Published by the Open Science Centre, University of Jyväskylä, Finland

ISSN: 1795-6889

HUMAN TECHNOLOGY

Volume 17, Number 1, June 2021

Jukka Jouhki
Editor in Chief

www.humantechnology.jyu.fi

HUMAN TECHNOLOGY
Volume 17, Number 1, June 2021
https://doi.org/10.17011/ht/urn.202106223974

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Original Articles

HUMAN TECHNOLOGY

ISSN: 1795-6889
humantechnology.jyu.fi

Submission: humantechnologypublishing.jyu.fi

Human Technology is an interdisciplinary, scholarly journal publishing innovative, peer-reviewed articles exploring the issues and challenges within human–technology interaction and the human role in all areas of ICT-infused societies.

HUMAN TECHNOLOGY

ISSN: 1795-6889

www.humantechnology.jyu.fi Volume 17(1), June 2021, 1–4

From the Editor in Chief

LIFE-SAVING TECHNOLOGIES THAT ARE NOT USED TO SAVE LIVES

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A hundred years ago, on July 17, 1921, a Parisian woman was killed by a mass murderer a few hours after she had given birth. She was survived by her newborn infant, but concern abounded whether he was to be the next victim. The killer was old, efficient, and experienced, having massacred 20–25% of the European population during the 19th century Europe alone (Sakula, 1983, p. 807). This mass murderer went by different names, such as consumption, the White Plague, or phthisis. Many people had been hunting it down for decades already. In 1882, German microbiologist Robert Koch caught and identified it with the help of new technology: a microscope with oil immersion lenses and a device that would later be called the Petri dish. Koch named the culprit *Mycobacterium tuberculosis*. It could now be detected, studied, and perhaps even vaccinated against (Barnett, 2017; Saleem & Azher, 2013; Sakula, 1983, p. 809).

In 1896, tuberculosis was the main worry of French microbiologist Louis Calmette when he began as the director of Pasteur Institute in Lille. He and his assistant, a veterinarian named Camille Guérin, wanted to develop a method to immunize people against the disease. In 1919, after many years of painstaking trial and error—and a bit of luck, an important element of scientific discoveries—they finally were able to modify the *tubercle bacillus* in a way that, when inserted into a living being, it would awaken the immune system to prevent the host from contracting the bacterial infection . After a few years of animal testing, Calmette and Guérin thought the time was ripe to test their invention on a human. On July 18, 1921 in Paris, the infant who had survived the death of his mother a day earlier, was the first human to be given Bacille Calmette-Guérin—or BCG. The vaccine proved safe and functional, and soon mass production was underway. Finally, after a two decades-long search for a prevention to this killing disease, BCG became a worldwide vaccine to combat tuberculosis (Sakula, 1983, pp. 810−811).

https://doi.org/10.17011/ht/urn.202106223975

BCG was not, and still is not, a perfect vaccine, as it prevents only 20 % of its recipients from being infected. However, as a result of the vaccine, half of those who are infected do not develop any symptoms. Moreover, an effective antibacterial medication to cure tuberculosis has been around for more than 75 years now (Iseman, 2002, p. 87s). Combined, the vaccine and medical treatment have saved hundreds of millions of lives.

One could say the invention and implementation of BCG to prevent tuberculosis (TB) and the medication to treat it have been one of the major medical technological success stories of last century. Indeed, in many countries, tuberculosis has become nearly extinct. However, although the disease is quite preventable and almost totally curable, it still kills as many as 1.5 million people a year, a death toll close to that of COVID-19 in 2020 (World Health Organization [WHO], 2020a). Despite the technology to prevent and cure it, tuberculosis remains the leading cause of death from a single infectious agent in the world (WHO, 2020c).

Factors keeping TB as a persistent global killer are human in nature: the antivaccination beliefs, patients' noncompliance and/or abandonment of treatment and, more importantly, the simple lack of commitment to fund organized health care (Iseman, 2002, p. 88s; Sullivan, Esmaili & Cunningham, 2017). If TB symptoms are not treated, half of the patients die. Yet, just about a billion dollars of additional annual funding to fight TB would eradicate the disease by the end of the decade (Makoni, 2018). However, it seems that because tuberculosis is not a disease of the more affluent countries, where people often do not even know it still exists, the relatively small amount of money needed to kill the killer is hard to come by as foreign aid. Hence, tuberculosis makes a useful—but also very sad—example of how humans can invent technologies to improve and save lives but fail to do so because of unevenly distributed resources. Unfortunately, it is only one of the many such cases.

For example, around 4 million people die each year from indoor air pollution because they do not have proper cooking stoves, chimneys, and vents (WHO, 2018b). Another big killer is malaria, with a million preventable deaths a year, deaths that could be avoided with indoor spraying and mosquito nets or curable with medication (WHO, 2021). Other relatively easily preventable causes of death are diarrheal diseases, killing 1.6 million a year (Dadonaite, Ritchie, & Roser, 2018), or neonatal deaths due to sepsis/pneumonia, tetanus, diarrhea and more ending the lives of 3 million every year (WHO, 2020b). For comparison, WHO (2018a) estimates that climate change, a valid and important worry of the whole of humankind—including the wealthy countries—is predicted to kill 250,000 people (directly or indirectly) annually in the coming decades.

This is not to say people should invest in health problems only if the body count is high enough. All deaths are certainly tragedies. But if resources to fight life-threatening problems are limited, and the aim would be to maximize the number of lives saved on the planet, then some tragedies are easier to prevent or alleviate than others. There are "smart targets" that save more lives with simpler and less costly solutions than others (see, e.g., Lomborg, 2015). However, it is quite evident some causes of death appear more alarming and some victims perceived as more "valuable" due to the amount of information about and the media coverage of them—and, of course, how probable people think it is they that would be in danger of that illness. Technologies and their applications do not exist in a vacuum; rather, they are embedded in economic, political, and sociological realities that determine their uses and targets. That is pure human technology.

The articles of the current *Human Technology* issue are not dealing with technological issues that are matter of life and death, but one can still say they are dealing with quite essential phenomena of life, money and music. **Laura Stark**'s article, "Mobile Money and the Impact of Mobile Phone Regulatory Enforcement Among the Urban Poor in Tanzania," is a qualitative study based on 165 interviews conducted in Dar es Salaam, Tanzania, over 8 years. Stark examined the role of mobile money in the survival strategies of the urban poor in that city, and, for example, how their valuable microvending practices are challenged and even disrupted by the government's new regulatory policies. The two other articles of the issue focus on music. In "Appropriating Biosensors as Embodied Control Structures in Interactive Music Systems," **Luís Aly, Hugo Silva, Gilberto Bernardes**, and **Rui Penha** compiled, categorized, and analyzed a catalog of artistic uses of biosensing technologies based on their proposed taxonomy and how the taxonomy could apply to interactive music systems. They looked at the historical trends, starting from as early as 1965, and they see a growing emphasis on the role of biosensing in enabling or controlling interactive music creation, which may lead to new noncorporeal ways to create and perform music. **Andrew Danso, Rebekah Rousi,** and **Marc Thompson** investigated music technology in the classroom in their article, "Novel and Experimental Music Technology Use in the Music Classroom: Learning Performance, Experience, and Concentrated Behavior." They a used mixed methods approach to discover how different music applications, such as digital tables, specifically the iPad, and new types of embodied music technologies, in this case a glove with sensors and musical buttons, contribute to learning music.

With these articles, *Human Technology* wishes you an enjoyable journey to the ways technology can make a better and enjoyable world for humans.

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Human Technology
ISSN 1795-6889
www.humantechnology.jyu.fi

HUMAN TECHNOLOGY

ISSN: 1795-6889

www.humantechnology.jyu.fi Volume 17(1), June 2021, 5–21

From the Managing Editor

WHAT MATTERS MORE IN OPEN ACCESS JOURNAL PUBLISHING: SCIENTIFIC RIGOR OR FINANCIAL VIGOR?

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Scholarly journal publishing originated in universities as early as the 17th century (Björk, 2011; Morrison, 2011; Potts, Harley, Montgomery Neylon, & Rennie, 2017), with the term "journal" applying to these serial publications by the 19th century (Potts et al., 2017). These serials almost always rose from within scholarly societies, from and for dues-paying members (Björk, 2011; Cutler, 2006; Morrison, 2011). However, the processes of publishing and distribution were difficult and time consuming; many journals lacked sufficient readership to offset the costs (Potts et al., 2017). Nevertheless, journals became more popular by the early 1800s because they allowed academics to disseminate research results faster and more conveniently than monographs and treaties (Larivière, Haustein, & Mongeon, 2015). The financial footing for journals did not improve until the mid-20th century, when the post-war, government-funded research boom increased the number of researchers and thus journal manuscripts, all leading to the formation of the modern journal publishing system (Morrison, 2011; Potts et al., 2017). The demand for publishing scholarly research outstripped the ability of scholarly societies to manage, and into this gap between demand and supply, stepped for-profit journal publishers (Morrison, 2011). These commercial journal publishers filled the growing need for research outlets by launching topic-specific journals (Björk, 2011) and by taking over the publishing (and ownership) of struggling titles established by academic societies (Potts et al., 2017). Through an ongoing process of consolidation through mergers and acquisitions (Morrison, 2011; Remy, Cohn, Gallegher, & Leaman, 2006), multinational publishers acquired both academic journals and smaller journal publishers, resulting in the "Big 5" journal publication houses—Elsevier, Taylor & Francis, Springer, Wiley, and Sage—that today are highly influential and powerful. These few journal publishers own a majority of scholarly journals (Potts et al., 2017; Remy et al., 2006), up to 70% of the social sciences journals, although just

https://doi.org/10.17011/ht/urn.202106223976

20% of journals in the humanities (Larivière et al., 2015). In addition to the financial constraints and inequality in academic knowledge (addressed more below), some researchers and librarians are concerned over what voices and research output might become suppressed—or would not even have a seat at the table (Gajović, 2019)—when so few players are expanding their dominance in research communication (Remy et al., 2006).

Certainly independent journals are still being published by academic societies, university presses, some university faculties or libraries, and small publishing houses around the world (Cutler, 2009; Morrison, 2011), representing nearly half of the scholarly publishing in 2006 (Crow, 2006), although that number may have changed (downward) by now. However, Boismenu & Beaudry (2004) found that some of these non-profit and so-called responsible publishers "occupy a central place in scientific journal communication" (p. 344) and can hold higher impact factors than their subscription-based peers.

Nevertheless, Morrison (2011) described the current oligopolistic structure of the contemporary journal publishing as "enclosed," meaning many readers are unable to access publicly funded research because it exists behind the commercial publishers' paywall. Academic libraries, often the gatekeeper for access to vast databases of scholarly articles, are key customers of commercial journal publishers, resulting in up to 75% of the publishers' income (Larivière et al., 2015). Yet, because they are constrained by budgets, often their decisions are not based on what would be best for the university users but reflect only products combinations they can afford, often representing the commercial publishers' "big deals" (Morrison, 2011). This can cause frustration because, as Larivière et al. (2015) noted, the scholarly content in journals are not interchangeable. Thus, the rising costs of scholarly journal subscriptions require university librarians all around the world to make difficult choices regarding what research reporting is made available to its students, academics, and researchers (Crowe, 2019; see also Bergstrom, 2014; Matthews, 2019). These decisions are difficult particularly for less affluent libraries (Bateman, 2006), causing a "crisis" in the availability of certain research (Owen, 2007; see also Gajović, 2019). Of special frustration is that universities' staffs and researchers are the creators of the new knowledge in these subscription-based journals, and yet they have little control over the process of their scientific publishing. In most cases, universities are paying twice: once to create the research and a second time to have access to it through costly journal subscriptions (Crowe, 2019).

Several researchers have posed the question about what value commercial publishers bring to scholarly journals in the age of digitalization. For example, Björk (2011) noted that a scientific journal is successful (and thus sustainable) if it delivers the values that the readers expect and want, no matter whether that journal is not-for-profit or for-profit. Morrison (2011) and Björk (2011) observed that the bulk of the work in getting a paper from concept to publication is completed by academics—authors who conducted the research and wrote up the report, editors who determined it was of sufficient quality for review and (often) handled the review process, reviewers who contribute to quality control of scientific reporting, and authors and editors who work collaboratively in the revising process until the paper is ready to be accepted for publication. The vetting of the research by editors and reviewers is particularly important, Remy et al. (2006) pointed out, because of the abundance of misinformation on the Internet; peer-reviewed journals assure readers of the scientific rigor. But, again, that process is handled by the scholars overseeing the journal. Larivière et al. (2015) concurred, noting that when journals were only available on paper, publishers handled the mechanics of typesetting, printing, and manual dissemination, among other tasks. Yet none of those are part of the journal publishing process in the 21st century, although some aspects of the process (e.g., layout, copyediting, marketing; Morrison, 2011) are supplied if the editor-academics are unskilled in these tasks. So the question Larivière et al. (2015) posed is, What value are the publishers bringing to the process that warrants universities investing continually more funds for subscriptions? And, as a follow up, many researchers in this field are asking how can the scholarly communities and individuals take back control of their own work

From these and other questions regarding the current state of the scholarly publishing world, many scholars, researchers, and librarians advocate for exploring and enacting financially sustainable approaches toward open access (OA),[1] independent, non-profit, scholarly publishers and journals to counter the dominance of the commercial scholarly journal publishers, but also to serve as integral components of a scholar-led research ecosystem with societal imperatives (see, e.g., Kronman, 2012; Lange & Severson, 2021; Morrison, 2011). This applies also to the ability of scientific societies to continue their tradition role of publishing journals, where Crow (2006) states that this outcome brings important implications for societies, as well as universities and their libraries. However, scientific societies often lack a strong and coherent structural capability to sustain themselves as entities, let alone serve as research publishers (Crow, 2006), and individual researchers are still beholden to the symbolic function of scholarly publishing to advance their careers (Larivière et al., 2015). Even universities rely on journals to provide documentation of significance of the institutions and its researchers outputs and to help raise its profile and remain competitive (Harrison & Stephen, 1995).

Thus, to counteract these challenges, Crow recommends the concept of "publishing cooperatives," where the collaborative skills, financial support, organizational model can create an efficient environment where the sustainability of scientific societies and their publishing capabilities are strengthened. A similar approach could be e-portals, which have either direct or indirect governmental (e.g., university) funding and help local scholarly journals master the processes for successful publishing and establishing a global reach (Björk, 2011; see also Cutler, 2009; Morrison, 2011). And, as a result of such efforts, other stakeholders within the scholar-led research and publishing ecosystem (e.g., libraries, small publishers) benefit as well. In support of universities stepping up to contribute to the underwriting of a technology infrastructure that would support open access to published research, Holcombe and Wilson (2017) emphasized that the required costs would be less than when they are currently paying for the annual subscriptions rates for commercial journals and the APCs paid for research reports in commercial journals to be open access. In the current system, the universities and public funds are feeding both the publication processes and the profits for the commercial publishers (Morrison, 2011). As Morrison noted (2011, p. 6), the global expenditure for library subscriptions in 2011 amounted to nearly £3 billion, a portion of which funded both the publication process and commercial publishers' profits.

In the recent literature, two distinct approaches are advocated regarding the current financial challenges in scholarly communication and the role of OA:

- Follow the traditional journal publishing practices but with different key actors and new financial models.
- Disrupt the current scholarly journal system and imagine new options.

I will address each of these issues briefly here.

A Modern Take on Traditional Journal Publishing

The foundation of any journal is the academic discipline: a community of practice. To continue to serve researchers and field advancement that ongoing research provides, the publication system would benefit from looking at the process as a means of community support. Harrison and Stephen (1995) emphasized the content aspect of publishing embodied within communities. Journals and their published papers present the discourse and state of an academic field, as well as serve as the repositories of the known body of knowledge, concepts and beliefs, and the accepted and contested terminology of an academic discipline. Naturally, as research continually is being produced, journal papers facilitate the ongoing discourse (i.e., represent a "part of a multiplicity of means by which communities communicate with themselves"; Lorimar, cited in Harrison & Stephen, 1995) and research directions of a field. Indeed, Björk (2011) noted that, through public citations, research reports are bound with the scientific discipline's body of knowledge, particularly when the journal articles have been peer reviewed, the gold standard for quality. As an extension of these perspectives, then, is making open access journals easy to establish, viable through stable funding, and visually and professionally attractive and functional through ongoing support for the skills development of the editors and/or non-profit publishers a sustainable means to support and enhance scientific communities?

Related to this is the need for a publishing environment that levels the knowledge fields and scholarly access between richer universities and national education systems and those of developing and emerging economies. Solomon (2006) and Gajović (2019) pointed out several issues of the current publishing environment that put up barriers for researchers beyond the Western borders regarding both access to contemporary knowledge as well as being able to contribute to their fields. These authors underscore that certain OA options do not eliminate the barriers.

From the access perspective, the insufficient academic budgets in less affluent economies results in university libraries' inability to purchase access to the top journals for their researchers because of the expensive subscription-based paywall. As a result, academic inequality is built into the system when researchers in these universities and research labs are denied access to the current research and knowledge generation within their fields (Gajović, 2019; Wilson, 2017), putting them at significant disadvantage to their more affluent peers in other countries. Gajović continued, noting that even if these researcher could obtain some level of access, they may lack the ability within their communities to absorb the knowledge in order to bring it to bear on their own societies and economies. In other words, he stated that the longer these researchers in emerging research communities are deprived of full access to the body of knowledge and discourse of the field, the more likely they are to fall behind their peers in wealthier areas of the world not just related to exposure to research theory and practices but in their own sufficient knowledge and skill to translate that global knowledge to the particulars of their own society and economy. This reality is even more problematic because often grants, doctoral positions, technology transfer, and the like are directly related to a researcher's ability to access and absorb the body of knowledge of his or her field (Gajović, 2019). This brings unfortunate implications not only for the individual researcher and perhaps his/her university or research unit and colleagues, but also for the capacity to translate current knowledge into a means of advancing one's country's economic status and outputs, industrial development, market expansion, and social and educational advancement (see Gajović, 2019). And even if one's university library is able to purchase subscriptions for materials of benefit, the user is restricted, for example, by having to physically be in the library to access the materials. As Solomon (2006) related, this requirement is often unpleasant because the library subscription portals in many developing countries are cumbersome and frustratingly slow, particularly when compared to the ability to access OA journals through a simple Internet browser.

From the academic contribution perspective, anything less than a fully open and free submission process places hurdles—and perhaps barriers—before researchers in emerging economies to add their knowledge to the field, to bring alternative perspectives for foreign peers' consideration, and raise the research output level of his/her colleagues, university, and society. Perhaps the clearest barrier is the article processing costs (APCs), the fee commercial journal publishers charge for researchers to have their published article available immediately as open access, rather than a delayed availability, potentially dating important research contributions to the field. Yet many academic associations (Bull, 2016) and OA publishers use the same requirement as a funding tool, underwriting the cost of operation on the backs of authors who already have invested in the system by creating the research report. As Solomon (2006, p. 3) explained,

> In the developing world, which includes approximately 80 percent of the world's population, even modest charges for access or publication can be beyond the economic means of libraries and individuals who wish to access the materials or authors who wish to publish their material.

Some journals offer waivers in APCs to researchers from developing economies. However, those who do not qualify for waivers and do not have sufficient funding are shut out of freely and expediently publishing their research (Lawson, 2015).

Open access journals that have a funding model other than built upon APCs allow researchers anywhere and anytime to submit their research for publication consider without artificial constraints, what Solomon (2006, p. 3) called the "purest form of open access." Such journals decrease the inequalities among researchers and open opportunities for genuine dialogue and collaboration unencumbered by time, distance, or financial barriers. Moreover, open access journals can help reduce knowledge gaps between South to North researchers and enhance South to South research interests, as well as decrease developing countries' reliance on Western-based journals or topics unrelated to, for example, the social, economic, or environmental needs of local area (Morrison, 2011).

