borbon 2020: 27). For the 2022 NIME conference, with its theme of decolonising musical interfaces, organisers aimed to reverse this trend by calling for submissions that questioned the methodologies of Western empiricism

and the valorisation of technological innovation in music technology. Repurposed instruments and systems integrated into cultural practice were encouraged.

Innovation is commonly defined as that which is different to what has gone before and extends to new products, processes or practices that challenge or transform the status quo and disrupts established norms (Griffin 2021). Questioning this focus on the 'new' in relation to technological innovation, Constanza-Chock (2020: 116) argues that the term is often limited to 'the most visible narratives about design and innovation' informed by 'well-resourced corporate mythologies'. She describes the whole technology industry as a marketing-driven space shaping notions of innovation through 'press releases from established firms, start-ups, and venture capital–backed incubators' (ibid.).

The concept of innovation is linked to individual genius and brilliance in popular narratives, Constanza-Chock (2020: 110) observes, equating it to prestige, status and claims to authorship of new inventions among scientists, researchers, inventors and technologists. Within the professional software and technology industries, designers have high status and are rewarded accordingly, she explains (73). Their contributions are linked to innovation and entrepreneurialism under informational capitalism. Yet the participatory turn in technology, encompassing collective spaces such as hacklabs and makerspaces, which embrace DIY and collaborative methods, allows the lived experience of users and activists to be reflected and incorporated into design, opening up broader contributions to innovative practices. However, even some of these grassroots sites have succumbed to neoliberal discourses of individual mastery in the service of start-up culture and government initiatives capitalising on 'technofetishism', she notes (27).

In related research on live coding, Joanne Armitage and Helen Thornham (2021) liken the performance practice to other technologically mediated practices in which creative output, agency and authorship are highly regarded, such as in software development. Behind this thinking is the elevation of what they view as white, masculinist values of 'speed, smartness, smoothness and autonomy' (93), which have roots in neoliberalism. Through an examination of first-person experience captured within live coder diaries, they focus on the creative process, rather than what is seen on screen or heard through speakers (95). The technological setups are complex, requiring constant testing and retesting to gain reliable audio output. Armitage and Thornham report that live coders constantly attempt to avoid machine crashes, undermining 'claims to power, authorship, agency over technology' (97). They expand the definition of code

as a 'tool' or language to a more wide-ranging phenomenon that reflects the artistic interests and working practices of live coders, asserting, 'This is not a linear, agential process, but multiple temporalities and interdependencies that the live coder is living within and through' (103):

> [I]t is worth noting that the event of live coding continues to fetishise and value code, abstracting it (despite these experiences of live coding) from the body (of the live coder). In thinking about the set-up of live coding events, it is worth noting that it is the code that is showcased, projected onto the screen, yet again (as Rodgers, 2010 reminds us) represented as vital and as having vitality, fetishised, abstracted and represented as 'smooth'. (Armitage and Thornham 2021:100)

Rodgers (2010: 249) also refers to the fetishisation of gear and technology that promotes 'slick production' values. Precision and control emerge as priorities of these dominant techno-scientific narratives (ibid.: 8). An analysis of the since renamed Gearslutz forum by Eliot Bates and Samantha Bennett (2022) reveals a continuing tendency towards the objectification and fetishisation of audio equipment, or gear, in online discussions. This trend extends to studio workplace practices, where discussion about equipment is shown to reinforce hegemonic masculinities that favour cis-gendered men.

In the following section, I compare the dominant values of competition and innovation that drive established audio technology development with alternative values emerging in embodied interaction that embrace broader inclusion and diversity in the field. These values include agency, authentic identity, empathy, empowerment, transparency and pluralism, drawing on the feminist principles espoused in Bardzell's (2010) agenda for more diverse HCI design.

4. FEMINIST AND EMBODIED DESIGN NARRATIVES: PROCESS AND PLURALISM

Feminist and embodied design methods challenge the values of precision, control and centralised authorship dominating traditional design perspectives. The main tenets of feminism, as spelt out by Bardzell (2010: 1301), in an overview of feminist-inspired HCI, include 'agency, fulfilment, identity and the self, equity, empowerment, diversity, and social justice'. In order to promote agency, feminist HCI approaches need to expose the common and different ways that men and women participate in emerging embodied interactions, acknowledging gender identity, human sexuality and emotion while focusing 'the agency of interaction not on the interface or its designer, but the bodies, motivating drives, and primordial urges of users' (ibid.: 1307).

Rather than endorsing designs for a specific type of user that requires conformity to particular assumptions, Bardzell (2010) calls for software that does not pressure a user to adopt an identity that is not their own, but instead offers room for users to develop a deeper understanding of themselves. This agenda aligns with the feminist recognition of the full gamut of women's experiences and self-definitions. The exploration of diverse and multifaceted identities includes intersectional perspectives that explore how gender intersects with other elements of identity such as race, ethnicity, sexuality and class. The pursuit of gender equality involves addressing the various socioeconomic, racial and cultural experiences affecting women's representation and opportunities. Feminist design approaches in turn not only aim to dismantle oppressive structures that limit women's power, voice and potential for fulfillment, but also target related forms of oppression including racism, ableism, homophobia, transphobia and classism.

Part of the social justice orientation of feminist HCI involves recognising the experiences and perspectives of users, specifically those who have been historically marginalised or excluded from technology development and design. The design approach seeks to correct structural inequalities and power imbalances existing in technology design. It applies ethical and collaborative values to participatory and user-centred design processes, highlighting issues such as privacy and consent.

Countering the perception of feminism as a critical strategy applied to mediate existing inequities, Bardzell (2010) endorses an action-based approach reflected in all phases of design – from prototyping to evaluation. The range of qualities she sees as contributing to a feminist strand of HCI include pluralism, in which design artefacts do not reflect a specific, universal or absolute theory or perspective, but instead promote participation, advocacy, ecology, embodiment and self-disclosure.

Bardzell's (2010) overview of feminist HCI informs the pluralist approach to somaesthetic design presented by Kristina Höök et al. (2018) in their book *Designing for the Body: Somaesthetic Interaction Design*. Based on somaesthetics (Shusterman 2003: 109), soma design hinges on self-knowledge rather than artificial interpretations of the body based on external appearances. According to philosopher Richard Shusterman (ibid.: 109), 'somaesthetics blends aesthesis, cognition, and praxis to address some of philosophy's most central aims: knowledge, self-knowledge, right action, happiness, and justice'. Soma is shaped through biology, experiences and interaction with the environment and others, leading to the formation of the ego, which is a public manifestation of the self in which 'we project ourselves onto the world and the world is projected onto our bodies' (Höök et al. 2018: 184).

Soma design recognises the primacy of the body and physical experiences. Höök et al. (2018: 24) argue that 'attending truly and deeply to one's own soma ultimately cultivates a deep empathy and respect for other somas, which will benefit more liberating, less oppressive forms of design'. They debunk the dichotomies that occur in design – such as masculine/feminine, which has become associated with the separation between thinking and emotion, as well as the mind/body split. These biases can limit the scope and patterns of behaviour individuals can engage in when interacting with technology. They contend:

> This association casts females as emotional beings, anchored in their bodies, without the ability to reason and think rationally … Women, as well as men, need to adhere to and be cultivated into particular movement patterns to be accepted. (ibid.: 177)

Addressing the dualistic stance seen in fitness trackers that promote a third-person understanding of the body as an object, soma design encourages individuals to observe their bodies not only from the outside but also from the inside (Höök et al. 2018: 181).

Through group physical exercises and reflection during design activities, social conventions can become unbound from unconscious awareness and participants can learn to occupy the body more intentionally:

> Only when we engage with our own somas, discerning different experiences, engaging with others intersubjectively, empathically, can we come to see these norms, which in turn means that they can be challenged and altered. (Höök et al. 2018: 185)

This collective and exploratory approach is also found in an alternative view of live coding as kinship presented by Armitage and Thornham (2021). In their live coding practice, they disrupt the patriarchal and colonial aspects of (re)production by reimagining common accounts of live coding as mastering technology and often negating the body. They challenge the notion of agential control as a directional force exercised by the human performer over neutral and pliable technology. Instead live coders are continuously negotiating with their setups during improvisation, engaging in an embodied way through repetitive gestures and taps to activate patterns and loops.

Armitage and Thornham (2021: 99) present an alternative vision of live coding practice where code and bodies are intertwined and the live coder becomes attuned and responsive rather than directive, rejecting interpretations of technology as imbued with an authorial agency or creative intention.

In the next section, I explore how musicians performing with gestural systems also engage with the soma in new ways, reimagining relationships with their bodies and machine setups by foregrounding collaborative and embodied design values. Taking inspiration from the technofeminist principles outlined by Annika Richterich (2022: 19) in her analysis of feminist hackerspaces, the participatory and experiential design processes covered address both gendered social relations and intersectional dynamics rather than simply applying feminist values to technological development.