Perhaps the greatest question regarding OA journals is how to fund the publication process sustainably. True, OA journals do have a lower capital expenditure than commercial journals (Harrison & Stephen, 1995), particularly when most of the work already is completed by volunteer academics. But "price-free is not cost-free," as Boismenu and Beaudry (2004, p. 349) noted, and OA journals require at least modest financial support, particularly for some level of staffing, even with academic volunteers (Morrison, 2016). Moreover, even though the learning curve for quality journal publishing is not prohibitive, the support that academics need for a viable journal is not only financial. OA journals staffs will need to attend to the mundane aspects of journal publishing, such as submissions management, layout and copyediting, finding a platform to host their journal, secure maintenance for the technical side of publishing, and address basic marketing and journal indexing so that readers know the journal exists.

In the face of these realities, scholars committed to running an OA journal need significant (and perhaps, ongoing) support. The benefit of an OA environment is that many academics who have already gone through the process are very willing to share their experiences, learned lessons, and suggestions for easing the processes. In addition, many universities have personnel who possess great know-how regarding many aspects of journal publishing, external indexing, marketing, language editing, and so on, particularly librarians, digital content experts, and IT professionals. The key, however, said Cutler (2009), is establishing processes so that these experts provide not just philosophical encouragement but also concrete economic support, technical know-how, and skills development to lower the bar of practical matters of associated with OA publishing. Particularly for scholar-led journals, whose focus typically is directed toward the knowledge and know-how being generated within his or her field, practical matters, technology solutions, and innovative practices are always evolving, resulting in the scholars' continual need to rethink their operating procedures in search for efficiencies or advantages (Kaiser, 2003). On some level, this reality underscores the need to have at least some professional management support, handling the day-to-day operations and advances and leaving the academics to attend to the journal's content, reputation or brand, and/or tapping into peer networks to draw in other volunteers to share the burden and to provide for succession.

In considering funding streams for OA journals, much discussion revolves around the various options. At the moment, APCs represent the primary funding model. Advertising is another option (Potts et al., 2017), as could be sponsorships; internal subsidies from, for example, association or society dues; external subsidies from, for example, foundations, institutions, and governments; donations and fundraising, endowments, in-kind support, partnerships (Crow, 2009). Meanwhile, some academics have suggested that portions of the university libraries' budgets cold be redirected toward scholarly OA endeavors. In Morrison's (2011) view, active involvement of scholars—and particularly scholarly societies, professional associations, or consortia—can begin to impact in time the stranglehold of the large commercial journal publishers. However, she noted, designating funds within library budgets toward new OA initiatives will prove difficult, particularly in the short term, because those budgets are tied to providing research materials needed now, and thus much of their budgets are going to the "big deals" with the commercial journal publishers.

What may be needed for the transition from public and private education funds away from commercial journal publishers is case-making to public funding agencies and nonprofit and nongovernmental organizers to step up temporarily to fill the gap. Such funding could support individual journals (or, for example, multiple titles being published at a university) or be directed to scholarly societies, consortia, or portals committed to sharing resources and economies among many OA journal titles. Such approaches already are taking shape continent wide (e.g., Scielo in Latin America and African Journals Online), as well at the country level in, for instance, Japan, China, and Croatia (see, e.g., Gajović, 2019; Laakso et al., 2011; Morrison, 2011), giving fledgling journals and those longer-operating-but-struggling journals the opportunity to obtain firmer financial footing and put into place practices and funding streams that will help them remain viable. And, of course, the opportunity continually exists for universities and research institutions—the primary source of the research output—to avoid enclosure and instead work toward emancipation, that is, contributing to the sustainability of a scholarly OA environment by underwriting journals operated by their own academics or faculties (Morrison, 2011).

Much has been written about the benefits of OA publishing and the multiple means to accomplish the goal of making, specifically, publicly funded research results immediately and completely available. For some, OA represents an ethical, socially responsible, and equitable movement toward decommercializing the research output of scholars. According to Laakso and Björk (2012, p. 8), "It no longer seems to be a question whether OA is a viable alternative to the traditional subscription model for scholarly journal publishing; the question is rather when OA publishing will become the mainstream model." To reach the goal of OA as the expected norm in the scholarly publishing world, hard choices and creative thinking are essential toward the discussions, funding challenges, and editorial practices (particularly when research points to the stress that academic editors experience in balancing their scholarly and editorial responsibilities; Lange & Severson, 2021) necessary for this paradigm shift. Interest and commitment to this process—perceived by many as simply a change in scholarly publishing funding models—has been growing for a couple of decades now, starting with the early launches of electronic journals in the late 1980s (Owen, 2007). Yet, with all the technological advances for creating and distributing online journals, and the widespread commitment to—and young scholars' expectations for (Remy et al., 2006)—free and unhindered access to all research, the field continues to struggle with how to make it so in practicality. That has led to some academics to call for radical changes.

Rethinking Scholarly Publishing

Morrison (2011) stated that scholarship and research reporting can be "emancipated" from the shackles of the current enclosed model of scholarly journals, as exhibited by practices such as subscription, pay-per-view, or purchase of research articles, by launching and supporting OA initiatives of various kinds. Some academics, however, feel a more drastic approach is needed, specifically activities aimed at a disrupting the current underlying business model in favour of a large-scale transformation toward OA as the default journal publishing model (Schimmer, Geschuhn, & Vogler (2015). Owen (2007) advocated for revolution in, and Bateman (2006) called for radical change for, scientific journal publishing amid the dramatic technological advances since the mid-20th century. They note that it is unclear yet how such advances have significantly impacted the substance of formal scientific communication or its form. Potts et al. (2017) emphasized that many scholars feel the current scholarly publishing process is "broken," requiring a new business models and publishing processes. They proposed a dramatically different approach to scholarly publishing and journals with an economic view on how journals are conceived as "knowledge clubs" and structured in a way for academic peers to contribute and benefit from their research and those of others within a specific economic and academically beneficial way. "Clubs are non-market solutions to public-good problems that rely on the ability of self-constituted groups both to self-organise and successfully to self-govern … [that is,] groups of people who share a common concern, who are willing to pool their common resources and specialization skills, and to act in concert in pursuit of shared externalities" (Potts et al., 2017, p. 80). They believe knowledge clubs would embody the model of the personally engaged academic community that was prevalent in the days of scholarly publishing nearly three centuries ago.

However, even as they support greater interaction by these knowledge clubs, it is hard to see how these would, in practice, serve the general research environment. From my point of view, these authors' ideas on how technology is changing the role and processes of scholarly communication—as well as recognizing that academics of all kinds have skills and interests and visions for new approaches—needs wider discussion and consensus, at both the institutional and individual scholar levels. Their arguments on what is needed is presented as "radical," but the challenges these groups and organizations face may not be substantively different from what has been discussed above. Of course, if ongoing research takes place within knowledge clubs, the benefit of the collective knowledge could be both more productive and more focused when all members of the club are operating within similar visions and discourse practices. In that regard, looking at how scholarly societies from centuries ago made new knowledge available and applicable to growth in the discipline, the expectations and understanding of what research could and should change the very nature of what contemporary scholars do. Additionally, innovative technological applications can decrease the learning curve and, perhaps, open ideas on streamlining the entire research process, from concept to published research reports. Interestingly, it might be a challenge to tease apart the separation of university communities of scholars from those of knowledge clubs or discipline-specific scholarly associations. Unless the entire vision of the university is revisited, and perhaps that is a reasonable topic for discussion, the role of the university community in the research and publishing functions of knowledge clubs might simply represent a new term for a familiar concept. Nevertheless, considering how the university can more actively support, both explicitly and implicitly, the free exchange of ideas and research findings is an important consideration as well.

Revolutionary thinking can and should be part of any discussion of revisioning higher education and scholarly research and the access to both. Altbach and de Wit (2018) have presented one example of this approach. Although the exact number of scientific journals is unknown but estimated at around 30,000, with the more than two million articles published annually (p. 7), Altbach and de Wit note these outcomes result from the never-ending drum beat on academics around the globe to publish, publish, publish. They stated that such expectations have resulted in excess pressure on the top journals (the aim of every researcher and his/her university or grant provider), immense stress on the peer review system, an increase in the publication of marginal research, and the rise of predatory journals (see, e.g., Beall, 2016; Berger & Cirasella, 2015, for more on the latter phenomenon). Altbach and de Wit stated that these negative outcomes result from two behaviors of universities in recent years: (a) most academic institutions' desire to emulate top universities, thus taking on similar practices, including increasing research outputs; and (b) the growing trend in doctoral education away from monographs and toward article-based dissertations. They concluded that too much research is being published—no matter whether it is by commercial journals or OA avenues. Thus,

> reducing the number of academic articles and books would permit the peer review system to function more effectively, would reduce or eliminate the predatory journals and publishers that have emerged recently, and would, perhaps most importantly, remove massive stress from academics who worry about publication rather than teaching and service. (Altbach & de Wit, 2018, p. 9)

This perspective points to many concerns amid continually expanding (steadily, on average, about 3% each year; Ware & Mabe, 2015, p.6) annual scholarly research output. Moreover, such commentary can elucidate the number of options available to scholars—and higher education institutions—regarding academic research and scholarly publishing. It also points to the role and practices of universities that, in turn, can inform the discussions regarding the role of universities in supporting journals within their academic portfolio of practices. If indeed only research universities should require their academic staff and doctoral students to publish (as per Altbach and de Wit, 2018), then the skills and practices needed to assure the quality of academic output of their own people can readily be applied to one or more OA international journals that they support.

Regarding the nature of OA publishing, Laakso et al. (2011) studied the challenges faced by OA journals and the failure rate of more than a third of them over about a decade. Their research pointed to the challenges many OA journals face early on, citing the 2002 research by Walt Crawford who found a pattern in ceased OA journals that he called the "arc of enthusiasm." Many discontinued journals succeed in their first few years but ultimately cannot expand their publication volume or article counts and ultimately discontinue or limp along with only a few papers published per year. This is a reality in journal publishing generally but perhaps more frequent in OA journals because of the low bar for start-up. Attracting sufficient quality submissions is a challenge, especially in a competitive journal environment. But that also points to the value that a university's reputation brings to small-to-medium-sized OA journals, those that will not compete with the top journals but nevertheless provide an important service to the academic world—particularly those who are indexed by Scopus (as is *Human Technology*) and/or Web of Science. Although all universities—as do all authors—want to publish and be published by a top tier journal, the reality is that most research—still very good research—will not be accepted into those journals. Therefore, university-supported OA journals offer an important, valuable even, service to the knowledge communities by drawing on the group's shared knowledge of the field regarding the significant contributions of research outcomes. Altbach and De Wit's recommendations and Laakso et al.'s statistics on the fate of OA journals over time could open serious discussion about the purpose of research (besides being a published author) and the role of shared knowledge across one's university, national university system, regional higher education associations and alliances, and global discourse.

Ware and Mabe wrote,

> Journals form a core part of the process of scholarly communication and are an integral part of scientific research itself. Journals do not just disseminate information, they also provide a mechanism for the registration of the author's precedence; maintain quality through peer review and provide a fixed archival version for future reference. They also provide an important way for scientists to navigate the ever-increasing volume of published material. (2015, p. 6)

Those associated with universities also are the primary consumers of academic scholarly publication, as the ever-growing body of research forms the foundations of their own members' academic discussions, scholarly interests, and quality research. It remains in the universities' (both as an institution and as a body of academically minded individuals) best interest to be active parties in the distribution of scholarly work. In that sense, that is why many universities are actively creating and maintaining their institutional repositories. But Altbach and de Wit (2018) will come back to their thesis that not all research is equal—or necessary. And no matter what the forum for making research results more accessible to all interested parties, a fundamental question must be asked within the respective scholarly organizations—universities and academic disciplines: Is the current system of scholarly research considered broken only because of the practices of commercial journal publishers or is there a deeper rot? Commercial journal publishers arose after the Second World War because of the dramatic governmental push for researchers and an emphasis on research studies. If that emphasis on research was recast or rethought, would commercial journal publishers still be the primary concern? Perhaps fewer research studies and easier access to research reports could form the foundation for an entirely new concept of scholarship and academic excellence.

THE EXPERIENCES OF *HUMAN TECHNOLOGY* AND THE UNIVERSITY OFJYVÄSKYLÄ

This discussion up to this point has a personal purpose for me because of my role as managing editor of an OA journal. Boismenu and Beaudry (2004) noted that rather than focus on the role of commercial journal publishers, those who want to advance the OA environment should focus on nonprofit journals that already occupy important spaces in the dissemination of research. They conclude that there is no need, in most cases, to create new journals.

In the case of *Human Technology*, its conception was based on experiencing a gap (or niche) in the scholarly journal universe. When the planning for an interdisciplinary journal that was international in draw and OA in dissemination, very few journals had a similar mission. At that time, the publisher of *Human Technology*, the Agora Center, was a recently formed independent research unit of the University of Jyväskylä that also occupied a niche, both within the university and in the greater research community. The founders of the Agora Center—Professors Pekka Neittaanmäki, Lea Pulkkinen, and Heikki Lyytinen—were bold and forward-looking internationally acknowledged scientists who were passionate about and dedicated to the advancement of interdisciplinary research. They conceived of the Agora Center as a research unit built upon collaboration and alternative disciplinary perspectives on phenomena, practices, and technology innovation, which was key to understanding and advancing society and knowledge. The administration of the University at that time saw value in this broad and innovative mission as well and established the Agora Center in 2002.

From that vision also arose the realization by Professor Pertti Saariluoma and others at the Agora Center that standard discipline-focused journals at that time had difficulty in embracing interdisciplinary research. *Human Technology* was positioned within that gap, embracing multiple disciplines and multiple research approaches as well as the free movement of scholarly knowledge. This vision struck a note with researchers around the world.

During my time at the Agora Center, I had always valued the vision of both the research center and the journal. OA as a practice was just arriving on the scholarly research scene and the visionaries at the Agora Center clearly understood the research benefit and sense of equality embodied in this journal model. Thus, the Center's managers were committed to underwriting the journal so that neither readers nor authors had to pay to obtain or contribute to scientific knowledge. In this sense, emphasis on quality scientific research was a cornerstone of the academic approach of both the University and the Agora Center, and by extension, *Human Technology*.

As reported earlier in this paper, one of the major challenges of OA journals is funding. But unspoken also is perhaps a difference in visions of what quality research represents. Thus, no matter how a journal (or its supporting scholarly organization) contributes to the scientific discourse, no matter how it is committed to quality in scientific discovery and reporting, no matter how many scholars around the world contributed to or drew on the articles in the journal or collaborated with the organization's researchers, external forces can dramatically challenge these entities' fortunes. These realities confront all academics at some point during their careers.

In the case of the Agora Center, it was a matter of single-minded administrative thinking about the value of an interdisciplinary unit, even though successful and financially stable, not as an asset for the University and its community of scholars but rather as competition for the discipline-based faculties. The previous administration of the University appeared to believe that the ability to organize the finances of the University, establish goals and rewards, and articulate the work of the University was easier, perhaps even more efficient, if everyone operated from within their own disciplinary silo. As a research innovation, applying interdisciplinary perspectives and practices to highlight the different—perhaps unseen—facets of a phenomenon, and striving for alternative approaches to scientific organization were no longer valued. The Agora Center was shuttered and, as a result, *Human Technology*'s funding source was eliminated. The journal's first era of survival had come to an end.

To some extent, the journal was adrift. The University's administration decided that most logical place for an OA journal was within the newly forming Open Science Centre (OSC). This reinvisioned unit of the university encompasses the work of the university's library, museum, and digital publishing, the latter activity embodying the "green" OA path via its institutional repository for the research reports and articles produced by the university's researchers and staff (for more information on the role of such repositories, see Crow, 2002). Publishing an interdisciplinary OA journal through this unit, on paper, made sense. And so *Human Technology* soldiered on into its second era. Yet it did not take long to see how, in practice, the mission of scholarly journal did not align with that of the OSC or its publications unit. So the managers of the OSC decided to shed the journal, thus ending *Human Technology*'s second era.

From this story of a little journal that tried and tried—and, over the years, fulfilled its mission of growing from an idea of an interdisciplinary, international OA journal focusing on the intersection of humans and technology to eventually being accepted into Scopus—is a lesson that all OA journals must acknowledge. It represents perhaps one of the greatest threats to OA scholarship: the reality of the financial "bottom line." In other words, what is the priority of the scholarly funding source: scientific excellence or financial vigor?

Of course, the fundamental basis for almost everything in higher education (and a multitude of other business endeavors) is that of finances: How much of what a university wishes to do brings returns on that investment? What choices must be made within limited financial resources? And must those returns be strictly financial or are there other less tangible but important benefits for an activity?

I contend that, at least in the case of *Human Technology*, other benefits, albeit intangible, communicated about the University of Jyväskylä and potentially its brand and image. In this case, the name of the research institute and the University are prominently featured on the front page of each paper and on the journal's website. Each time a paper is opened on *Human Technology*'s website or downloaded and read, the University was, at least passively, identified. Thus the reader could easily infer that the University of Jyväskylä actively promoted interdisciplinary and OA research. Moreover, the journal provided a means for the university, again however passively, to give back to the academic community and the interested reading public as part of its societal mission. Thus, each *Human Technology* article placed in a reader's mind a positive academic and social value regarding this University and its internal units. That, in short, is a key marketing principle.

Surely when the Agora Center was active, the benefits of the journal as a marketing tool were clearer: The Agora Center not only supported the free exchange of knowledge through its underwriting the costs of the journal but also benefited by building international networks and bringing knowledge of the interdisciplinary research unit to potential research collaborators. Nevertheless, each time, the University of Jyväskylä clearly was part of the equation, all for the tidy sum of less than .00025% of the university's annual budget.

What is notable here is that universities actively participate daily in the movement of research outcomes and knowledge generation beyond that of their own students and researchers. Universities have always played a role in disseminating scholarly knowledge—ranging from in-class oral assignments all the way up to dissertation publishing and, as in past centuries, scholarly journal publishing; these at times represent a university's societal obligation. These activities embody the various types of formal and informal information sharing aspects of the research cycle (Ware & Mabe, 2015). And universities, including this one, could be thought to hold an obligation to embrace all information channels in bringing to its society information and new knowledge (whether or not it was created on its campus or involved researchers from around the world sharing research outcomes) as a return on the investment entrusted through public funding (e.g., Bateman, 2006),

Had it continued as publisher of this niche scholarly journal, the University of Jyväskylä could have had the opportunity to participate with other universities in reconceiving or perhaps even revolutionizing the practices surrounding how scientific information is distributed. Laakso et al. (2011, p. 1) pointed out that because OA journals (typically online) are not constrained by the physical printing process, they offer not only innovative ways to publish but also "offer new possibilities for niche- and emerging subject areas to establish dedicated research outlets." Additionally, universities—which are more open to entertaining a diversity of ideas, approaches, and outcomes, even in discipline-specific discourse and writing methods—could help mitigate the "homogenization" of scholarly publication practices that seems to be on the rise, particularly in the social sciences (Paasi, 2005).

Certainly, *Human Technology* has not reached its full potential as an online journal, that is, one that broke free of the constraints of traditional journal publishing, despite many discussions to do so. As a fully online journal, the editors and publisher of the journal when at the Agora Center explored how digitally published papers could take advantage of multiple means of conveying information, data, and scientific material. One explicit idea was to employ video as figures in papers where such information would enhance the explanation of, for instance, experiments or data gathering. Including OA data sets through links was another option, as was some means to engage readers in discussion of published articles (see also Owen, 2007). Unfortunately, we found that, generally, researchers were not yet ready to employ such alternatives in their publishing activities. But surely this will not be the reality forever and, as in most paradigm shifts, often just a few good visionaries can redirect the practices of a field. Thus, a university dedicated to innovation could have made its mark on the publishing world, over time, by implementing and promoting forward-thinking journal publishing through an aptly available human-centered technology journal.

Other OA journals are still active on the University's campus. However, each them has support either from its research department or a scholarly society. So did *Human Technology* at one point. But when the decision arose regarding the scientific value of this journal as compared to its financial cost, the financial motivation to end it trumped its scientific value.

This perspective must be an important—essential even—component of the discussion surrounding the value of institutional support for OA journals, not just on this campus, or even in this country, but wherever and whenever the OA funding issue is raised.

In advocating for a more active role for universities in scholarly publishing, I acknowledge that such recommendations require a financial investment from, particularly, the research universities around the world, my own as well. In taking all that has been laid about above, I view university-published OA scholarly journals as an immense opportunity for the institutions—either overall or by individual research units or faculties/departments—to influence the future form, function, and content of scholarly research. At the moment, the "Big 5" commercial scholarly journal publishers make significant profits from public-supported universities who annually spend several millions of euros or dollars for access to research by their own and other scholars whose research already has been paid for by public funds.

But imagine if the top 500 or 1000 universities in the world would commit to taking back some control of the scholarly publishing system. If a journal such as *Human Technology* required .00025% of the University of Jyväskylä's annual operating budget, it is possible that, with human efficiencies and improved technical systems and processes, the university could possibly publish six journals (one for each of its faculties) for just twice or three times the cost. If a thousand universities did the same, then 6,000 OA journals—and perhaps more if larger universities invest proportionally the same percentage of their budgets—would influence the scholarly disciplines run by academics for academics. That represents one fifth of the current estimate of active journals. And for their investment, for example, the University of Jyväskylä would have access to all its peers' journals at no additional cost.

However, the financial benefit would not be the only positive outcome. First, such activities make a statement about the role of universities—particularly those in Western economies with more available funding—committing to and supporting the academic world (a global entity) by funding OA journals in areas in which they are experts. This would represent one aspect of their commitment and duty to society, not just in their own countries but around the world. Such an approach and commitment also would demonstrate that research communities (i.e., universities) worldwide value the free exchange of ideas. Moreover, it would demonstrate that universities in advanced economies understand and are willing to help level the uneven academic environment in which scholars and researchers in poorer economies struggle to compete. Finally, by underwriting one or more OA journals, all universities remove any artificial barriers to allowing quality research to flow and contribute concretely to every field of inquiry.

This is not the only answer to the addressing the pressures building within the scholarly publishing field, but it presents movement in the better direction for international interaction and knowledge development. Indeed, universities taking responsibility for and underwriting one or two (or more) OA journals is simply a cupful of water in a great big ocean. But if the largest universities in the world did so, then academics around the world would have hundreds or thousands of journals and archives of scholarly research available to them with few barriers. And if each of the estimated 25,000 universities in the world (TruOwl.com, 2018) would publish just one OA journal, then the scholarly community, over time, would surely have taken back control of the scholarly communication process.

THE DAWN OF A NEW ERA

Human Technology's first two eras have not turned out as well as I would have wished—or the founding academics imagined in the prelaunch planning. But fortunately for the journal, it will have a third era—one that I hope will be long and fruitful. The editorial staff of the journal and the editorial board members are pleased that the journal will not cease its mission but rather will continue in a new home: the Centre of Sociological Research (CSR) in Poland.

Originally established as a platform for publishing research by its team of scholars, it soon expanded to serve as a platform for research dissemination from scientists from the Commonwealth of the Independent States and European Union countries. Yet its evolution did not end there, as it became an official publishing house, but with a vision of attending to the human relations that are so essential in any publishing endeavors. We who have worked on *Human Technology* for so many years feel very fortunate that the emphasis on the humans (in any scenario) remains a key focus and value. As my role as managing editor for *Human Technology* ends with this final issue, I extend my best wishes and great thanks to the staff and scholars of CSR who will take very good care of my "baby," a journal that I was part of before its launch in 2005 and now am sending off for its next big adventure! I have every confidences of its continued success.

Before I sign off, though, I want to provide an appropriate farewell to the humans associated with this journal. Since 2004, I have had the honor and privilege of working with some incredibly talented scholars who were wholly dedicated to the quality of the journal in content, form, and function—and with authors from many countries who invested their time and energy in striving for quality research reporting, even if, ultimately, the paper was not published in our journal. I first extend my thanks to Dr. Päivi Fadjukoff, the former head of the Agora Center, who represented the publisher on the day-to-day work of journal publishing. She was always a visionary and natural problem-solver; her dedication set the stage for what a niche OA journal could accomplish. She worked closely with the other visionaries of the Agora Center: Professors Lea Pulkkinen, Heikki Lyytinen, and Pekka Neittaanmäki, without whom neither the Agora Center nor *Human Technology* would have made their mark on the University of Jyväskylä's campus and in the worlds of interdisciplinary and human-technology research. In addition, I express my thanks to the former director of the Open Science Centre, Ari Muhonen, and his management team, who took in the orphaned journal when the Agora Center was closed and, as best as possible, gave it a go within the work of creating the Open Science Centre at the University of Jyväskylä. I also deeply appreciate the commitment and dedication of our editors in chief: Prof. Pertti Saariluoma, the founding editor in chief of the journal, and the subsequent editors—Prof. Päivi Häkkinen, Dr. Pertti Hurme, and our current editor, Dr. Jukka Jouhki. The quality of the papers published in *Human Technology* certainly rested on your capable shoulders!

We also recently benefited from the efforts and scholarly insights of our current and former associate editors: Dr. Sakari Taipale, Dr. Rosa Mikeal Martey, Dr. Tuomo Kujala, Dr. Johanna Silvennoinen, and Dr. Marc Thompson. And, I would be remiss if I did not give a special shout out to our guest editors, the score of scholars who took on a topic within their academic passion and brought together research that not only contributed to the diverse fields of human–technology interaction but also were excellent reads. I am also grateful for the hundreds of academics around the world who voluntarily participated in evaluating the quality of the papers submitted to our journal. Our biennial "thank you" appears in this issue. Finally, of course, our authors: You are the entire reason why all the editors and reviewers volunteered their immense time and expertise, so that your research can be available readily to scholars around the world. Thank you for seeking out this particular international, interdisciplinary journal for your research reporting. Your work lives on in *Human Technology*'s archives!

Our editorial board members have been an immense source of support and guidance for *Human Technology* over the years. Thank you for lending to us your expertise and exposing those within your spheres of influence to all that *Human Technology* could offer. I personally appreciate those of you who agreed to continue in this important role when the journal moves to the CSR. I extend my personal appreciation to our editorial assistants over the years, Rachel Ferlatte Kuisma, Maiju Lindholm, and Milla Koivuniemi. To our technical staff, where would the journal be without your expertise? Thanks to Rikupekka Oksanen, Asko Soukka, Teppo Naakka, and Riku Eskelinen. Thanks also to Fotini Boyiatzi and, more recently, Jussi Pajari and Hannamari Heiniluoma, who made the transfer of materials and information to *Human Technology*'s new home as easy as possible. And many thanks to the support staff at both the Agora Center and the Open Science Centre who assisted whenever the journal (or I) needed you! Finally, our readers: to the tens of thousands of individuals who came to our website and read our articles—and especially, when you found them worthy of citation—thank you! We trust you will continue to find quality and informative research available for years to come in this journal under its new publisher. I am confident that editors and staff at the CSR will strive, as we have, to provide the highest quality papers possible.

I certainly close the book on my efforts on behalf of *Human Technology* with bittersweet emotions. How could I not be proud of all the work invested in creating and maintaining a quality scholarly journal? Moreover, I am so very pleased that the journal has found a new home with a new set of qualified, dedicated, and enthusiastic academics to protect what the journal is and advance it to new levels of success. I wish them the very best of luck and look forward to becoming an avid reader of upcoming issues. Yet I can't help but feel a little sad that the University of Jyväskylä could not see the value of this journal and the potential it held to not only for filling a niche in the very crowded scholarly publishing field but also the public relations values it projected. I wish this university would have been willing to assume some tiny measure of responsibility to keep a small but growing journal available to academics worldwide. Thankfully, the CSR has assumed this commitment.

ENDNOTE

1. For information on the various aspects of open access publishing, see Hurme (2015).

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Human Technology
ISSN 1795-6889
www.humantechnology.jyu.fi

HUMAN TECHNOLOGY

ISSN: 1795-6889

www.humantechnology.jyu.fi

Volume 17(1), June 2021, 22–44

MOBILE MONEY AND THE IMPACT OF MOBILE PHONE REGULATORY ENFORCEMENT AMONG THE URBAN POOR IN TANZANIA

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Abstract: *Mobile money provides a tool for survival, particularly in urban conditions shaped by city regulations that make microvending difficult for the poor. An analysis of 165 interviews conducted in two low-income neighborhoods in Dar es Salaam, Tanzania over 8 years demonstrates how interlocked layers of technology and interaction make mobile money services semiformal. I introduce two mobile money-enabled survival strategies: intrahousehold transfers for day-to-day survival (transfers within the same city) and resource safeguarding through kin remittances of start-up capital (home-based subsistence business capital stored for kin access in emergencies). The recent tightening of mobile phone regulations in the global South has disrupted users' multilevel and formal/informal-hybrid infrastructures of money movement in these communities. Such tougher regulations could result in a new digital divide that hinders rather than facilitates the financial inclusion of the poor.*

Keywords: *Africa, financial inclusion, poverty, mobile phones, women.*

https://doi.org/10.17011/ht/urn.202106223977

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INTRODUCTION

Mobile phones often are the most complex technological device available to persons living in poverty in the global South (Dodson, Sterling, & Bennett, 2013, p. 79; Murphy & Priebe, 2011). The money services enabled by mobile phones have been heralded as a solution to the challenge of financial inclusion of unbanked segments of populations across sub-Saharan Africa, especially the poorest, whom traditional commercial banking institutions tend not to deem as profitable targets (Global Partnership for Financial Inclusion, 2016; World Bank, 2012). The term mobile money in this paper refers to financial transaction services that can be accessed by anyone using a basic feature phone. Services include storing currency in an account, depositing or withdrawing cash via the account, and sending or receiving currency between two people's mobile accounts. The processes use text messages and menu commands and are made secure by the use of personal identification numbers (PINs; Donner & Tellez, 2008). Mobile money services are highly developed in East African countries and have been shown to be useful in improving livelihoods and reducing long-term poverty (Riley, 2016; Suri & Jack, 2016). However, existing studies on this phenomenon typically have focused on rural areas.

The optimism surrounding the potential that mobile money offers for financial inclusion has tended to overlook the fact that mobile technology usage is constrained by the structures and dynamics of everyday life on the African continent. These include the unreliable nature of the mobile technological infrastructure (Comfort & Dada, 2009; Murphy & Priebe, 2011; Uimonen, 2015), the high costs of airtime and services (Comfort & Dada, 2009; Han, 2012; Murphy & Priebe, 2011; Wyche, Nightingale, & Othieno, 2016), low levels of digital and textual literacy (Dodson et al., 2013; Wyche et al., 2016), poor eyesight (Wyche et al., 2016), and specifically gendered factors that disadvantage women (Abraham, 2009; Archambault, 2011; Kyomuhendo, 2009; Stark, 2013; Svensson & Wamala-Larsson, 2015). One rarely mentioned structural barrier to full digital inclusion in Africa is regulation[1]—the decisions made by governmental actors regarding the degree to which mobile practices are monitored and how. Following Maurer, Nelms, and Rea (2013, p. 56), I approach mobile money as technology-enabled "infrastructures of money's movement" and the processes surrounding their regulation as political struggles for control over these infrastructures.

Mobile operators in Tanzania initially offered access to mobile money in the spirit of market liberalization advanced by their government's Structural Adjustment Programs (Uimonen, 2015). Little government oversight was apparent (Burns, 2018; de Bruijn, Butter, & Fall, 2017; di Castri & Gidvani, 2014), and mobile venders typically provided the Subscriber Identification Modules (SIM) card registration. This made the process relatively quick and easy; however, the process resulted in transactions that were not always traceable to individual identities. In 2009, the Tanzanian Communications Regulatory Authority adopted Know Your Customer (KYC) regulations, part of international Anti-Money Laundering standards (di Castri & Gidvani, 2014). At that time, however, the country did not have a functioning national identification card system. It was not until 2013 that citizens began to register for the new national identification cards (Malibiche, 2018). Yet even after 2013, vendors frequently did not demand a personal identification document when registering a SIM card but, for example, could use his/her own identification card when registering a customer lacking documentation (de Bruijn et al., 2017; Uimonen, 2015). Until 2016, Tanzania was highlighted in the research literature as an African country with an enabling regulatory environment for mobile money, argued to be the key to mobile money's success in the country, a pattern also noted in other East African countries such as Kenya and Uganda (Burns, 2018; di Castri & Gidvani, 2014). In 2016, however, unlicensed or "fake" phones were prevented from connecting to networks via the government's database of International Mobile Station Equipment Identity numbers. That same year, the central government began to link SIM cards directly to subscribers' biometric national identification cards, which featured the holder's name, fingerprints, picture, gender, date of birth, and nationality.

Rigorous enforcement of the 2009 KYC regulation through mandatory registering of SIM cards using biometric identity cards was carried out in the name of reducing fraud, identity theft, money laundering, and illicit financing of terrorist activities (Jentzsch, 2012; Makulilo, 2020; Reuters, 2020). As Jentzsch (2012, p. 611) noted, however, "there are essentially no robust empirical studies that show that such measures make a difference in terms of crime detection as criminals have a number of ways of circumventing rules (Jentzsch, 2012; Omondi Gumba, & Wanyonyi, 2020)." Government surveillance and access to personal data also became a concern to many, especially Tanzanian political dissidents and opposition party members (Jentzsch, 2012; Makulilo, 2020).

In late January 2020, a Tanzanian government regulator announced it had locked out roughly 650,000 mobile users from their phones because they had failed to register their SIM card with their national identity card by the January 20, 2020 deadline (Xinhua, 2020). Local telecoms claimed that even larger numbers of subscribers—into the millions—had been locked out, leading to large losses for these companies in the first months of 2020 (The Citizen, 2020). Because not all low-income mobile users may have been counted and in many households more than one person uses a single mobile device, possibly millions of citizens lost access to mobile phones, with the poorest hit hardest.

In this paper, I examine whether the rhetoric of "financial inclusion for all" aligns with the realities of mobile money use from the perspectives of low-income users. Focusing on two neighborhoods in Dar es Salaam, a port city of 4.36 million inhabitants (National Bureau of Statistics & Office of Chief Government Statistician, 2013, Table 1.2), my analysis focuses on what the poorest in Dar es Salaam use mobile money for and how the regulation of informal practices, including mobile money, affects this usage. *Poorest* here refers to those who pay the lowest rents in the city, have residences typically in flood-prone areas, and live in households that lack food security and the income to obtain medical care in emergencies. None of the interview participants, male or female, received regular wages at the time of the interview. Previous research on financial inclusion for underserved populations in the developing world has focused on mobile money for saving and borrowing. By contrast, I argue that, for the poorest, the simple transaction of transferring money between two persons' mobile phones represents a fundamental means for survival.

Through the analysis of my rich qualitative interview data on mobile phone usage (comprising in-person interviews with 165 participants conducted between 2012 and 2020), it quickly became clear that women were an economically marginalized segment within the chronically poor neighborhoods studied; most were financially dependent on men. Interview participants underscored that even chronically poor Tanzanian men had better access to low-skilled employment, such as jobs in construction and transportation, than did women (see also Plummer & Wight, 2011, p. 378).

Research on the use of mobile money among low-income women in the global South has been biased noticeably toward studies of female entrepreneurs, female vendors in open-air markets, and women working in agriculture. This focus overlooks large numbers of women in sub-Saharan African cities who are none of these things due to a lack of land, education, aptitude, starting capital, or social networks (Cai, Chew, & Levy, 2015; see also, Cleaver, 2005; Ferguson, 2015; Meagher, 2010). In this paper, I focus on women in two situations: those dependent on household members for income and female vendors who lack the business capital to sell in public spaces but instead sell within the semiprivate spaces of their neighborhoods. I explain the practices within which simple mobile transfers of money become the most valuable function of mobile money for the chronically poor, thereby contextualizing them within larger processes and everyday experiences. Although mobile money transfers usually are understood to mean urban-to-rural remittances or emergency cash sent in sporadic crises, these transfers also are used routinely by some Tanzanians for day-to-day survival.

METHODS

In Dar es Salaam, roughly 70% of the city's inhabitants live in low-income, informal settlements (Baker, 2012, Table 1.3). An estimated 50% of the population in these settlements live on an average income of roughly US$1.00 per person per day, well below the international poverty line of US$1.90 (Ndezi, 2009). The physical environment of the neighborhoods in which my interviews took place lacked sanitation, sufficient living space, easily available safe drinking water, durability of structures, storm drainage, and security of tenure, and therefore qualified as a slum under the United Nations Habitat definition (UN-Habitat, 2010).

The people in the neighborhoods I studied covet regular wage work, but this remains beyond the reach of most due to lack of education and/or social connections. Therefore, these residents chose from a variety of informal types of work to obtain income, including vending or working as a day laborer, tailor, or seamstress. Many women with children have turned to sex work when there was no other option. Survival in these neighborhoods require that adults remained able-bodied and to work even in the face of health threats such as malaria, HIV, and high blood pressure, and the high costs of health care.

In sub-Saharan Africa, much chronic poverty can be traced to the Structural Adjustment Programs aimed at neoliberal economic restructuring that were implemented by the International Monetary Fund starting in the 1980s. These programs resulted in high rates of unemployment and the rapid expansion of the urban informal sector (Rakodi, 1997; Tranberg Hansen & Vaa, 2004; UN-Habitat, 2010). Although the most dramatic privatization measures were not implemented in Tanzania until the 1990s, workers' real wages and living standards began to decline dramatically already in the late 1970s and continued through the 1980s (Tripp, 1989, 1994; UN-Habitat, 2010, p. 46). Under the Structural Adjustment Programs in Tanzania, expenditure in education declined by a quarter from 1975 to 1990 (UNICEF, 2000, p. 87). Social sector spending on health care dropped from 2.4% to 1.9% during the period 1974 to 1988, while during the same period, the population of Tanzania rose from 17 million to 22.5 million (Lugalla, 1997, p. 21). These changes left most people paying more for higher education and health care, and the situation has not improved. The erosion of employment and service conditions in Tanzania has meant that persons and families can only survive through ever more strenuous feats of endurance.

Between 2012 and 2018, as a university project leader, I interviewed 165 persons on a broad array of topics related to mobile phone use. My semistructured qualitative interviews were part of an ongoing, university-funded study, begun in 2012, that examined poverty and gender in two chronically low-income neighborhoods of Dar es Salaam. I refer to these neighborhoods here with the pseudonyms Kijito and Mahalikavu.

Key informants, one woman in each of the two neighborhoods, were identified through local NGOs. The key informants in turn asked persons they knew if they would agree to an interview; they did not exclude anyone on the basis of gender, age, ethnicity, or any other criteria. Only a few persons declined to participate. The language of the interviews was Kiswahili, the national language in which all respondents were fluent. Female interpreters who shared similar socioeconomic backgrounds with the interview participants translated between English and Kiswahili.