5. GESTURAL MUSICIANS

Embodied design methods are applied to combined improvisation, coding sessions and evaluative performances of musicians who compose for body-centred performance systems over the long term, including Laetitia Sonami, Atau Tanaka, Marco Donnarumma, Julie Wilson Bokowiec, Lauren Sarah Hayes and Pamela Z. These artists record autoethnographic reflections of their experiences in interviews, articles and original lyrical content, reimagining human–machine relations and embodied experience with bespoke technology (Mainsbridge 2022). They act in multiple roles as performers, coders, instrument builders and composers, often becoming the sole users of their customised instrument designs and software systems.

Musicians who learn and grow with self-designed systems over sustained periods illustrate the cyclical nature of designs that respond to individual performers' movement patterns and felt sensations. In an interview I conducted with Sonami (2020), she described this process as liberating, linking the exploratory conceptualisation of her two main instruments, the Spring Spyre and lady's glove with the imperative that 'an instrument should be free'. After several iterations, the lady's glove (Figure 1), evolved to control multiple parallel sound parameters by converting movement data captured by flex sensors on each finger, microswitches, hall effect transducers and two accelerometers on the right wristband to MIDI signals. An ultrasound receiver measures the distance between both hands, while a finger band carries a microphone. Captured spoken vocal fragments are layered against electronic sounds and field recordings.

A farewell to the instrument, 'Requiem to a Glove' (Sonami 2017), raises the body's vulnerabilities and tendency to fall into staid habits, which influenced Sonami's decision to eventually retire the lady's glove as her main live controller:

> I did not want to stand onstage at ninety shaking my arms with trembling folds of flesh. Gestures, sounds and geographies slowly became mummified. I left it behind
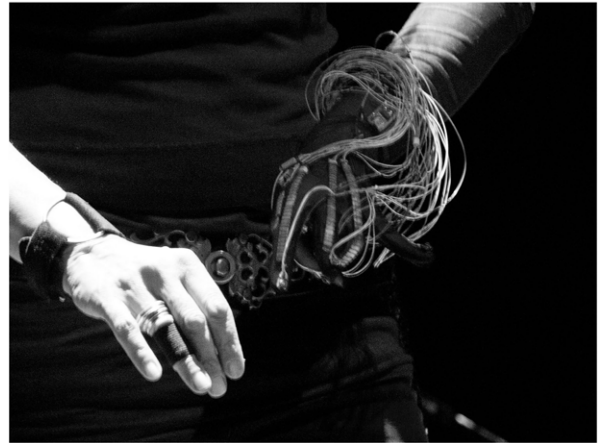

Figure 1. Laetitia Sonami wearing the lady's glove (1991–2016). Photo: Frank Baldé.

because I did not want to blemish it with poor looking associations. So … I leave gloves and other wearables to small dictators and corporate powers. (Ibid.: 140)

Resisting the increasing popularisation of wearable control, Sonami relegated the hand-based controller to corporations that have co-opted gloves for external surveillance of the body in the name of activity monitoring and behavioural modification, creating systems that reinforce body norms rather than support creativity.

Sonami's next major instrument, the Spring Spyre, arose from a rejection of increasingly ubiquitous gloves directly coupling effects such as reverb to the voice or other one-to-one mappings, a phenomenon she termed 'parametric monotony' (Sonami 2017: 140). The improvised bicycle wheel frame construction links to machine learning (ML) software to predict the future based on extracted features. The instrument can be rubbed or struck, emphasising tactility and physicality that was lacking in the air-based lady's glove. Sonami dismisses desired values of accuracy and precision, instead collaborating with software developer Rebecca Fiebrink to create an ML system for the Spring Spyre that does not learn or replicate correctly.

The collaboration evolved organically over eight years (Fiebrink and Sonami 2020), exploring the intersection between electronic instrumental design and machine-learning software (Alessandrini 2018: 53). Without external funding or a set deadline, Fiebrink and Sonami adopted a free and exploratory design approach unrestricted by institutional priorities (ibid.). The pair spent extended periods integrating Fiebrink's ML software, Wekinator, into the instrument design. Sonami (cited in Alessandrini 2018: 54) experimented with subtle and nuanced movements throughout the process, remarking, 'I'm interested in

Figure 2. Lauren Sarah Hayes – live performance setup. Photo: Tobias Feltus.

small gestures. A lot is informed through non-intentional activity.'