Of the 165 persons interviewed, 87% (n = 144) were women and 13% (n = 21) were men. Significantly more women than men were interviewed because I conducted interviews inside the neighborhoods during daylight hours for security reasons, and women tended to be at home at least part of the day, unlike men, who were generally outside the neighborhood at work or seeking work. Only 14% (n = 20) of the women I interviewed had more than a primary-level education, whereas all (100%) of the interviewed men had gone beyond primary school. Ten women (7% of all women interviewed) had no schooling at all. Interviewees self-identified with more than 35 ethnic groups, reflecting the ethnically heterogeneous makeup of these urban neighborhoods. The focus of this paper—married women dependent on their close male relatives for income and female vendors who lack the business capital to sell in public spaces—comprised 73% (n = 105) of the 144 women interviewed.

Due to the intense heat year-round, I interviewed in the mornings each day for 4–5 hours, usually under the shade of a tree or at the home of the key informant's family. Although I did not sleep in the neighborhoods I studied due to security concerns (especially theft), when I was with my informants, I walked with these residents through the neighborhoods and listened to the topics they spontaneously brought up, including their most important—albeit infrequent—pleasures (e.g., music, food, nice clothes, celebrations, the Internet) and their all-too-common concerns (e.g., floods, theft, illness, hunger). My approach was ethnographic in the sense that it involved in-depth interviews and some degree of physical presence allowing for observation in the place studied. Ethnography implies a particular way of seeing how people understand their everyday experiences but from a critical standpoint that interprets these representations within their socioeconomic and cultural contexts. Ethnography focuses on the motives and attitudes of the people studied in order to learn not just *what* people do but *why* they do it.

Informed consent was problematic due to the informants' low levels of education. Although each interview started with an explanation of the purpose of my research, some interviewees did not know what a university or research study was, and they remained convinced that I must work for a humanitarian or development organization, the most familiar role for a white woman in Tanzania. Signed consent forms were not collected in order to avoid humiliating those who were nonliterate or revealing to neighbors their low literacy status, which often was kept secret. Because of the ethical challenge inherent in the ambiguous informed consent obtained verbally, I did not audiotape the interviews but rather wrote down their comments so that informants could see what I was doing with the information they provided. I transcribed verbatim as best as possible the conversations as translated by the interpreters; this included my asked questions and the translated answers from my informants. In other words, I wrote down word-for-word everything the interpreter told me the participant had said. I was painstaking in this process, and interviews proceeded slowly for this reason. During the interview, I typically reviewed my written notes during the interview and asked clarifying questions, for example, about the terms used in Swahili or about an unfamiliar practice or custom.

I began each interview by seeking a holistic understanding of the participant's livelihood, family and residence history, schooling, marital and parental status, as well as the greatest difficulties of living in the slum. Rather than presenting an exact set of questions to all informants, I started with only specific inquiries about each participant's concrete life events and circumstances to encourage them to bring up new topics and information I could not have anticipated. I pursued a single line of questioning until I reached a saturation point (Glaser & Strauss, 1967) on that topic, that is, when no new information appeared in responses. Then we moved to a new line of questioning. Additional data collection consisted of reviewing the interview notes after each session and thinking of continuation questions to ask the next day. I transcribed my handwritten notes to a digital format and, after multiple close readings, recurrent themes in the data were noted and categorized thematically by hand.

The analyzed interview data presented here is not intended to represent all lower income groups in African cities or in Tanzania specifically. Broad variations exist in types of economic opportunities for women, family obligations, and networks of remittance across and within the country and the continent. What this qualitative data from two low-income neighborhoods in one city shows is how mobile money practices, survival, and the regulation of informal businesses are causally connected in the understandings of those living in the same locality and who face the same challenges. Only an ethnographic approach can provide insights into the subjective perceptions that motivate particular uses of mobile technologies.

RESULTS

Everyone in Dar es Salaam depends on cash to survive, but the vast majority of the women I interviewed did not have formal bank accounts. Some had bank accounts in previous decades but had closed them due to high fees. One barrier to banking with a formal institution has been the relatively high cost of opening an account (TSh 20,000[2]); another has been the minimum balance needed for the account to remain open. By contrast, mobile money accounts cost nothing to open do not require a minimum balance, and do not charge monthly service fees. Until recently, another barrier to physical banking was the geographically sparse dispersal of physical bank branches and ATM machines in the city, unlike the large numbers of mobile agents and subagents operating on nearly every street corner (see also di Castri & Gidvani, 2014, p. 4). By using mobile money, people could thus avoid traveling long distances in congested traffic and waiting in long lines for a bank teller. This latter problem has been solved in part in recent years through personal bank accounts connected to mobile money accounts, thus bypassing the need for a teller or ATM machine. In addition to profiting from the sale of mobile airtime, mobile money providers receive small fees charged for withdrawing cash money from a mobile money account. Customers are not charged for sending money through their mobile phones, as long as they are sending 5 million TSh or less. Mobile agents and subagents, for their part, are incentivized by monthly commissions paid by the mobile money provider, which depend on the number of transactions mediated by the (sub)agent, the size of these transactions, and the overall number of customers served by the (sub)agent that month. Fees and commissions vary across different mobile money providers and customer plans.

Other important changes in mobile money practices reported by participants over the period 2012–2018 involved the widespread adoption of mobile money in the period of 2012–2013 and the increased number of people using smartphones in the neighborhood in the years 2017–2018. Not all these smartphones were bought new: Many were obtained through networks of theft and fencing that operate in the neighborhood and throughout the city (Stark, in press).

The two neighborhoods were physically similar and adjacent to each other. I spent the most time in Kijito, which unlike Mahalikavu, bordered a small river and was plagued by annual flooding during the rainy season. When entering Kijito from the main road, I saw houses built of cement, arranged haphazardly and connected by outdoor yards and open spaces, where brightly colored cotton wraps hung to dry. Children played barefoot, and women cooked food outdoors over charcoal fires. In some places, corn and local vegetables grew in the open spaces between houses, goats were tethered to trees, and chickens roamed the grass pecking at edible pieces of garbage. Few roads in the neighborhood were large enough for automobiles to pass and most were only paths and corridors between houses. The only vehicles that occasionally entered these spaces were pushcarts and narrow three-wheeled taxis (*bajajis*). Although garbage and waste covered the uneven ground, the predominant smell in the dry season was that of smoke from charcoal fires. In the rainy season, the ground of low-lying Kijito became a morass of foul-smelling water and slippery mud. Although the maps show that Kijito and Mahalikavu are just 5 km from the center of Dar es Salaam, the main impression gained of both these areas is that of rural villages: Palm trees swayed in the quiet breeze punctuated by the occasional blare of music from a radio, and typically only a few residents could be seen walking or carrying out daily tasks in the open spaces. These neighborhoods are not the "African urbanscapes" (Uimonen, 2015) that figure prominently in social media. They have no billboards displaying smart phones or fast Internet access, and the only images that hint at cosmopolitan urban youth or "beautiful, successful urbanites" (Molony, 2008) are the small hand-painted advertisements on the concrete walls of one-room hair salons showing chic haircuts.

Mobile Money Transfers in Tanzania

In 2008, the mobile money service M-Pesa was introduced in Tanzania and spread rapidly due to low taxation and an initial lack of government oversight (Burns, 2018; di Castri & Gidvani, 2014). At first, most mobile money transfers were person-to-person; now, they encompass a broader payment system for utility bills, rent, taxes, school fees, and retail payments (Aron, 2018). Between 2014 and 2016, four Tanzanian mobile network operators (Airtel Money, Tigo Pesa, EzyPesa, and Vodacom M-Pesa) negotiated and agreed on voluntary interoperability of mobile money accounts, which made it easier for people to send or receive money (Financial Inclusion Insights, 2017). As of 2020, Tanzania has a broad and efficient network of mobile money services run by five major telecom operators. According to 2016 data, roughly 83% (21 million) of all mobile subscribers in the country use mobile money (Global System for Mobile Communications, 2016). However, the actual number of beneficiaries and scope of mobile money transfers are not captured in official statistics because persons who do not have a mobile money account often use the accounts of other family members or neighbors. According to interview participants, the most popular mobile money service among low-income users in Dar es Salaam is Tigo's Tigopesa (*pesa* means money in Kiswahili). In other areas of the country, M-pesa and Airtel Money are more popular.

In Tanzania, mobile money accounts, analogous to checking accounts in other countries, are associated with a mobile phone number accessible by a PIN code (Economides & Jeziorski, 2017; Wamala-Larsson, 2019). A person installs an application onto aSIM card, establishes an electronic money account with a telecom operator, and deposits cash with real-life local agents (*wakala*) in exchange for digital money. Deposited money can be withdrawn as cash, for purchasing mobile phone airtime, or for paying bills. Dialing, for instance, *150*01# provides access to Tigopesa's menu of mobile money services. Each agent has a unique agent number, so when customers wish to withdraw cash, they enter the agent's number into the menu provided on the customer's phone. When the agent receives a phone message confirming the transfer of digital currency from the customer to the agent's account, the agent gives the customer the cash equivalent of the amount digitally transferred for a small service charge. Local agents in shops or on street corners (see Figure 1) thus serve as cash transfer points, equivalent to ATMs or bank automats (Maurer et al., 2013). Money within a customer's mobile account can be saved safely because the money in the user's account is protected by a PIN code, even if the phone is stolen (Economides & Jeziorski, 2017). Customers with mobile money already in their accounts can send money directly to relatives or friends without the need for a mobile money agent.

Figure 1. This shop near Kijito advertised that it functioned as a mobile money agent (*wakala*, see top and bottom left of image). Photo by Laura Stark, 2017.

Mobile money services have been described as "semiformal" because the providers of mobile financial services are not necessarily registered and thus not supervised by the formal financial sector (de Koker & Jentzsch, 2013; Shem, Misati, & Njoroge, 2012). In the urban settings I studied, mobile money transactions consist of four components:

- the handset or device itself,
- the technology and practices of the digital finance platform run by the telecom operator,
- the formal financial institution (bank) that provides digital money (e-float) to the agent's SIM card in exchange for the equivalent currency deposited by the agent in the bank, and
- the "human infrastructure" (Maurer et al., 2013, p. 58) representing the agents on the ground who sell SIM cards and dispense and receive cash. Even without a formal stall, an agent does not need much to register and sell SIM cards and receive and dispense cash: just a few feet of pavement, a mobile phone, and a metal cash box for storing paper money.

Although mobile money agents perform many functions that in other countries might be automated, they also advise, assist, and mentor customers in operations requiring digital finance literacy (Maurer et al., 2013). However, unlike the agents in Maurer et al.'s (2013) analysis who were established and already known in their communities, most full-time mobile money agents in the most trafficked parts of Dar es Salaam are *machinga*: men and women who work as self-employed subagents working under main agents, yet with relatively little oversight from either the main agent or the telecom provider. Due to their mobility and potential transience, these *machinga* may not know their customers, who choose them for the convenience of their location. From the perspective of urban residents who use mobile money, the numerous subagents operating throughout the city offer great convenience and enable them to send, receive, or store money wherever they are—exiting a bank, stepping off a bus, or wherever one does not want to risk theft by carrying cash.

Certainly, the first three levels of mobile money operations listed above could be defined as formal because they follow industry standards and national legislation. However, a significant number of subagents at the fourth level function informally. In Tanzania, in order to be a formally recognized agent of a mobile network operator, such as Tigo, Airtel, or Mpesa, the agent must apply for a customized agent SIM card directly from the operator, for which he/she needs a tax identification number, a national identity card, and a business license. Even if the agents meet these requirements, it can take up to a month for the agent's SIM card application to be processed. A customized agent's SIM card can be obtained more easily by buying it directly from another subagent who is leaving the business. In fact, as of late 2020, Tigo and Vodacom no longer issued agent SIM cards, making buying one from another subagent the only way to obtain one.

Subagents must fund their own operations and, in order to make an adequate profit from commissions, they need a minimum of TSh 1 million starting capital, a substantial sum for low-income residents in Dar es Salaam. Subagents deposit TSh 500,000 in the bank as the float in their agent line for customers who want to deposit cash and receive digital currency in their mobile money accounts. Subagents must also have TSh 500,000 in cash on hand for those customers who want to exchange the digital currency in their account for a cash withdrawal. When the costs of an agent SIM card (if bought informally from another agent) and the large umbrella stand that advertises the telecom operator's brand to customers are added to the above, the start-up costs for an informal subagent can easily be over TSh 1.4 million.

Subagents strive to work in the central areas of the city characterized by heavy foot traffic. A formal stand or kiosk from which to operate could cost TSh 200,000 per month, paid to the owner on whose land the stand is located. This sum represents two thirds of what is considered a decent average monthly income (TSh 300,000) for mobile money subagents. Being unable to afford a formal operating stand, subagents frequently are chased away from prime locations by municipal security guards known as *mgambo* (also *chachavi*; Malefakis, 2015). Further, subagents may be forced to pay fines directly to the *mgambo* under threat of imprisonment. The municipal security guards are tasked by the city with keeping the locations "clean," meaning free from informal vendors. The penalty fines are usually TSh 50,000 each time an informal mobile subagent is caught by the *mgambo*.

In addition to obtaining money for themselves, mobile money users can convert cash to credit via agents in order to send money to relatives or friends. This does did not necessarily mean sending money from urban to rural areas. Rather, as population and competition for income within the urban economy increase, some urban inhabitants are so poor that their rural relatives are comparably better off. Among those I interviewed, mobile money was sent in both directions. Interview data indicate that common remittance relationships among relatives involved

- adult siblings sending money to each other, for example, to fund children's school fees or to set up a small business,
- fathers or brothers sending money to daughters/sisters who were not provided for by a husband,
- adult sons and daughters sending money to parents,
- mothers with no possibility to house their child in the city sending money to grandparents who cared for the child in the countryside,
- couples inhabiting a house with renters sending the rental income to their nonresident parent who owned the house,
- relatives in the city sending money to a family member farming family-owned land and thereby maintaining the family's legal claim to it, and
- husbands sending money to their wives when either has traveled from home.

However, my interviews revealed that relatives send mobile money to each other not only under special circumstances such as these. One purpose of sending mobile money was to transfer cash within households in order to carry out daily activities.

Intrahousehold Transfers for Day-to-Day Survival

Literature on female entrepreneurs and even so-called Bottom of the Pyramid (Prahalad & Hart, 2002) businesses typically focus on urban socioeconomic groups whose members possess more resources than those living in the neighborhoods I studied. This literature often is industry driven, infused with a techno-optimism unsupported by the interview responses I received. Within the mobile communications industry, the emphasis on market-led economic growth, encouraged in part by microcredit's promise of the profits to be made from the poor (e.g., Maurer et al., 2013; Roy, 2010) has made the notion of mere survival uninteresting. But survival is dynamic and creative; it is an achievement in itself.

A vast body of literature has shown that the poorest women in the global South often cannot access the wage work that is more available to men. There are many more job opportunities in cities than in the countryside, but even urban jobs for women typically are informal, erratic, and poorly paid. The poorest women also often lack sufficient education needed to be hired or the capital needed to start their own small businesses. Adult women in poverty thus tend to be dependent on money from others, mainly relatives. In contrast to Kusimba, Yang, and Chawla's (2015) study of mobile money in rural Kenya, the women in my data who were dependent on kin for their own and their children's survival received most of their income from their husbands or the fathers of their children and, in rarer cases, from their own fathers. As neoliberal economic restructuring depletes resources from households through higher costs for food, education, and healthcare (Fraser, 2017; Hickel, 2014; Rai, Hoskyns, & Thomas, 2014; Rioux 2014), what used to be known as kin networks in both the anthropological and sociological literature are no longer necessarily robust or extensive social ties. Individuals in these low-income areas typically must rely on a few persons whose support has become meager and unreliable (Cleaver, 2005; Desmond, 2012). Urban settings enable high mobility and anonymity leading to a weakening of the formerly rigorous obligations of solidarity networks (Olivier de Sardan, 1999; Portes & Sensenbrenner, 1993). The women I interviewed reported that networks have become increasingly smaller and weaker, and now in urban areas, it is shameful for married women to ask for help from relatives who expect husbands to provide for their wives.

According to many interview participants, family members in their households were highly dependent—in some cases wholly dependent—on the money earned by male heads of household in informal jobs. The role of the masculine provider is vitally important for Tanzanian men's self-respect, and the authority that men enjoy as heads of household depend on their fulfilling that role, at least to some extent. In the past, husbands left small sums of money for their wives before they left to work in the morning. Sums less than TSh 3000–5000, wives reported, were inadequate to cover the costs of a family's meals for the whole day. In such cases, husbands often were willing to go to great lengths to find a little money in the morning and ensure that it reached home by the middle of the day. This money nearly always was sent via mobile money. Mobile money transfers reduced transaction costs for sending and receiving money, and these costs included the costs of travel, travel time, and waiting time in long queues, as well as coordination costs between individuals. Dar es Salaam is a densely populated city with an insufficient transportation infrastructure, severe traffic congestion, and unmapped city areas that can be difficult to navigate. As a result, bringing home money in person, even to a nearby neighborhood, entails considerable time and effort. Husbands at work in the city, had they needed to deliver the cash themselves, would have faced traveling considerable distances on foot through heavy traffic between work and home. Even a trip in a relatively inexpensive three-wheeled *bajaji* taxi might have cost all the money a husband possessed at that moment, as well as take up to an hour due to traffic jams. Mobile money agents, however, are found readily along roadsides throughout the city—either in small shops or at tables set up on sidewalks—so that income-earners could find, with relative ease, an agent to send money to a wife's mobile account. Mobile money services thus saved men the extra time, effort, and costs they would have had to expend to take money home in person.

Many of the women I interviewed lived in families who possessed no savings, no refrigerators to store food, and no food stocks such as dried beans or rice. Thus, the money sent by husbands via mobile money paid for food consumed the same day. For instance, Aziza's[3] husband, a city bus driver, was paid by the bus's owner every evening. If he could not leave enough money for his wife and two children when he left for work at 4 in the morning, he borrowed money from the bus fares collected by 8 a.m. and sent it to his wife through his phone, using a local agent he trusted along his bus route. Aziza concluded, "If he can't send money, we can't eat during the day."

In a similar case, Zahra[4] explained that her husband worked as a cook for a wealthy non-Tanzanian family. At times, he was sent to the shop with money to buy food for his employer's family and was allowed to keep the leftover change from the purchases. If the money from his monthly salary ran out before the end of the month, he sent the extra money to Zahra through Tigopesa so that she could buy that day's food for their family.

Intrahousehold transfers also were sent by adult children to their mothers who were responsible for the family meals. Fatima,[5] who lived with her adult children and grandchildren, explained that as soon as her children received small sums of money from their day jobs, they transferred it via mobile money so she could buy food for the evening meal to feed everyone.

> *My daughters working in the hair salon sometimes send money to me, sometimes in the morning when they go to the job if there is no money for food in the family. They send money through Tigopesa so the family can buy food. The daughters working in the saloon get paid daily…. In the morning, if nobody in the family has any money for food, each goes to the job and if they get roughly TSh 5000, they contact me by mobile phone; they call or text to my younger daughter who has a phone and ask, "Mama, have you found anything yet?" And if not, they send it through Tigopesa and the food is bought and cooked by the time they come home in the evening.* [Fatima, aged 58]

The introduction of user-to-user mobile money transfers thus has given rise to the strategy of sending home tiny sums as the money is earned throughout the day so that other members of the household can buy the food needed for the evening meal. Mobile money allows for the moment-to-moment flow of resources within poor families that otherwise would not have been possible. For those persons and households who must use their entire meager income for each day's food, mobile money is not just a convenience but a necessity for survival.

In this survival-oriented practice, the role of informal mobile money agents, and particularly their ubiquitous presence in the most trafficked parts of the city, is crucial. Mobile money agents can be counted among the multitudes of urban informal workers involved in the day-to-day movement and distribution of resources throughout the city. The cheap labor they provide is crucial for the continued functioning of this sub-Saharan African neoliberal city and keeps down costs of living for those with low incomes (de Oliviera, 1985; Roever & Skinner, 2016). Yet, the demands from the city administration that informal mobile money agents maintain a permanent stall in the city center threatens the availability of the services that these agents provide. Paying rent for such a stall may benefit the landowners in the city, but offers little to the roughly 35% of residents in Dar es Salaam who live below the poverty line and need speedy transfers using mobile money agents in the places they frequent most often.

Resource Safeguarding Through Kin Remittances of Start-Up Capital

Most research on informal vending/microtrading in urban sub-Saharan Africa has focused on street and market vendors selling in fixed, public locations. In reality, a far broader range of informal actors are involved in the day-to-day manufacture and transport of goods throughout Dar es Salaam. Many microtraders do not sell in streets or large public markets but in spaces where different logics apply (Lappi, 2017; Lappi & Stark, 2013). Of my female interview participants, 35% had been involved in microtrade of goods or skilled services in the past 5 years. To understand what microtrade meant to the women I interviewed, it is important to specify how they perceive the distinctions between various types of self-employed vending, based on the profits that could be generated for the vendor. From most to least desirable, these are

- Owning a permanent shop or stand in a busy marketplace
- Renting a market stall or street vendor's stand
- Being a vendor moving on foot in busy areas of the city
- Selling clothes, food, or other goods to neighbors within an informal settlement.

The most preferred types of self-employed vending requires initial capital investments that are inaccessible for the majority of the residents I interviewed. Vending also requires licenses, fees, and the rental or purchase of a "frame" in which the goods are displayed (Skinner, 2008; Wamala-Larsson & Svensson, 2018). For these reasons, most female vendors I interviewed are not street or market traders but sell goods and foodstuffs within the semiprivate spaces of their neighborhoods, where they can operate under the radar of government regulations (Lappi, 2017; Lappi & Stark, 2013). Such spaces are primarily in front of or beside their dwellings, which means that most of the female vendors I interviewed cook food for and sell goods to their neighbors (see Lappi, 2017, in press). Their neighbors, in turn, sell goods and foodstuffs to them. Neighborhood vending is thus home-based work that either produces or circulates goods for persons living within a relatively small radius of the vendor's home, rather than for the broader market. The most useful item to sell from the vendor's point of view is food because, if business is slow, then a woman's family could simply eat the cooked food or snacks that she had prepared for customers. Yet women also sell a highly diverse assortment of clothing, cigarettes, soap, charcoal, and even beauty products. The result has been a dynamic internal economy of the slum (Lappi & Stark, 2013) that provides income, albeit meager, for roughly 30% of the female residents I interviewed and represents the largest income-generating category among women.

Neighborhood vending not only provides livelihoods, but also makes the neighborhood more livable for all residents. Long distances, traffic jams, and lack of public transportation make it difficult for people to shop farther afield for everyday necessities, even if these would be cheaper in distant open-air markets. Female customers, occupied at home by their own neighborhood vending businesses and domestic tasks, are thus willing to pay the additional markup for goods sold by neighbors. A busy resident needing milk, eggs, or tea could quickly buy small quantities from neighbors rather than walk to the open-air marketplace 20 minutes away, and children could be sent by mothers to neighbors to buy breakfast snacks or *chapattis* (unleavened flat breads, a staple in East Africa) for the family supper if parents were busy. Despite its importance, the internal economy of the slum has been overlooked in policy and research literature. Whereas street and market traders conduct their business in highly visible public areas and have therefore received considerable attention (e.g., Skinner, 2008), neighborhood vending is relatively invisible and inaccessible to outside observers. Even within neighborhoods, a woman cooking food outside her front door may not be recognizable immediately as a vendor (Lappi, in press; Lappi & Stark, 2013).

Although microtrade benefits city residents overall, many barriers exist to neighborhood vendors expanding into public areas. The women informants acknowledged that moving their vending location to a main street would increase their profits, but this also risked their being noticed by the *mgambo*. Harassment of street vendors by these municipal officers and the destruction of goods and stock are reported to be widespread in sub-Saharan Africa (Lyons & Msoka, 2010; Roever & Skinner, 2016; Skinner, 2008). Among the women I interviewed was Maria,[6] who sold roasted *cassava* (a nutritious tuberous root from the Manihot plant) to residents inside her neighborhood. She felt that a higher-traffic area such as a main road would be more profitable, but a barrier for her was the higher starting capital (TSh 30,000) needed to increase her sales. Another obstacle was the *mgambo*, who did not venture inside the neighborhood but likely would have noticed her if she were selling along the main road.

> *[The* mgambo*] don't want people to sell along the road. They may take your things, keep them if they are good things or throw them away if not, and if you don't want them to do that, you need to pay them.* [Maria, aged 35]

The municipal council also requires medical check-ups for vendors who cook and serve food—nearly all of whom were female—along roadsides and in marketplaces. The penalty for food providers caught without a health certificate was TSh 50,000. Many unlicensed women in these businesses sought to escape the surveillance of such inspectors who appeared to be more interested in collecting penalty fees than in evaluating the sanitary conditions or health risks posed by the vending site and vendors, as Chiku[7] explained:

> *Most people, when they hear that the inspector is coming, they close shop quickly and run away and reopen when they are gone…. When the inspectors come, they don't care if it is clean or dirty; they just want money or they can lock you up.* [Chiku, aged 26]

Even for an informal neighborhood vending business, women generally need start-up capital of at least TSh 10,000. Many of my respondents stated that they did not have such a sum. Some women managed to acquire start-up capital through local informal group savings groups, such as ROSCAs (Rotating Savings and Credit Associations). In these groups, all members contribute small sums of money each day (often through their mobile phones) that are kept (often in a mobile money account) by a trusted member who serves as the treasurer. Often these sums come out of the housekeeping money given wives by their husbands. The entire pot of money is then paid out at an agreed time interval, for instance once per day, week, or month, to one member at a time in a prearranged order. The time interval and amount of the pot awarded to one member depended on the number of members paying in each day and what they agreed. The groups in the neighborhoods I studied were known as *mchezo* or *upatu* and were informal and self-organized, with anywhere from three to 96 members each. These savings groups did not solve every woman's needs for ready cash, however, because not all women had money to contribute every day, and not all female neighbors were invited to join a local ROSCA because these associations rely on strong trust among members. Additionally, groups were sometimes organized to run for a limited period only, and frequently the last person in line to get the pot did not receive it because other members were not motivated to pay their daily contributions after they had received the pot for themselves. Therefore, instead of saving through ROSCAs, some women asked relatives, usually living in another part of the city or elsewhere in the country, to send them start-up capital by mobile money transfers. In some cases, husbands give their wives start-up capital, but other male relatives also send money to female relatives to start these small businesses.

In the context of the neighborhood survival economy, however, start-up capital often does not grow because these small-scale neighborhood vendors sell mostly to neighbors who were struggling equally hard to survive. Most female vendors earn only a meager profit, if any. Small vending businesses also fail on a regular basis when the female vendors or their family members faced illnesses, accidents, funerals, marital separations, school fees, or unplanned pregnancies; the female vendors are forced to use the capital from their business to pay the costs arising from these needs. Women then often had to ask the same relatives who had provided the initial start-up capital to replace it, and many did. For instance, Aisha[8] lived with her three adult children and two grandchildren. She cooked fried snacks from rice flour (*kitumbua*) in front of her home and sold them to neighbors as breakfast treats. Her younger brother, who worked for the government in the capital city of Dodoma, had sent her TSh 50,000 via mobile money to cover the costs of starting her business. Although she did not have a mobile money account of her own, she had used the account of her 25-year-old son who was living with her. The business afforded her a subsistence living, and she sent any extra money onward to her younger brother who was a farmer in the countryside. When her 30-year-old son died, however, she had to stop her business and use its capital to pay for his funeral. The same brother in Dodoma then sent her an additional TSh 50,000 through mobile money to restart her business after the funeral.

Circulated capital thus flowed down from mostly income-earning male relatives toward the most vulnerable female members in the kin network. Yet these vulnerable vendors, in turn, could send the capital stored in their microbusinesses to other relatives in dire need.

Therefore, the purpose of women's small businesses is not necessarily to increase the start-up capital provided to them by brothers, husbands, or cousins. All parties seem to understand the function of start-up capital: to retain this capital for as long as possible while surviving on its meager profits—until the next crisis wipes it out. Mobile money is vital to sustaining these businesses through infusions of cash. This system enables geographically scattered kin groups to distribute quickly their assets within the survival economy to ensure that members of the entire kin network remain able-bodied. If healthy and able to work, each kin member could assist the others and accumulate income for the network, while keeping the network resilient enough to withstand urban shocks. These businesses thus can be viewed as part of broader networks of resource safeguarding by groups who circulate value. The purpose of these networks is not the success of the individual but the survival of the kin group as a whole (Ferguson, 2015; Kusimba, Chaggar, Gross, & Kunya, 2013; Kusimba et al., 2015; Kusimba, Yang, & Chawla, 2016; Meagher, 2005). In the cases I studied, this system of resource safeguarding could operate only under the municipal government's radar, however, because neighborhood vending operated without permits or health inspections.

Impact of Regulatory Enforcement of Mobile Money on the Survival of the Poorest

Beginning in January 2020, new SIM card registration in Tanzania required a national identification card, which many Tanzanians lacked (Stark, 2020; Uimonen, 2015). To obtain a national identity card, applicants needed to show their birth certificates. However, because birth certificates were not needed previously in Tanzanian life, many citizens did not have one (Lichtenstein, 2020). In the global North, citizens' lives tend to be highly documented through driver's licenses, passports, social security numbers, bank accounts, and so forth. In the neighborhoods I studied, by contrast, people rarely used official documentation in their everyday lives, until recently (see also Uimonen, 2015). Most sources of income in these neighborhoods have been informal, and relations and communication have been face-to-face or through mobile phones. Most people have not had access to computers and have had little or no money for newspapers or books. As long as they traveled within Tanzania, they needed no identification.

Applying for a national identity card has been free of charge, but the process has not been free of problems. In September 2020, when on-site interviews were not possible due to the Covid-19 pandemic, I conducted interviews by phone and email, through a female interpreter, with key female informants. I was told that, even in earlier years, not everyone who applied for a national identity card received one, either because their application had been lost inside the bureaucracy or because the card itself, usually sent by post several months after application, never reached the applicant. Understandably, then, the Tanzanian government's announcement in April 2019 that mobile phone users would be blocked if they did not register SIM cards with biometric national identity cards caused a sudden and dramatic surge in applications that overwhelmed the National Identification Authority, the agency in charge. The backlog included many persons who had recently turned 18 and needed to apply for an identity card for the first time as well as those who had lost their previous identity card and needed a replacement. As a result, large numbers of persons waited 7 or more months to receive their biometric identity cards. Nevertheless, on January 20, 2020, the Tanzania Communication Registration Authority blocked all SIM cards not registered with the national identity card, which meant that persons waiting for their application to be processed were unable to use their SIM cards and thus their mobile phones. This included at least six persons (five women and one man) whom I had interviewed in Kijito on previous visits.

How did these persons who were unable to use their SIM cards receive money or even alert relatives and friends that they needed help? Once again, they were compelled to circumvent official policies and, on the advice of their local government officials, they used a nonsanctioned strategy. Because anyone holding a national identity card legally was allowed to register up to five SIM cards for personal use, people with identity cards began to register new SIM cards under their own names for their relatives, friends, and trusted neighbors. They did this by going to a mobile phone agent operating outside their own neighborhood who did not know them personally and would not know they were circumventing the rules.

Receiving a new SIM card registered in another person's name did not help, however, in cases where contact numbers had been saved to the previous SIM card and the user could not remember them. For example, Jasmin[9] had to manage 2 months without a working SIM card before a local government official advised Jasmin's mother to register Jasmin in the mother's name. Although Jasmin's mother had the phone information for their relatives, Jasmin did not remember the phone numbers of her friends and could only hope that she would run into them, an improbability in a city of nearly 5 million inhabitants. During the months when Jasmin had no mobile access, she also lost a job opportunity—a loss compounded by the rarity of such an opening in the high unemployment environment. Previously, she had asked a friend working in a hospital cafeteria to alert her if any jobs at the cafeteria became vacant. When a position did open up, Jasmin's friend was unable to contact her, and the job was given to someone else, as her friend told her months later when they happened to see each other at Dar es Salaam's largest open-air market, Kariakoo.

The two mobile money practices discussed above—intrahousehold transfers for day-to-day survival and resource safeguarding through kin remittances of start-up capital—indicate that lenient SIM card registration enforcement in Tanzania actually helped the majority of the urban poor in their daily survival. Even before the recent drive to enforce KYC regulations (2018–2020), regulatory tightening had been shown to reduce the use of mobile phones among those living below the poverty line (Aron, 2018; van de Walle & Sahai, 2017). The new regulatory tightening has added significantly to the burdens of those who find it difficult to cope financially even one day without mobile phone access. It disrupted the fine-tuned, multilevel, formal/informal-hybrid infrastructures supporting the movement of digital money. By forcibly integrating the quite unprepared National Identification Authority into this infrastructure, the Tanzanian government introduced a weak link that crashed the system. Although the Tanzanian and international media noted this crash, the majority of those affected were low-income residents with lower levels of education and less prominent voices in public affairs, which meant that the full scope of the disruption remains unclear.

DISCUSSION AND CONCLUSIONS

Low-income users in the global South are predicted to remain unbanked by formal financial institutions and thus will continue to rely on mobile money (Aron & Muellbauer, 2019). In urban areas, as indicated by my respondents in Dar es Salaam, Tanzania, mobile money transfers are used for purposes other than just remittances to rural areas or sent as help in crisis situations. Mobile money is used frequently for short-distance transfers within the same city to circumvent or compensate for obstacles such as unreliable road infrastructure and heavy traffic. It also is used to sustain the capital stored in home-based subsistence businesses so that the kin network can access it in emergencies. Such access is important in a context in which health care is unavailable or expensive, crises come in many forms, and few safety networks exist outside of relatives.

This study focused on two mobile money-enabled survival practices used by female residents in two low-income neighborhoods. First, intrahousehold transfers allow members of the poorest households to send money to each other as they earn it so that the whole family can eat on the same day. These “as needed” or “same-day consumption” transfers from income earners to nonearners occurred frequently enough to be nearly routine. The second mobile money survival practice involves resource safeguarding through kin remittances. Money is supplied via mobile phone transfers by relatives to small-scale neighborhood vendors in order to maintain the capital “stored” in their struggling businesses until it is needed for emergencies by the vendor or her relatives. When relatives send start-up capital to women to establish microbusinesses, they are not investing in a business expected to expand. Instead, they are participating in a form of group circulation of resources as a means for the kin group to protect themselves in times of crisis.

As is often the case in the interlocking relationships between formal and informal spheres of urban life in Africa (Wamala-Larsson, 2019), the case I studied in Dar es Salaam demonstrates a clear disjuncture between what is publicly asserted and what is experienced on the ground. Numerous means of officially endorsed surveillance as well as expulsion of independent business operators create barriers to officially stated aims of reaching underserved populations. Mobile money services have been declared by governments and international development organizations to be one solution to the challenges of financial inclusion. Yet at the level where official policy meets the everyday lives of the urban poor, formally sanctioned practices impede the use of informal survival strategies. Municipal security guards demand permits and health inspections from vendors who venture into more highly trafficked areas seeking customers. If vendors cannot provide these official documents, they risk the security guards threatening them with imprisonment, pocketing coerced fines, and destroying their vendor's stock. Excessive regulation of where informal mobile money agents can operate in the city also hampers the agent–customer interaction that is vital to digital financial inclusion.

The disconnect between official policy and residents' lived realities prevents full use of mobile money by the poor. This was evident in the impact of new regulatory enforcement that demanded biometric identity cards for access to mobile network services. The analysis presented here supports recent literature that cites "enabling" regulatory environments as the key to the growth of mobile money in sub-Saharan Africa (Burns, 2018; di Castri & Gidvani, 2014). It further shows how, precisely, strict enforcement of KYC standards can significantly and negatively impact low-income users. My results point to one of the mechanisms that can go wrong in the implementation of such standards: a lack of coordination across enforcing government agencies. When the separate elements of regulatory enforcement fail to work in synchrony, the poor are those who suffer the most. This may be one reason why regulation seems to negatively impact the poor more than other socioeconomic groups (Aron, 2018; van de Walle & Sahai, 2017) and why it has hindered the growth of mobile money services in countries such as Nigeria, Ghana, and South Africa (Burns, 2018). Such nonsynchrony in the enforcement of regulations can itself represent a barrier to mobile money use by disturbing the delicate mechanisms operating in the semiformal system of mobile money. In the absence of evidence that tougher controls actually reduce criminal monetary transactions through mobile phones, plans for tighter regulation of SIM card usage and mobile money agents' operations should be examined carefully at every stage of the implementation to see whether alternatives exist to achieve the same goals. The indications in my analysis that strict enforcement of KYC guidelines in mobile money can impede financial inclusion of the poorest should raise concerns about the creation of a new digital divide.

IMPLICATIONS FOR RESEARCH, APPLICATION, OR POLICY

The findings from this study of the use of mobile money by poor women in urban Tanzania contribute to knowledge in two important ways: They expand the literature and raise implications for the impact of government mobile regulations on the urban poor. This research underscores the vital role that mobile money plays in the daily lives of poor women in the global South. Two primary uses of mobile money identified in this research—intrahousehold transfers for same-day food purchases and resource safeguarding in the form of kin remittances for informal home-based businesses—contribute to understanding how essential mobile money is for day-to-day living and ongoing kin network support.

At the policy level, this research points to the need for governments and their agencies to consider more closely how regulations and laws play an essential role in either supporting or undermining the financial inclusion of the most economically vulnerable within their societies. In this sense, governments need better understanding of how members of different socioeconomic strata manage the daily challenges of survival. Such knowledge then increases the opportunity for fair and equitable regulations on, for example, mobile phones and mobile money. Without clear comprehension of the impact of regulations on low-income groups in particular, enforcement of laws can seriously complicate the lives of a country's poorest citizens. This is because the poorest have little flexibility in managing the fallout of regulations that disrupt the socially established financial patterns for their daily survival.

ENDNOTES

1. For exceptions, see Burns (2018) and di Castri & Gidvani (2014).
2. The currency conversion rate of 1,000 Tanzanian shillings (TSh) on 26 March, 2021 was €0.36/US$0.43. Some currency conversion companies abbreviate the Tanzanian shilling as TZS.
3. Aziza, 24-year-old mother of two children, secondary school education. All names have been changed to protect the anonymity of interview participants.
4. Zahra, 41-year-old mother of two children, primary school education.
5. Fatima, 58-year-old mother of six children, primary school education.
6. Maria, 35-year-old mother of four children, primary school education.
7. Chiku, 26-year-old mother of three children, primary school education.
8. Aisha, 58-year-old mother of six children, no education.
9. Jasmine, 26-year-old mother of one child, primary school education.