This intuitive and experimental approach was initially forged during Sonami's design and performance work with the lady's glove over two decades. Butting up against the idea that fresh, new systems are highly regarded in electronic music composition and performance, Sonami (2020) has instead prioritised her mission to learn about herself through the process of novel musical instrument creation, as she mentions in our interview:

> The lady's glove changed how I defined myself. It really changed my identity in the sense that what I learned through it was what I cared about – finding ways to create an instrument or create a system that would allow me to be different, to expand or to think differently.

Also confronting expectations of continuous innovation in live electronic music, Hayes adapts an inexpensive gaming controller in her constantly evolving hybrid analogue/digital live system. The brand exclusivity of selected equipment does not concern her, but rather how the assembled equipment forms an ecosystem on which to base her improvisations. Hayes's (2023) body-centred improvisational performances within live electronic music bear many similarities to Julie Herndon's (2022: 170) definition of live embodied composition as a practice where the body becomes a source of knowledge and a musical material. Performing at the 2022 Edinburgh Fringe Festival, mysterious whistles and vocal grains scatter and explode from Hayes's setup of software, analogue synthesisers, MIDI controllers, vocal processors and a handheld controller offering haptic feedback (Figure 2).

In addition to programming a range of Max/MSP performance patches, Hayes uses customised software packages such as the Fluid Corpus Manipulation Toolkit (FluCoMa), developed by Pierre Alexandre Tremblay, Gerard Roma and Owen Green (2022) at the University of Huddersfield in the United Kingdom. She employs the toolkit to separate and rearrange audio based on an analysis of transients and pitch, allowing her to dissect and rearrange her live vocal input and facilitate new sound and gesture design.

The FluCoMa cross-platform framework offers ways to explore sound banks and gestures through machine listening and ML algorithms in popular creative coding environments. It aims to support the development of long-term musical strategies, data-driven techniques and creative workflows emerging from sustained practice (Tremblay et al. 2022: 9). The toolkit is informed by and evaluated through intense usage by a community of musicians and early adopters outside the development team, who are supported by online learning resources and a discussion forum (ibid.: 14). As part of her collaboration with the FluCoMa researchers for 14 months, Hayes premiered the commissioned solo work *Moon via Spirit* in 2019. Her code and use of the software to improvise with looping and processed vocals was analysed and fed into the toolset's further development and educational materials (Hart n.d.).

Hayes, who has engaged with her personalised instruments combining software and hardware devices for the past 14–15 years, continually makes new discoveries during phases of active development and hiatus (Hayes 2023). Founded on a rich assortment of musical experiences including piano lessons, playing in bands and clubbing, her work is tangible and physically focused. Each of these embodied experiences influence her identity and interests as a musician.

Embracing broader sociological research, Hayes (2023) analyses the social and political implications of

increased embodied engagement with technology through an enactive-ecological cognitive frame. Enactive theory acknowledges the influential role of actions in shaping perception and conscious thought, as well as sensory and motor processes (Varela et al. 2016). This approach to cognition is anchored in the body, deriving meaning through sensorimotor links between organisms and their environment. The related theory of embodied cognition recognises the influence of physical and sensorimotor activity on cognitive processes. Drawing also on James Gibson's (1986) ecological framework for understanding the interplay between the perception of self and environment, Hayes (2023: 27) argues for the expansion of the embodied cognition perspective to recognise the influence of interconnected social aspects, which are relevant to group improvisation environments where the way individuals interact with and affect each other can shape dynamic relationships and collective sense-making. An extension of this theory is an enactive ethics of care (Loaiza 2019), based on evolving identity and meaning-making processes of enactive music cognition. While embodied music cognition recognises the fundamental role the body, perception and action in musical experience (Leman 2008), an enactive approach contends that cognition stems from 'ongoing affective and sensorimotor couplings that occur between organisms and their environments: the processes of living within, shaping, and being shaped by both their physical as well as sociocultural niches' (Hayes 2023: 24).

Hayes questions whether practice-based research in music and technology has fully grappled with the turn toward the body since the mid-1980s (Turner 2008), as has occurred in science and technology studies and sociology (Hayes 2023: 24). She wonders what is omitted when the body is treated as a sensorimotor actor that physical data are extracted from and converted into music within embodied music cognition and the NIME community, while the mind becomes the meaning-maker in DMI design, arguing that:

> [R]ather than simply replicating this quantification and representation of movement and physical energy, it can be more fruitful to explore the ways in which such technologies might afford collectively co-determined musical spaces to emerge through a rejection of such approaches. (Ibid.: 29)

To this end, Hayes (2023: 30) pursues a variety of interactive musical activities, including collaborative workshops involving the spontaneous design of participatory instruments 'where individuals can develop musical worlds in relation to the materials in their environments'. Her practice is also informed by community-based musical work in care homes, dementia care centres and assisted support needs

schools, where she facilitates dynamic explorations between sound, people and technology through events such as sensory workshops for adults experiencing learning disabilities. Hayes also channels her early haptic and vibrotactile design findings into research dedicated to enhancing musical perception and hearing experiences of cochlear implant wearers (Luo and Hayes 2019). These collaborative projects in turn inform Hayes's solo and ensemble improvisations that navigate haptic, tangible and digital systems, balancing equipment, physical, environmental and software constraints.

6. SPECULATIVE FUTURES

Circling back to the initial themes of the article, this final section considers the implications of artist-developed sonic interaction methods for music technology development and approaches to innovation. Artist designers of novel movement-based systems explore new futures that reflect diverse individual values and challenge opaque, hierarchical and homogenous styles of end-user design. Bespoke systems are designed using pluralist, transparent and interdisciplinary approaches and tested against the rigours of performance. Both Hayes and Sonami explore and refine their individualised systems through physically inspired design and live embodied composition. Rather than pursuing continuous innovation, the focus of Hayes's (2023: 24) practice-based research is to explore collaborative and social music-making approaches, surpassing the novelty and throwaway culture surrounding commercial music technology development.

Both artists assume multiple identities of performer, designer, sound engineer and composer. Hayes collaborates across disciplines with software programmers and community groups, while Sonami's collaboration with programmer Fiebrink has yielded enhancements not only to her creative output but also to the machine-learning software itself. These blended roles can transfer embodied knowledge between performative and programming practices, as Hayes does in her work with Laboratory for Laptop and Electronic Audio Performance Practice (LLEAPP) (Conz et al. 2018), where electronic music becomes a method for targeting issues such as gender and racial imbalances.

When performing, Hayes and Sonami also confront the separation between 'hard' and 'soft' skills in music technology (Rodgers 2010). Hard skills are typically associated with the male-dominated technocentric domains of electronic music, audio engineering, software design and hardware development, while roles showcasing body-related communicative and interpersonal skills, such as singing and dance, are

seen as soft skills and more likely to feature women. By contrast, the areas of live embodied composition and embodied computing, in which technical, design and performance roles often overlap, are characterised by a more even gender distribution. This can lead to a greater sense of autonomy and empowerment for artists who move fluidly between technical and performative realms.

Both Hayes and Sonami account for unpredictability and instability in their software and hardware setups, resisting the precision and perfection promised by commercial music technology. While Sonami seeks randomness through ML software in her Spring Spyre instrument, Hayes's (2023: 29) system constrains her movement range, tethering her to the haptic feedback of a gaming controller or glove. It limits the scale of her gestures in augmented piano pieces where she moves between key strikes and metal, wooden and glass object manipulations across the soundboard. This constant negotiation between physical and technical thresholds exposes physical challenges and vulnerabilities that feed into the creative process, as Hayes notes: 'While traditional HCI research has focused on developing ergonomic relations between humans and machines, there is nothing within these frictionless interactions that appeal to me as a musician' (29). Hayes is attracted to a far less rigid, site-responsive practice that is flexible enough to adapt to unpredictable live performance conditions influenced by varying concert spaces, speaker layouts and staffing arrangements (32).

Unlike the promises of low latency and slick production outcomes promised in commercial music technology marketing materials, performing with personalised motion-operated systems is often fraught with imperfection, iterative development, crashes, unexpected outcomes and increased vulnerability for performers incorporating last-minute technical adjustments during soundchecks or on stage. In contrast to the optimum control promised by purchased gear, Sonami recognises value in the 'awkwardness of an external apparatus, a mechanical system that the body's trying to adapt to, and the struggle that comes with it' (Sonami cited in Rodgers 2010: 229) when working with idiosyncratic digital instruments. In gestural system performance, musicians challenge the notion of the skilled virtuosic performer accessing precise control. Novel and ever-changing software and hardware combinations inevitably fail. Systems built around emerging sensor technologies also challenge musicians to attempt new movements publicly for the first time, creating a heightened sense of vulnerability.