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Human Technology
ISSN 1795-6889
www.humantechnology.jyu.fi

Human Technology

ISSN: 1795-6889

www.humantechnology.jyu.fi Volume 17(1), June, 2021, 45–80

APPROPRIATING BIOSENSORS AS EMBODIED CONTROL STRUCTURES IN INTERACTIVE MUSIC SYSTEMS

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Abstract: *We present a scoping review of biosensors appropriation as control structures in interactive music systems (IMSs). Technical and artistic dimensions promoted by transdisciplinary approaches, ranging from biomedicine to musical performance and interaction design fields, support a taxonomy for biosensor-driven IMSs. A broad catalog of 70 biosensor-driven IMSs, ranging in publication dates from 1965 to 2019, was compiled and categorized according to the proposed taxonomy. From the catalog data, we extrapolated representative historical trends, notably to critically verify our working hypothesis that biosensing technologies are expanding the array of control structures within IMSs. Observed data show that our hypothesis is consistent with the historical evolution of the biosensor-driven IMSs. From our findings, we advance future challenges for novel means of control across humans and machines that should ultimately transform the agents involved in interactive music creation to form new corporalities in extended performative settings.*

Keywords: *biosensors, appropriation, interactive music systems, control structures.*

https://doi.org/10.17011/ht/urn.202106223978

INTRODUCTION

The advent of novel, portable, and more accessible microcomputers in the 1970s hailed a cultural transformation in contemporary music practices, in particular, improvisatory musical practices. This transformation led to a new aesthetics of musical performance called “interactive composing” (Chadabe, 1984). Interactive composing implies the use of electronic instruments that make musical decisions in response to the human performer sharing control of the musical process, thereby establishing a new critical space to explore communication between the human(s) and machine(s). Interaction is a concept frequently adopted across multiple musical expressions and activities, such as musical performing, composing, or listening. Despite the common use of the word *interactive* in musical practice, interactive music denotes a particular compositional approach that emerges from a feedback loop between humans and computational agents (Rowe, 1992). Figure 1 shows a prototypical architecture of an interactive musical system (IMS) that involves two agents: a human and a computer. Yet, IMSs can adopt somewhat fluid multiagent architectures when incorporating multiple computational or human agents, in line with the practice of ensemble practice in instrumental music. As an example, the interaction between a human and a computational agent or between computational agents and an audience (i.e., multiple human agents) is a typical multiagent IMS approach (Levin, 2006). Even an IMS featuring computational-only agents has been pursued (Codognet & Pasquet, 2009).

The interplay and communication flux among agents in an IMS is bidirectional, using varying degrees of control and feedback instantiated by their sensor and actuator components, respectively. Furthermore, the natural and artificial cognition and memory at the core of each agent recognize and process all the sensed data and then act accordingly.

Although acoustic instruments offer several degrees of interpretational affordances, digital instruments (such as IMSs), with their score-driven instructions written for the metamachine (nonphysical) nature of electronic and digital musical systems, allow for an augmented degree of arbitrary relations between the control and feedback (Magnusson, 2009). IMS practices that rely on metacompositional practices range from random or stochastic procedures to rule-based (Chadabe, 1997) and cognitive models (Çamcı, 2012).

Agents in an IMS can influence, affect, and alter the underlying compositional structure, and the musical work emerges through this control and feedback process (Drummond, 2009). Particular emphasis is given to the sensing and control structures of an IMS as well as the IMS’ potential for agency. Furthermore, the design of frameworks in IMSs are increasingly fostering interdisciplinary

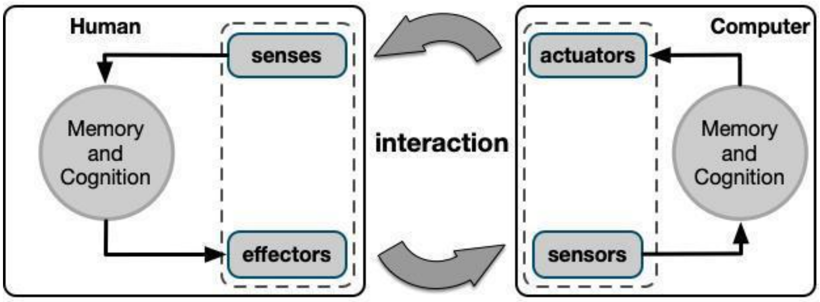

Figure 1. An interactive system architecture as a control and feedback loop, adapted from Bongers (2000).

dialogues, such as human–computer interaction (HCI) and music focusing on the intersection among an IMS, a human body, and the biosensing technologies. These new design strategies have expanded IMSs toward environmental sensings, such as the exploration of video-based tracking as a control structure for interactive music creation (Caramiaux & Tanaka, 2013; Jordà, Geiger, Alonso, & Kaltenbrunner, 2007) and biosensing technology (Arslan et al., 2005).

Biosensing employs biosensors—analytical devices that convert a biological and chemical event into a measurable signal—to provide opportunities for sensorimotor control, thereby affording musicians performing with an IMS various experiences with their bodies. Coupling body physiology and music promotes new interaction modes and, ultimately, impacts music by re-envisioning the role of the musician's body during the performance (Tanaka, 2019). Furthermore, compelling creativity questions arise for both researchers and IMS musicians when the use of biosensors is expanded to capture the audience's physiology. For example, by capturing high-level cognitive traits from audience members using biosensors, interactive musicians can ultimately access the audience's emotional states during an ongoing performance, thus unpacking new strategies for interaction across multiple humans and computational systems.

More recently, IMS musicians appropriated biosensors as expressive control structures for controlling the generation of music in IMSs. In this context, *appropriation* refers to a recontextualization of specific technology beyond its primary application (Naccarato & MacCallum, 2017). Throughout our study, we verify that biosensing allows the scope of interactions available to the musicians to expand. Biosensors in close contact with the body promote the capture of a wide range of movements—from low-to-high body expressions—typically inaccessible through traditional sensor tracking devices, such as video tracking. By lower- and microexpression levels, we mean both the smallest controllable and perceivable human motion—such as small facial expressions—and the continuous motion of various parts of the human body, such as the rhythmic patterns of breathing or pulse. Therefore, as a control structure for musical interaction, biosensing decodes inner structures of the performer's body as a control variable in an IMS.

Additionally, biosensing captures a particular type of interaction when it measures unseen electrical activity captured through sensors placed on the surface of the skin. For example, electromyography measures muscle activity, electroencephalography estimates brain activity, and electrocardiography measures heart activity. IMS musicians adopt biosensing as a control structure for driving IMSs with high degrees of expressiveness (Caramiaux, Donnarumma, & Tanaka, 2015; Donnarumma, 2011; Erdem, Schia, & Jensenius, 2019). Body movements and their rich and complex gesticulation is increasingly explored in HCI by using touch screens, depth cameras (e.g., Kinect camera), video controllers, or smartphone motion sensors.

Fostered by artistic and technological developments, namely open-source biosensing devices, biosignals have received increasing attention in recent years as control structures in interactive systems and HCI. To advance the understanding, categorization, and classification of these biosensing IMSs, researchers have proposed various taxonomies (e.g., Christopher, Kapur, Carnegie, & Grimshaw, 2014; Da Silva, 2017; Drummond 2009; Ortiz, Grierson, & Tanaka, 2015; Prpa & Pasquier, 2019). Christopher et al. (2014) debated the impact of new emerging paradigms incorporating brain activity through electroencephalographic signals (EEG) in music making. Drummond (2009) focused on the potential interactions with IMS. Da Silva (2017) presented a taxonomy characterizing biosignal data sources that balanced expectations around their use in HCI. It highlighted aspects such as controllability and acceptability, which are fundamental to the design of biosensing systems in real-world cases such as medical monitoring in Fitbit applications. Ortiz et al.'s (2015) taxonomy concentrated on, in particular, EEG-based musical practice. Finally, Prpa & Pasquier (2019) provided a comprehensive catalog of 40 works guided by a taxonomy to categorize brain-computer interfaces (BCI) in contemporary artworks that incorporate EEG signals mapped to music, video, painting, print, and virtual environments. However, none of these studies considered the interplay between the biosignals from an HCI perspective and the potential interaction within a musical system. We believe our proposed taxonomy can fill that gap in the literature.

By integrating both functional and empirical categories in our proposed taxonomy, we provide a more detailed description of an IMS and help envision future pathways for biosensing IMSs. For example, the recent growth in the use of nonobtrusive devices (i.e., the miniaturization of devices) for capturing biosignals promotes multiple performers' potential interactions in an IMS due to more pervasive and easy-to-use devices. Another example of the interplay among functional and empirical categories is the correlation between the musician's perceived controllability over the system and its response type in terms of musical structures. A highly controllable signal fosters manipulation of higher musical structures, such as differences in volume or frequency.

The present study presents an integrated taxonomy for analyzing biosensor-driven IMSs. Focusing on functional and empirical dimensions, our taxonomy encompasses a broad catalog of IMSs, spanning a time frame from 1965 to 2019. Additionally, we sought to identify any visible trends across IMS biosensing controls, responses, and affordances, while noting the abstraction levels that have been considered in IMSs from raw biosignal. Our study raises the hypothesis that biosensing technology in IMSs is expanding the array of control structures within IMSs and can be seen as a new mode of control among human and musical systems—opening new creative avenues for interaction, expressivity, and embodiment in music performance (see also Tanaka, 2019).

The remainder of the paper is organized as follows. The Methods section details the research methodology for data collection and analysis. Then the Biosensing Technologies: A Technical Overview section presents biosensing technology according to its typology and specifications. The A Taxonomy for the Analysis of Biosensing in IMS section characterizes the multidimensional taxonomy adopted in our study, both the functional and empirical categorizations. The section Biosensing in IMS: A Temporal Perspective revises temporal applications of biosensing technologies within biosensor-driven IMSs presented in the catalog, based on visible trends and extrapolated from global statistics applied in the catalog's items across IMS biosensing control, response, and affordances. In the section Toward an Embodied Control Structure in IMS: Future Challenges, we outline novel perspectives on the integration of biosensing when designing new musical interfaces. The paper closes with the Conclusions and Implications sections, in which we discuss the novelty, originality, and the limitations of our study. Our aim is to discuss the future challenges involved in embodied control in IMS creations through the use of biosensors.

METHODS

In pursuing the main objective of our study—that is, an integrated taxonomy for analyzing the functional and empirical categories of biosensor-driven IMSs—we also aimed to identify historical trends in IMSs regarding (a) biosensor adoption as control structures, (b) response types in terms of the musical output of the system, and (c) performative affordances. The process of identifying these trends would allow us to classify IMSs according to their appropriation of existing biosensor technology. Moreover, such a process also would raise our awareness of the human body in performative musical contexts, which ultimately could lead to identifying artistic and technical challenges in a future roadmap for the biosensor-driven IMSs. To this end, the following four-fold methodological goals were adopted: (a) compiling a comprehensive catalog of biosensor-driven IMSs, (b) defining a biosensor-driven taxonomy of IMSs, (c) applying the proposed taxonomy to the catalog, and (d) identifying historical trends from the resulting taxonomy application data.

To compile the comprehensive catalog of biosensor-driven IMSs, we adopted a scoping-review method, a process particularly suitable for a wide range of transdisciplinary fields (Arksey & O'Malley, 2005). The search for biosensor-driven IMSs was conducted online on relevant scientific archives, such as IEEE Xplore, ACM Digital Library, Google Scholar, as well as art catalogs and musicians' websites. We completed the entire online search during April 2020. To filter the search, we mapped key concepts to their related sources: *biosensors, interactive music systems, music, sound, HCI, performance, embodiment*, and *biophysical*. We manually surveyed the retrieved documents to identify their potential to be included in our catalog from the collected sources. To this end, we took into the catalog only entries that met the following two criteria: (a) biosignals from either performers or audience members were present, and (b) biosignals were mapped to sonic feedback and response. The first criterion ensured the inclusion of biosensor-driven works, while the second criterion specified the underlying qualities of an IMS.

Furthermore, we reviewed each source document that met the above criteria for related sources. For example, in scientific literature, we inspected the reference section to identify additional potential biosensor-driven IMSs that met our criteria. A particularly relevant case was that of Prpa and Pasquier (2019), who had compiled a list of 40 interactive BCI artworks.

To define a biosensor-driven IMSs taxonomy, our point of departure lays within three earlier taxonomy proposals by Prpa & Pasquier (2019), Drummond (2009), and Da Silva (2017), which focused on artistic categorization, sonic feedback, and HCI, respectively. The lack of an articulated taxonomy reflecting the interrelationships of both functional and empirical categories has significant impact when defining mapping strategies among musical events and functional properties of a biosignal, such as perceived controllability. To accommodate both these categories, we compiled all dimensions featured in each previous taxonomy and empirically tested them in our catalog by annotating each entry according to the complete set of dimensions. We then pursued simplifying the adopted dimensions to reduce redundant information and organized them uniformly according to our functional and empirical categories. Due to the subjective nature of most IMSs and with the goal of unifying the proposal, we redefined some dimensions to account for relative description spaces rather than specific discrete types. In the final step, we gave careful consideration to the adoption of continuous or discrete spaces in each dimension within the taxonomy. The decision between the adoption of continuous or discrete spaces in each taxonomy dimension was done by inspecting their manifestation on the collected catalog data and by surveying existing literature on the topic. Once the taxonomy was finalized, we adopted it to categorize and compare all entries of the biosensor-driven IMS catalog.

Regarding the process of identifying the historical trends resulting from the taxonomy, we plotted the data of each dimension of the taxonomy to reflect its temporal evolution with multiple resolutions. We aimed at finding points in time where abrupt changes in the defined dimension occurred. Peaks and valleys in the data exposed various appropriation strategies of biosensors in the scope of IMSs. Peaks indicate historical moments where the appropriation of biosensors in the artistic IMS practice had greater attention by musicians. Conversely, valleys denote historical moments where the appropriation of biosensors had a steep decline.

The ultimate goal of the taxonomy was to articulate the functional and empirical dimensions of IMSs. A preliminary data analysis identified where explicit representative dimensions were noticeable. Thus, we focused on the analysis and interpretation of the following dimensions: type of biosignal used, the type of response expected from a specific IMS, and the performative affordances IMS musicians seek when conceiving an IMS. Conformity in terms of these temporal marks across dimensions were the basis for extrapolating representative periods of the biosensor-driven IMS practice as well as for extrapolating current directions, challenges, and future endeavors in this line of research and artistic practice.

BIOSENSING TECHNOLOGIES: A TECHNICAL OVERVIEW

Human psycho-physiological activity has multiple bodily manifestations, including biophysical, biochemical, bioelectrical, and biomechanical processes, which we define collectively as biosignals, in line with Northrop (2017) and Saltzman (2015). Recent sensor technology has been developed to detect and measure these manifestations, notably to support medical care (Cacioppo, Tassinary, & Berntson 2007; Webster & Eren, 2017). Although some biosignals can be measured only under controlled conditions (e.g., magnetic resonance imaging), others can be obtained unobtrusively using inexpensive sensor devices. Examples include motion, respiration, brain activity, skeletal muscle activity, cardiac rhythm, and skin functions, to name a few. Beyond their medical applications, biomedical sensing technologies have been attracting the attention of interactive musicians, who are increasingly adopting this technology to control the parameters of interactive digital systems.

Over the past few decades, researchers have proposed a wide range of taxonomic perspectives of biosensing, rooted in various disciplines and applications. Horowitz and Hill (1989) organized sensor technologies according to their circuit design, while Sinclair (2000) arranged them according to the physical quantity measured by a sensor (i.e., the type of energy: radiant, mechanical, gravitational, electrical, thermal, and magnetic). Bongers (2000) categorized sensors based on the ways human movement changes the surrounding environment. In the context of IMSs, the most common control structures relate primarily to bioelectrical or biomechanical processes, resulting in, for instance, motion, airflow, or muscle activity. We grouped the sensors by their specific functions and, in Table 1, we provide a list of common sensors, their abbreviations, and functions. All the abbreviations adopted in our study stem from Heck (2004).

Table 1. Biosensing Technologies: A Comprehensive List of Bioelectric and Biomechanical Sensors Grouped According to Their Specific Function.

Bioelectric sensors		
ECG	electrocardiogram	measures the electrical activity of the heart using electrodes placed in contact with the body surface (Malmivuo & Plonsey, 1995; Votava & Berger, 2011)
EDA	electrodermal activity	Measures, through electrodes applied to palms of the hands or soles of the feet, the skin conductance changes that result from the sympathetic nervous system activity (Boucsein, 2012; Ortiz, Coghlan, & Knapp, 2012)
EEG	electroencephalogram	measures the electrical activity of the brain using electrodes in contact with the scalp (Malmivuo & Plonsey, 1995; Ortiz et al., 2015)
EGG	electrogastrogram	measures the electrical signals associated with the gastric muscles via electrodes in contact with the stomach region of the skin (Chen, Xu, Wang, & Chen, 2005; Yin & Chen, 2013)
EMG	electromyogram	measures the electrical activity of surface (sEMG) or internal (iEMG) muscles using electrodes attached noninvasively to the body surface (in the sEMG) or, for the iEMG, placed invasively in contact with the muscle fibers (Basmajian & Luca, 1985; Nagashima, 2002)
EOG	electrooculogram	measures the corneal-retinal potential variation associated with the eye movement (Kopiez & Galley, 2002; Ramkumar, Kumar, Rajkuma, Ilayaraja, & Shankar, 2018)
TEMP	temperature	measures body internal temperature via thermistors, thermopiles, infrared, thermal imaging, or analogous elements
Movement sensors		
ACC	accelerometer	measures static (i.e., relative to gravity) or dynamic acceleration (e.g., due to motion, shock, or vibration) generally employing a damped mass mounted on a spring (Donnarumma, Caramiaux, & Tanaka, 2013; Niu et al., 2018)
AF	air flow	measures the air inflows and outflows typically by way of a thermal element or a spirometer turbine (e.g., can enable air volume estimation) placed in the nostril or mouth (Hedrich, Kliche, Storz, Ashauer, & Zengerle, 2010).
FSR	force sensing resistor	measures the load applied in tension, compression, or torsion typical via a force-sense resistor (FSR) or strain gauge (Lee et al., 2018; Schwizer, Mayer, & Brand, 2005).
FLEX	flex sensors	measures the amount of flexion in an element applied to the body surface by way of a bend sensitive resistor, strain gauge, or optical fibers (Saggio & Orengo, 2018; Torre, 2013)
GYR	gyroscope	measures angular rate through a vibrating structure or spinning disc (Höfer, Hadjakos, & Mühlhäuser, 2009; Passaro, Cuccovillo, Vaiani, Carlo, & Campenella, 2017)
MAG	magnetometer	measures the strength of a magnetic field (e.g., of the earth) or magnetic anomalies in a particular location (Essl & Rohs, 2009; Merayo, 2002)

(continued)

Table 1. Biosensing Technologies: A Comprehensive List of Bioelectric and Biomechanical Sensors Grouped According to Their Specific Function. (Continued)

MMG	mechanomyography	measures via ACC, FSR, piezoelectric, or strain gauge sensors the skin displacement as a result of muscle activation (Donnarumma et al., 2013; Talib, Sundaraj, Lam, Ali, & Hussain, 2019)
PST	position sensors	measures the angular and tilt position of the body typically through linear or rotary adjustable resistors that change their electrical properties with the position of a wiper element (i.e., a moving contact for making connections with the terminals of an electrical device; Y. Park, Lee, & Bae, 2014)
RESP	respiration sensors	measures the displacement of the chest induced by the inhaling and exhaling activity using a piezoelectric element, a pressurized tube, or inductance variations in a coil embedded in fabric (Vidyarthi, Riecke, & Gromala, 2012).
Optic Sensors		
MOCAP	motion capture/tracking	measures the motion of an individual with varying degrees of sensitivity via multiple video cameras (visible or infrared, with optional depth-sensing), passive infrared sensors, ultrasound, or related sensors (Bevilacqua, Naugle, & Valverde, 2001; van der Kruk & Reijne, 2018)
PPG	photoplethysmography	Measures, via sensors using an illumination element in the visible or infrared range and a photodetector, the blood volume changes as expressed by the amount of reflected or transmitted light that changes with the perfusion variations associated with the blood pumping activity of the heart (Alian & Shelley, 2014)
Environmental Sensors		
AP	air pressure	measures via a force collector (e.g., a diaphragm) the tension resulting from the force applied by a gas (e.g., blowing through a mouthpiece) or liquid over a known area (Nagashima, 2002)
HUM	humidity sensors	measures the volumetric water content of a medium typically through a resistance or capacitance variation sensor
LUX	luminosity	measures the intensity of light (visible or invisible) that reaches a photosensitive element

In this section, we presented the most-used biosensor technologies per functional categories. In the next section, we provide a description that takes into consideration the nature, specificities, and peculiarities of the type of signal biosensors capture. By classifying the signal sources as a basis for the taxonomy of biosensor-driven IMSs, we propose an analysis of IMSs both functionally and empirically.

A TAXONOMY FOR THE ANALYSIS OF BIOSENSING IN IMSs

In this section, we propose a taxonomy to classify biosensor-driven IMSs. We apply our taxonomy to the collection of 70 IMSs that we present in a table below. The inclusion of IMSs in the catalog followed the criteria stated in Methods.

Figure 2 shows the taxonomy categories featuring a twofold (functional and empirical) organization. The functional category is adapted from an existing taxonomy (Da Silva, 2017). We subdivided the functional category into dimensions to detail biosignals from HCI and signal-processing perspectives according to perceived user controllability, device obtrusiveness, feature observability, and signal property. The perceived user controllability and device obtrusiveness dimensions consider the perceived accuracy of user control over the degrees of freedom of a biosignal and the ergonomic implications of the biosensors. Feature observability and signal property dimensions describe time and frequency-domain signal attributes, such as the description of typical time scales at which information rate is acquired from the sampled signal and the stability of the signal's statistical properties over time.

The empirical category adopted in our study describes the potential interaction of a musical system in facilitating the categorization of IMSs according to the creation of compositional sonic architectures (Drummond, 2009). We subdivided empirical categories into dimensions to detail

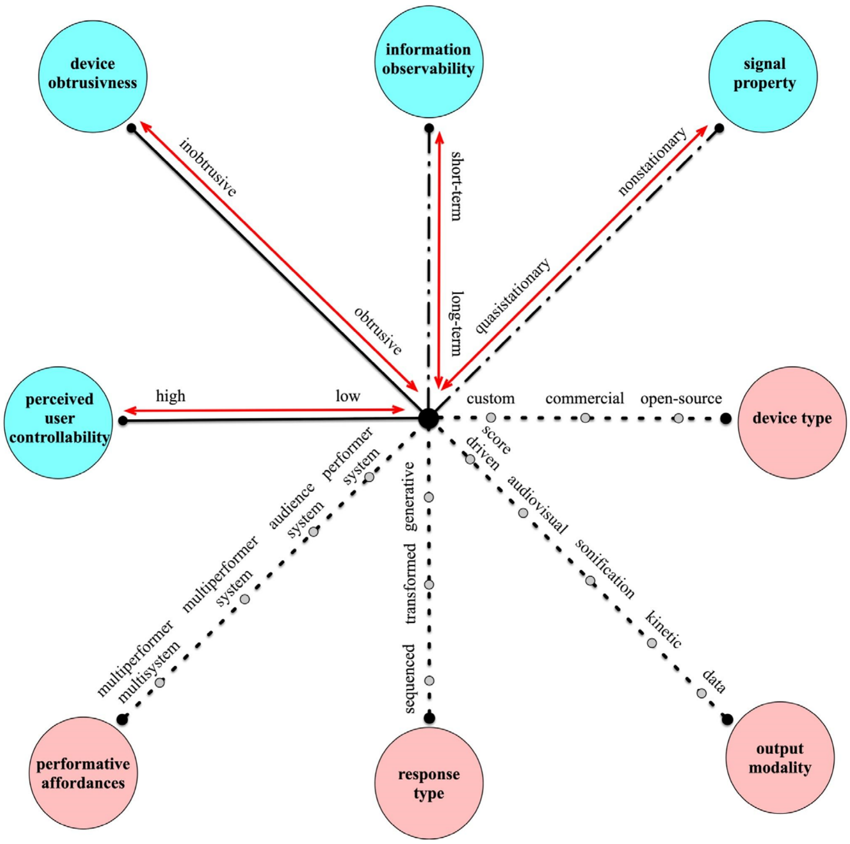

Figure 2. The functional and empirical categories in a dimensional space adopted in the IMS works' presented in Table 2 (see below). Here, we differentiated the functional and empirical categories by the colors blue and red, respectively. In the star diagram, each line from the center of the space denotes a different dimension, with line strokes identifying its area of knowledge: human–computer interaction (solid line), signal processing (dashed line), and interactive music system (dotted line). Dimensions in our taxonomy can be continuous or discrete. The continuous dimensions are denoted as (red) arrowed lines whose endpoints are identified as qualitative spaces.

biosignals as control structures from a technological perspective (device type) as well as their interactive musical qualities, such as output modality, response type, and performative affordances.

For example, we define the information observability of a biosignal as a temporal scale along with a continuous space whose limits are short-term and long-term observability. Depending on the application domain, long or short degrees of changes can promote different information rates. The discrete qualitative spaces designated with a gray circle along the dotted lines can be positioned along or within dimensions' lines. A specific IMS can belong to a single or to multiple types. For example, the type of output musical response of an IMS can be either generative or sequenced or adopt both strategies along the musical time, yet as separate entities. A hybrid degree of generative and sequenced responses cannot exist.

We detail in the following two subsections each of the functional and empirical dimensions in our taxonomy according to (a) its grounded area of knowledge, (b) its definition and associated concepts in the literature, (c) its dimensions, and (d) its associated sensing device.

Functional Dimension

The functional category comprises four dimensions: perceived user controllability, device obtrusiveness, information observability, and signal property. From an HCI perspective, the perceived user controllability dimension represents the perceived control accuracy a user has over the output of a biosignal (Wanderley & Orio, 2002). In other words, the perceived user controllability indicates the degree of control a user maintains in the action–reaction (i.e., input–output) loop of an interaction system. It exists as a continuous dimension between two types: high- and low-perceived user controllability. A high degree of perceived controllability encompasses responses that originate from the somatic portion of the peripheral nervous system that controls skeletal muscle and voluntary movements, such as arm muscle activation or limb displacement. Examples of biosensors that users typically perceive as having a high degree of controllability are the EMG, FLEX, and GYR. A middle degree of perceived controllability would reflect EEG signals that capture a mixture of signals with a relative degree of control movements, such as eye opening and closing, as well as involuntary activity, such as the level of focus or relaxation through measurements of alpha or beta waves, respectively (Ray & Cole, 1985). An IMS musician can explore these many correlations to enrich the IMS musical experience. A low degree of perceived controllability is linked to responses that originate from the sympathetic nervous system's activity and is associated with involuntary activities that increase energy expenditure and arousal levels, such as electro-dermal, temperature, or cardiac activity (Tahiroğlu, Drayson, & Erkut, 2008). Examples of biosensors typically perceived by the user as having low controllability are the ECG, EDA, and RESP.

Also from HCI perspective, the device obtrusiveness dimension (i.e., both sensor and the respective signal-processing device[1]) denotes the user's physical experiences of that specific technological device. It exists as a continuous dimension between two types: obtrusive and inobtrusive. An obtrusive device refers to a physical experience of a specific technological device that the user may perceive as uncomfortable (Hensel, Demiris, & Courtney, 2006). Biosensors perceived as having a high degree of obtrusiveness typically are worn or attached to the body, such as headsets with electrodes for capturing brain activity (Çiçek, 2015). In extreme cases, obtrusive devices can be invasive, that is, placed inside the body (Filas, 2013). Invasive methodologies include indwelling needles and wire electrodes inserted into the muscle tissue to extract information about the processes at the muscle membrane level (Rau, Schulte, & Disselhorst-Klug, 2004). At the opposite end of the scale are inobtrusive devices, referring to the miniaturization of monitoring devices and the potential for the noninvasive capture of biosignals (Van den Broeck & Westerink, 2009). An example of a control structure sharing the property of being inobtrusive is body temperature when captured through an (off-the-body) infrared camera that detects heat patterns in body tissues. A middle degree of obtrusiveness is likely to be associated with smartwatches or toolkits for biosignal acquisition (the latter being more obtrusive).

From a signal processing perspective, the biosignal information observability dimension denotes the time scale at which changes in the biosignal-captured data (beyond residual noise) are observed. The information observability dimension exists as a continuous dimension between two types: short-term and long-term. A short-term information observability implies a biosignal from which information is retrieved at the millisecond range. For example, an EMG conveys information from muscle electrical activity that can have sudden degrees of change at the sample level; typical sampling rates of 250 Hz (Open BCI) and 1000 Hz (BITalino) are assumed. A middle degree of biosignal information observability can be linked to an ECG and PPG, for example. These signals capture cardiac activity within the 300 ms to 1.5 s range (Alian & Shelley, 2014; Malmivuo & Plonsey, 1995). Long-term information observability implies a biosignal in which information rate is lower due to its smaller degree of change over time. A long-term information observability occurs within the seconds range. A representative long-term information observability example is the EDA, whose response time to stimuli typically ranges between 1 and 5 s (Boucsein, 2012).

Finally, the signal property dimension denotes how stable the signal statistical properties are over time. The signal property exists as a continuous dimension between two types: quasistationary and nonstationary. A quasistationary signal has nearly steady statistical properties, that is, might change very slowly over time. An example of a quasistationary biosignal is body temperature measurements: The human body does not present abrupt temperature changes. A middle degree of signal stability is reflected in a respiration measurement during physical effort. At the beginning of the exercise, the respiration rate will be quasistationary, but as the physical effort increases, the measurements will be nonstationary, reflecting an increased acceleration in the pulmonary activity. A nonstationary signal has expressive statistical variations over time (Escabi, 2005) as demonstrated as an EEG measuring sudden eye-blinks or EMG measuring spikes in the muscular activity.

When working with biosensing technologies, one must recognize the devices' sensitivity to external interferences. Due to the dynamic nature of some IMS applications, motion is a primary source of the artifacts. The feeble nature of bioelectrical signals (i.e., in the millivolt range for the ECG and EMG and the microvolt range for the EEG, EGG, and EOG), brisk and high-intensity movements can result in electrode displacement—even when the device is attached to the skin over the target area—which introduces noise in the signals. Force also influences the measurement in some sensors. For example, the EDA, which measures skin impedance, can suffer from variable artifacts when pressure is applied to the electrode (which changes the contact area between the electrode and the skin). Additionally, the crosstalk between adjacent recording muscle sites is not negligible when electrodes are located on muscles with different functions (antagonist pairs or muscles with one common and one different function). Electromagnetic noise (e.g., from a transformer or fluorescent light) also is prone to mask the signals of interest or even lead to erroneous measurements (i.e., from strong magnetic sources influence, e.g., MAG signals). Environmental factors, such as air conditioning or heating units, can influence control structures such as HUM and/or TEMP. Other external factors also may indirectly affect the control structures that are controlled by the nervous system. For example, EDA responses can be triggered by startling, unexpected events such as a mobile phone ringing.

Empirical Dimensions

We now describe the empirical category adopted in our catalog of IMSs. We split the information into four empirical dimensions: device type, output modality, response type, and performative affordances. Empirical dimensions focus on the interactions mediated by interactive systems and their interaction potential for facilitating the creation of music. For example, is an IMS designed to be played by one, two, or more performers, or even include the audience as a player? Is its audiovisual modality projected in a physical space? Are there symbolic instructions for a coplaying hardware synthesizer or just a direct sonification process? Is it a generative response type, transformative, or prerecorded sound? When combined with functional categories, the empirical categories provide a clearer critical view about IMSs as a whole.

The device type presents the range of biosensing devices applied in each artwork and encompasses three discrete types: custom, commercial, or open-source. In IMSs' early embodiment, custom devices with biosensors were pervasive; yet even contemporary IMS works employ creator-developed devices. Since 2010, however, commercial mobile biosensing devices have been available on the consumer market. The advantages of these new technologies include quick and easy positioning, wireless Bluetooth or Wi-Fi data transmission, easier mobility, and affordable pricing (Chabin, Gabriel, Haffen, Moulin, & Pazart, 2020). Commercial devices aimed at the consumer market include the Emotiv or Neurosky products, as well as reliable devices for research works, such as g.tech, Cognionics, or Neuro-electrics products. More recently, open-source devices have emerged onto the market. The advantages of open-source devices for research and artistic purposes include rapid assembling, integration, and prototyping with several programming languages. Moreover, open-source products do not maintain a commercial restriction over the biosignal data. BITalino (Da Silva, Guerreiro, Lourenço, Fred, & Martins, 2014) and OpenBCI (Durka et al., 2012) are examples of such devices.

The output modality dimension defines IMSs according to the many ways of outputting signals through actuators, that is, a transducer element that converts electrical energy into other physical quantities or displays. The output modality dimension encompasses five discrete types: score-driven, audiovisual, sonification, kinetic, and data. A score-driven output type implies an IMS with embedded knowledge of the overall predefined compositional structure and the ability to track the performer in real-time, accommodating subtle performance variations. An audiovisual output space implies an output such as light bulbs, light-emitting diodes (LEDs), liquid crystal displays (LCDs), or video projectors and lasers. A sonification output type indicates a direct mapping between a specific biosignal attribute and its respective sound parameter. A kinetic output space denotes vibrotactile displays, for example, loudspeakers or piezo buzzers that correlate to the sense of touch or small electric motors and solenoids to address an audience's kinesthetic awareness. Finally, a data output space implies collecting and analyzing biosignal data from performers to understand a specific musical task (e.g., the recordings of biosignal data and motion information to understand interpretative and affective information of a musical performance).

In the response type dimension, we adopted Drummond (2009) to classify how an IMS responds to its input (Rowe, 1992). The response type dimension encompasses three discrete types: generative, transformative, and sequenced. A generative type of response implies a system's self-creation is either independent of or influenced by an external input. Transformative techniques suggest an underlying algorithmic processing model and generation, including techniques such as filtering, transposing, delay, distortion, or granulation. Sequenced techniques refer to the playback of predefined musical instructions.

The performative affordances dimension categorizes the IMS according to the number and quality of the participating agents. Affordances do not take into account the underlying algorithms, processes, and expressiveness of the interactions taking place but rather the number and role of agents interacting with the IMS. The performative affordances dimension includes four categorical types: The human performer, the audience, computational system agents, and any configuration involving two or more of these agents. In the former category, whenever nonexpert performers, primarily from audiences, are participating agents in the IMS, we identified them as AUD (audiences).

BIOSENSING IN IMS: A TEMPORAL PERSPECTIVE

Table 2 presents a comprehensive historical record of biosignal driven IMS. In discussing the trends in this section, we flagged the IMSs with in-line text notation that provides an item number followed by the date, as noted on Table 2 (e.g., [Item 5; 1970]). The table's entries span chronologically from 1965 to 2019 and present biosensing as a control structure of the music performance with IMSs. To provide more than a simple textual catalog of IMSs, as in Table 2, we computed global statistics from the catalog data to extrapolate representative historical trends, as will be graphically depicted below. From all the categories presented in Table 2, we plotted dimensions that we considered the most representative of the evolution of biosignal-driven IMSs, in particular the empirical categorization and its respective dimensions: the type of biosignal used, the type of response expected from a specific IMS, and the affordances IMS musicians seek when conceiving an IMS.

We have identified three historical trends from this analysis: The first of one spanned 1965 to 1985; a second trend was detected from 1985 to 2005; and a third trend extends from 2005 to 2019. In the figures presented below, the column on the left shows the relative percentage of data in stacked columns, where the cumulative total of the stacked components within the columns always equals 100%. This column chart shows the part-to-whole proportions over time: For example, the column chart in Figure 3 shows which biosensing devices were used from 1965 to 2019. Although the column provides the historical scope, it is not easy to compare the relative size components that make up each column. For accuracy, then we present a stacked area chart on the right that, as in the example of Figure 3, shows the same progression and composition over time.

Table 2. A Catalog of 70 Biosensor-driven IMS Artworks, Compiled and Categorized According to the Proposed Taxonomy.

	Title	Year	Author	Control	Device Type	Output modality	Response Type	Performative Affordances	Perceived Controllability	Device Obtrusivness	Information Observability	Signal Property
[item 1]	**Music for a Solo Performer**	1965	Alvin Lucier	EEG	Custom	Sonification Kinetic	Generative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 2]	**Spacecraft**	1967	Richard Teitelbaum	EEG	Custom	Score driven	Generative Transformative	Multiperformer System	Low	Obtrusive	Long-term	Quasistationary
[item 3]	**In Tune**	1968	Richard Teitelbaum	EEG	Custom	Score driven	Generative	Multiperformer System	Low	Obtrusive	Long-term	Quasistationary
[item 4]	**Ecology of the skin**	1970	David Rosenboom, Richard Teitelbaum	EEG	Custom	Score driven	Generative Transformative	Multiperformer System	Low	Obtrusive	Long-term	Quasistationary
[item 5]	**DIMI-T "Electroencephalophone"**	1970	Erkki Kurenniemi	EEG	Custom	Score driven	Generative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 6]	**Environetic synthesizer**	1970	Woody Vasulka, Richard Lowenberg	EEG	Custom	Score driven	Generative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 7]	**DIMI-S "Sexophone"**	1971	Erkki Kurenniemi	EDA	Custom	Score driven	Generative	Multiperformer System	Mid	Obtrusive	Mid-term	Quasistationary
[item 8]	**Corticalart I and II**	1971-1973	Roger Lafosse, Pierre Henry	EEG	Custom	Score driven	Transformative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 9]	**Brain Wave Music**	1974	David Rosenboom, Richard Teitelbaum	EEG	Custom	Score driven	Transformative	Multiperformer System	Low	Obtrusive	Long-term	Quasistationary
[item 10]	**On Being Invisible I pt.1**	1976-77	David Rosenboom	EEG	Custom	Score driven	Transformative Sequenced	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 11]	**Clocker**	1978	Alvin Lucier	EDA	Custom	Score driven	Transformative	Performer System	Mid	Obtrusive	Mid-term	Quasistationary
[item 12]	**The Graphic Method Bicycle**	1979	Dick Raaymakers	ECG, RESP, EMG	Custom	Score driven	Transformative	Performer System	Mid and High	Obtrusive	Mid-term	Quasistationary Nonstationary
[item 13]	**HeartBeat:mb**	1981	Chris Janney, Sara Rudner	ECG, EMG	Commercial Transkinetics inc.	Score driven	Generative	Performer System	Mid and High	Obtrusive	Mid-term Short-term	Quasistationary Nonstationary
[item 14]	**Kagami**	1991	Atau Tanaka	EMG	Commercial BioMuse	Score driven	Transformative Sequenced	Performer System	High	Obtrusive	Short-term	Nonstationary
[item 15]	**Synesthesia**	1992	Rita Addison et al.	ECG, RESP, EMG	Custom	Audio-visual	Sequenced	Multiperformer System	Mid and High	Obtrusive	Mid-term Short-term	Quasistationary Nonstationary
[item 16]	**The Mnemonic Body**	1995-2001	Alan Dunning, Paul Woodrow	EEG	Commercial IBVA Brain Machines	Audio-visual	Generative	Audience System	Low	Obtrusive	Long-term	Quasistationary
[item 17]	**The Madhouse**	1995-2001	Alan Dunning, Paul Woodrow	EEG	Commercial IBVA Brain Machines	Audio-visual	Generative	Audience System	Low	Obtrusive Inobtrusive	Long-term	Quasistationary
[item 18]	**Dérive**	1995-2001	Alan Dunning, Paul Woodrow	EEG, ECG, TEMP	Commercial IBVA Brain Machines	Audio-visual	Generative	Audience System	Low and Mid	Obtrusive Inobtrusive	Mid-term Long-term	Quasistationary Nonstationary
[item 19]	**Body Degree Zero**	1995-2001	Alan Dunning, Paul Woodrow	EEG, EMG	Commercial IBVA Brain Machines	Audio-visual	Generative Transformative	Audience System	Low and High	Obtrusive Inobtrusive	Long-term Short-term	Quasistationary Nonstationary
[item 20]	**Conductor's Jacket**	1998	Teresa Marrin-Nakra, Rosalind Piccard	EMG	Custom	Score driven	Sequenced	Performer System	High	Obtrusive	Short-term	Nonstationary
[item 21]	**cubeLife**	1999	Greg Turner	ECG	Custom	Audio-visual	Transformative Sequenced	Performer System	Mid	Obtrusive	Mid-term	Quasistationary Nonstationary
[item 22]	**BIOS - Bidirectional Input/Output System**	2002	Thomas Tirel, Sven Hahne, Jaanis Garancs, Norman Muller	EEG	Custom	Audio-visual	Generative Transformative	Performer System	Low	Obtrusive	Long-term	Quasistationary Nonstationary
[item 23]	**Sensors Sonic Sights**	2003	Atau Tanaka, Cecile Babiole, Laurent Dailleau	EMG	BioMuse	Audio-visual	Generative Transformative	Multiperformer System	High	Obtrusive	Short-term	Nonstationary