When artists are also active in instrument design, they can develop flexible systems that reflect their individual workflows and physical preferences. Reducing the body to external standards set by designers far removed from an individual's experience can lead to less satisfying and potentially damaging movement-based interactions that do not reflect the needs of varied body types and skills. As Hayes and Marquez-Borbon (2020: 27) point out, the continuing divide between designers and imagined end users has implications for participation, referring to the vast differences between the software design approaches of disabled musicians and accessible technology solutions conceived by nondisabled programmers in Amble Skuse's (2020) work.

For future movement-based design, Spiel et al. (2018: 7) underline the need to target assumptions surrounding bodies and control. They present several recommendations for non-normative and diverse approaches to designing fitness trackers, including embracing uncertainty by making indications rather than pursuing accuracy and precision. In line with feminist HCI principles, critical engagement with technology is encouraged by acknowledging and dismantling biases and welcoming varied viewpoints from diverse user groups.

Further afield, collaborative and imaginative design projects promoting feminist values continue to emerge. Intimate Futures (Søndergaard and Hansen 2018) is a design fiction project that questions the gendered aspects of digital personal assistants (DPAs) and envisions alternatives to the polite, all-pervasive, voice-based virtual helpers. Marie Louise Søndergaard and Lone Koefoed Hansen (2018: 870) outline the inherent biases and collective imaginings that reflect dominant social themes, conventions and beliefs and undermine the perceived innocence and neutrality of DPAs, which 'build on and reproduce collective imaginings of women as interface between men and the world'. They draw on feminist, inclusive and cross-cultural design that responds to varying social needs and ethical concerns. The process addresses gender stereotypes by dropping the pitch of the voice to develop more androgynous DPAs, involving individuals usually excluded from the design process to diversify the results.

Within live embodied composition, improvisation and physical prototyping with customised systems and instruments delivers new imagined futures by highlighting what the body is capable of in novel contexts of the artists' own making. This involves understanding and incorporating bodily experiences early in the design process before creating fully functional prototypes that prioritise evaluation over ideation (Márquez Segura et al. 2016: 6014). Software development, in conjunction with live embodied composition, highlights individual agency and empowerment. The body is active in this process, rather than externally monitored and controlled. This direct physical participation in design brings persistent

mind/body, masculine/feminine and emotional/thought dualities into question, characterising a growing area of interest within feminist/gender studies that intersects with embodied activism in HCI.

Autoethnography becomes a political act (Spry 2016) and a common thread throughout these artists' practices. According to Tami Spry, embodied and performative autoethnographic research can be used to process personal experiences through a broader cultural lens and offer opportunities to identify and address social inequalities. It provides her with the power to reclaim her voice and body in private rehearsal and public performance (Spry 2003: 169). Höök et al. (2018: 178) acknowledge that focus on physical self awareness, such as in autoethnography, can be interpreted as self-absorbed and insular – a well-being indulgence for the economically privileged – however, it can also act as a holistic means to pursuing activism by challenging societal ills such as misogyny and racism:

> body consciousness can provide us with enhanced powers of concentration to help us overcome problems of distraction and stress caused by the new media's superabundance of information and stimulation. (Ibid.: 181)

Yet focusing only on first-person perspectives does not provide sufficient information about how other bodies experience the world. It is thus valuable to sample and share a range of perspectives through participatory and co-design activities (Höök et al. 2018: 181), which celebrate the diversity of perspectives and inclusive values endorsed by feminist HCI.

Collaboration has become vital to artists such as Sonami and Hayes, who regularly co-design with other artists, researchers and programmers. Rarely confined to research labs, their collective projects evolve in real-world settings over many performances or workshop iterations. By adopting participatory and user-centred approaches to design, Constanza-Chock (2020: 112) contends that women and other marginalised communities are uniquely positioned to innovate 'due both to the high amount of specialised domain knowledge they possess and to the low costs of testing possible solutions in the real-world "laboratory" of daily life'.

As a musician also improvising with personalised embodied instruments, I have begun to pursue interdisciplinary collaborations with dance researchers and community musicians to extend my movement capacity and body awareness. The formation of design communities across multiple roles, artforms and disciplines holds the potential to highlight feminist values of cooperation, empathy, diversity and inclusion. New sensory instruments that influence how performers and designers relate to their bodies help reframe movement experiences and offer increased options for addressing inbuilt biases and power structures relating to the body and technology design. With these developments, personal perceptions of the body are no longer regulated by external software applications and distant designers, but rather by collaborative and community-driven design that mirrors the lived experience of its diverse members.

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