(continued)

Table 2. A Catalog of 70 Biosensor-driven IMS Artworks, Compiled and Categorized According to the Proposed Taxonomy. (Continued)

	Title	Year	Author	Control	Device Type	Output modality	Response Type	Performative Affordances	Perceived Controllability	Device Obtrusivness	Information Observability	Signal Property
[item 24]	**Sitting.Breathing.Beating.[NOT] Thinking**	2004	Adam Overton	EEG, EMG, RESP	Custom	Score driven	Generative	Performer System	Low and Mid	Obtrusive	Long-term Short-term	Quasistationary Nonstationary
[item 25]	**Diamair**	2007	Miguel Angel Ortiz, Benjamin Knapp, Michael Arcon	EDA	Commercial ThoughtTec	Score driven	Generative Transformative	Performer System	Mid	Obtrusive	Mid-term	Quasistationary
[item 26]	**Carne**	2008	Miguel Angel Ortiz	EMG	Custom	Score driven	Transformative	Performer System	High	Obtrusive	Short-term	Nonstationary
[item 27]	**S&V**	2009	Miguel Angel Ortiz	ECG	Custom	Score driven	Generative Transformative	Multiperformer System	Mid	Obtrusive	Mid-term	Quasistationary
[item 28]	**The Multimodal Brain Orchestra**	2009	Sylvain Le Groux, Jonatas Manzolli, Paul FMJ Verschure	EEG	Commercial g.Tech	Audio-visual	Generative	Multiperformer System	Low	Obtrusive	Long-term	Quasistationary
[item 29]	**The subConch**	2009	Mats J. Sivertsen	EEG	Commercial Emotiv EPOC	Audio-visual	Generative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 30]	**Music Sensors and Emotion**	2009	SARC	EMG	BioMuse	Score driven	Generative Transformative	Performer System	High	Obtrusive	Short-term	Nonstationary
[item 31]	**Dentro**	2010	Miguel Angel Ortiz	EEG, ECG	Custom	Sonification	Generative	Performer System	Low and Mid	Obtrusive	Long-term Mid-term	Quasistationary
[item 32]	**Mind Pool**	2010	Kiel Long, John Vines	EEG	Commercial Emotiv EPOC	Kinetic	Generative	Audience System	Low	Inobtrusive	Long-term	Quasistationary
[item 33]	**The Brain Noise Machine**	2010	Greg Kress	EEG	Commercial Neurosky EEG	Kinetic	Generative	Audience System	Low	Inobtrusive	Long-term	Quasistationary
[item 34]	**Staalhemel**	2010	Christoph DeBoeck	EEG	IMEC	Kinetic	Generative	Audience System	Low	Inobtrusive	Long-term	Quasistationary
[item 35]	**Unsound**	2011	Miguel Angel Ortiz	ECG, EDA	BioMuse	Audio-visual	Generative	Audience System	Mid	Obtrusive Inobtrusive	Mid-term	Quasistationary Nonstationary
[item 36]	**MoodMixer**	2011	Grace Leslie, Tim Mullen	EEG	Commercial Neurosky EEG	Score driven	Generative Sequenced	Audience System	Low	Non-obtrusive	Long-term	Quasistationary
[item 37]	**DECONcert**	2011	Steve Mann, James Fung, Ariel Garten	EEG	Commercial ThoughtTec	Score driven	Transformative	Audience System	Low	Non-obtrusive	Long-term	Quasistationary
[item 38]	**Music for Flesh I and II**	2011	Marco Donnarumma	MMG	Open source Xth Sense	Score driven	Generative Transformative	Performer System	High	Obtrusive	Short-term	Nonstationary
[item 39]	**Hypo Chrysos**	2011	Marco Donnarumma	MMG	Open source Xth Sense	Score driven	Generative	Performer System	High	Obtrusive	Short-term	Nonstationary
[item 40]	**The Warren**	2011	Joel Eaton	EEG	Custom	Score driven	Generative Transformative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 41]	**Music for Sleeping and Waking Minds**	2011	BioMuse Trio	EEG	BioMuse	Score driven	Generative	Multiperformer System	Low	Obtrusive	Long-term	Quasistationary
[item 42]	**Brain Pulse Music**	2012	Masaki Batoh	EEG, ECG	Commercial Neurosky EEG	Audio-visual	Transformative	Performer System	Low Mid	Obtrusive	Long-term Mid-term	Quasistationary Nonstationary
[item 43]	**The Escalation of Mind**	2012	Vsevolod Taran	EEG	Commercial Emotiv EPOC	Audio-visual	Generative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 44]	**Clasp Together (beta)**	2012	Harry Whalley, Panos Mavros, Peter Furniss	EEG, ECG, ACC	Commercial Emotiv EPOC	Score driven	Sequenced	Performer System	Low to High	Obtrusive	Pervasive	Quasistationary Nonstationary
[item 45]	**Omnious**	2012	Marco Donnarumma	MMG	Open source Xth Sense	Score driven	Generative Transformative	Performer System	High	Obtrusive	Short-term	Nonstationary
[item 46]	**The Moving Forest**	2012	Marco Donnarumma	MMG	Open source Xth Sense	Score driven	Generative Transformative	Performer System	High	Obtrusive	Short-term	Nonstationary

(continued)

Table 2. A Catalog of 70 Biosensor-driven IMS Artworks, Compiled and Categorized According to the Proposed Taxonomy. (Continued)

	Title	Year	Author	Control	Device Type	Output modality	Response Type	Performative Affordances	Perceived Controllability	Device Obtrusiv ness	Information Observability	Signal Property
[item 47]	**[radical] Signs of Life**	2013	Marco Donnarumma	PPG, MMG	Open source Xth Sense	Score driven	Generative Transformative	Performer System	Low High	Obtrusive	Short-term Mid-term	Quasistationary Nonstationary
[item 48]	**Alpha Lab**	2013	George Khut, James P. Brown	EEG	Commercial Myndplay	Sonfication	Generative	Audience System	Low	Inobtrusive	Long-term	Quasistationary
[item 49]	**(un)Focused**	2013	Alberto Novello	EEG	Commercial Emotiv EPOC	Audio-visual	Generative	Multiperformer System	Low	Obtrusive Inobtrusive	Long-term	Quasistationary
[item 50]	**The Space Between Us**	2014	Joel Eaton, Wei Wei Jin, Eduardo Reck Miranda	EEG	BioMuse	Score driven	Generative	Multiperformer System	Low	Obtrusive Inobtrusive	Long-term	Quasistationary
[item 51]	**Conductar**	2014	Jeff Crouse, Gary Gunn, Aramique	EEG	Commercial Neurosky EEG	Audio-visual	Generative	Audience System	Low	Inobtrusive	Long-term	Quasistationary
[item 52]	**eeg-deer**	2014	Dmitri Morozov	EEG	Modified Necomimi	Audio-visual	Generative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 53]	**Fragmentation: a brain-controlled performance**	2014	Alberto Novello	EEG	Commercial Emotiv EPOC	Audio-visual	Generative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 54]	**Activating Memory**	2015	Eduardo Reck Miranda, Joel Eaton	EEG	Commercial g.Tech	Sonification	Sequenced	Multiperformer System	Low	Obtrusive	Long-term	Quasistationary
[item 55]	**state.scape**	2015	Mirjana Prpa, Svetozar Miucin, Bernhard Riecke	EEG	Commercial Emotiv EPOC	Audio-visual	Generative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 56]	**Deep Profundis**	2015	Davide Mancini, Simona Lisi	EEG	Soundmachines, Neurosky	Score driven	Generative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 57]	**Vessels**	2015	Grace Leslie	EEG, ECG, EDA	Muse	Score driven	Generative Transformative	Performer System	Low Mid	Obtrusive	Long-term Mid-term	Quasistationary Nonstationary
[item 58]	**Eyes Awake**	2015	Grace Leslie, Carolyn Chen	EEG	Muse	Score driven	Generative Sequenced	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 59]	**Emotion in Motion**	2015	Benjamin Knapp, JavierJaimovich, Brennon Bortz	ECG, EDA	Custom	Data Recording	Sequenced	Audience System	Low Mid	Inobtrusive	Long-term Mid-term	Quasistationary Nonstationary
[item 60]	**Choreography and Composition of Internal Time**	2016	Teoma Naccarato, John MacCallum	ECG	Custom	Score driven	Generative Sequenced	Performer System	Low Mid	Obtrusive	Mid-term	Quasistationary Nonstationary
[item 61]	**Behind Your Eyes, Between Your Ears**	2016	George Khut	EEG	Muse	Audio-visual	Generative	Audience System	Low	Obtrusive	Long-term	Quasistationary
[item 62]	**Corpus Nil**	2016	Marco Donnarumma	EMG, MMG	Open source Xth Sense	Score driven	Generative Transformative	Performer System	High	Obtrusive	Short-term	Nonstationary
[item 63]	**E.E.G. Kiss**	2016	Karen Lancel, Herman Maat	EEG	IMEC, Muse	Audio-visual	Generative Sequenced	Audience System	Low	Obtrusive	Long-term	Quasistationary
[item 64]	**Noor: a Brain Opera**	2016	Ellen Pearlman	EEG	Commercial Emotiv EPOC	Score driven	Sequenced Transformative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 65]	**Synchronism**	2016	Teoma Naccarato, John MacCallum	EEG	Custom	Score driven	Generative Transformative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 66]	**Tangente**	2017	Teoma Naccarato, John MacCallum	ECG	Custom	Score driven	Generative Sequenced	Performer System	Mid	Obtrusive	Mid-term	Nonstationary
[item 67]	**Harmonic Dissonance**	2018	Mathias Oostrik, Suzanne Dikker	EEG, EDA	Commercial Emotiv EPOC	Audio-visual	Generative	Multiperformer System	Low Mid	Obtrusive	Long-term Mid-term	Quasistationary Nonstationary
[item 68]	**Alia: Zu tai**	2018	Marco Donnarumma	MMG	Open source Xth Sense	Score driven	Generative Transformative	Multiperformer System	High	Obtrusive Inobtrusive	Short-term	Nonstationary
[item 69]	**Eingeweide**	2018	Marco Donnarumma	MMG	Open source Xth Sense	Score driven	Generative Transformative	Multiperformer System	High	Obtrusive	Short-term	Nonstationary
[item 70]	**Vrengt**	2019	Cagri Erdem, Katja Henriksen Schia, Alexander Refsum Jensius	EMG	Commercial Myo	Score driven	Generative Transformative	Performer System	High	Obtrusive	Short-term	Nonstationary

The first historical phase, from 1965 to 1985, involved a small group of early adopters of biosignal-driven IMSs and is explained by the novelty of biosensing as a means of control and interaction within IMSs. Spanning the years 1985 to 2005, the second historical phase was marked by a decrease in the use of biosensors during the late 1980s but a resurgence in IMS practices in the 1990s. Finally, the third historical phase, from 2005 and 2019, encompasses a major appropriation of biosensors. A healthy growth in the availability of open-source devices can explain this, supplemented by the introduction of wearable technology that facilitated the logistics for installing, running, and repeating a specific biosignal-driven IMS in various performative contexts.

In the next subsections, we detail a critical overview of the results computed to extrapolate representative historical trends. Thus, we interpreted the statistics of each identified historical phase, as well as their representative IMSs.

Biosensing in IMS: A Critical Overview

By computing global statistics from the catalog data, we extrapolated representatives to identify historical trends. In Figure 3, EEG sensors prevailed across biosensor-driven IMSs, featured in 55.9% of the IMSs listed in Table 2. We believe that the more extensive adoption of EEG sensor technology in IMSs was related to their expressive adoption by the pioneers with the goal of achieving incorporeal communication channels between the brain and the artistic feedback manifestation. Furthermore, it reflected the ancient human desire embodied in myths and magical characters for controlling and taking action on the physical world manifestation with the brain.

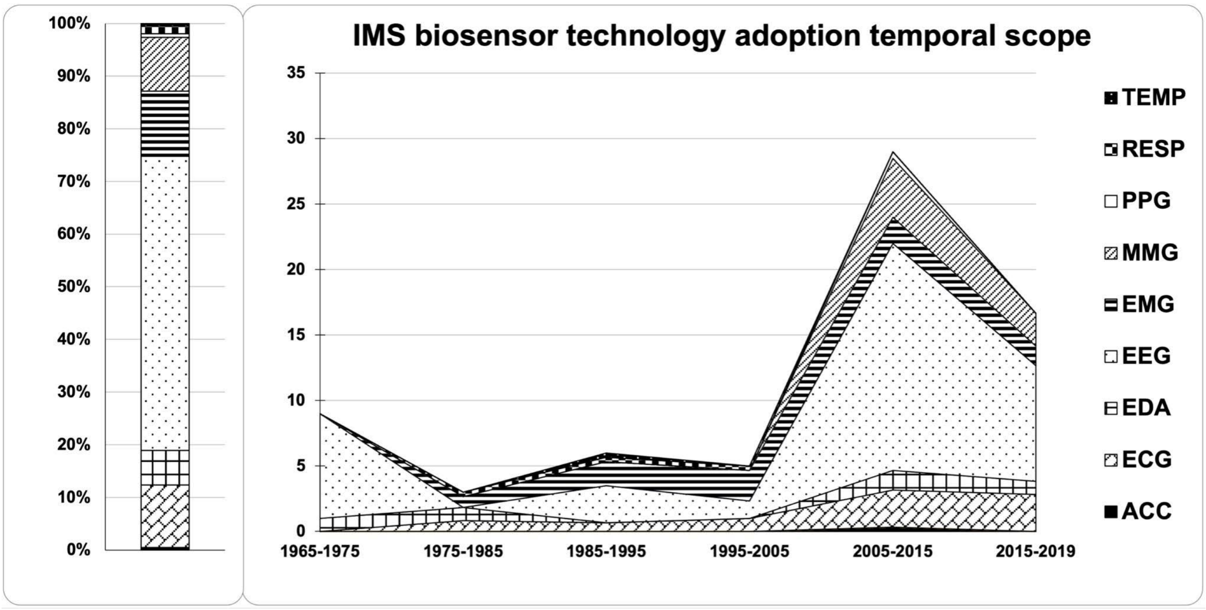

Figure 3. A global statistics visualization of the biosensors' appropriation within IMSs, 1965−2019. Abbreviations: ACC (accelerometer), AF (air flow), AP (air pressure), ECG (electrocardiogram), EDA (electrodermal activity), EEG (electroencephalogram), EGG (electrogastrogram), EMG (electromyogram), EOG (electrooculogram), FSR (force sensors), FLEX (flex sensors), GYR (gyroscope), MMG (mechanomyography), HUM (humidity), MOCAP (motion tracking), PST (position), PPG (photoplesmography), RESP (respiration), and TEMP (temperature).

The remaining types of sensor appropriated into IMSs per frequency of adoption are EMG (12.5%), ECG (11.8%), MMG (10.2%), and EDA (6.6%) sensors. The latter set of sensors captures muscle movements (limbs and heart) and skin conductance resulting from sympathetic nervous system activity. EMG and MMG sensors promote a voluntary control of the feedback, aligned with the typical fine degree of control fostered by instrumental practice. Meanwhile, EDA and ECG sensors enforce the impact of external conditions to act indirectly, pervasively, and repeatedly on the control structures via their embodiment in the performer. Biosensing technologies such as PPG, RESP, TEMP and ACC have a residual appropriation in IMSs, featured in only 3% of the IMSs of that era. Finally, AF, AP, EGG, EOG, FSR, BSR, GYR, HUM, MOCAP and PST biosensors were not identified in any IMS works between 1965 and 1985. This fact is due presumably to the technical difficulties. For example, EOG implies the use of fixed cameras that reduces the scope of eye movement detection to fixed positions. Sensors such as HUM have a prolonged signal evolution not fitting into the temporal span of a musical performance.

Another example is the low-level appropriation of the EGG sensor that captures the electrical signals in the stomach muscles. Because limb movements are more expressive in musical practice, sensors such as EEG were overridden by EMG and MMG sensors, which are more prominent in IMSs. A compelling case is the low level of appropriation of GYR and ACC sensors. GYR and ACC are ubiquitous sensors, although we did not note any IMS appropriating these types of sensors exclusively. Rather, our catalog of IMSs showed their use only in conjunction with adjacent sensors, for example, EMG sensors for a complete panorama of limb movement.

With advancements in areas of knowledge such as machine learning and software applications capable of dealing with large amounts of data, we envision a higher degree of appropriation of these less used sensors in IMSs. Cross-referencing the data from these sensors with other sensors, such as the EMG, will expand the scope of biosignal readings for a complete embodiment in IMS practices.

The temporal trend of appropriation of biosensors in IMS indicated in the right graph of Figure 3 shows that EEG sensors have prevailed since 1965 as a preeminent control structure in IMSs. However, since 1995, the EMG has peaked as a control structure for IMSs, owing mainly to a very productive practices of Tanaka and Donnarumma, whose IMSs are muscle-based. Moreover, the temporal peak in EMG use as a signal source presumably correlate with faster computers able to perform operations at faster sample rates. Despite technological improvement and artistic practices, EDA and ECG sensors tend to maintain a continuous baseline in terms of appropriation.

Figure 4 shows the type of response of IMSs across generative, transformative, or sequenced categories. We identified that 62.1% of the listed IMSs featured a generative response, followed by 25.5% of transformative responses, and 12.4% sequenced responses. The prevalence of generative responses indicates the growing trend toward cognitive-enhanced IMSs. Such systems typically embed levels of higher unpredictability and reflect the growing interest in cocreative systems involving computer programs collaborating with human musicians on creative tasks (Karimi, Grace, Maher, & Davis, 2018). As indicated in the main graph in Figure 4, the generative type of response prevails across the IMSs listed in our catalog. This comprehensive approach reveals in a more transparent way the concept of interactive composing introduced in our Introduction. However, we also witnessed a rise in IMSs employing a transformative type of

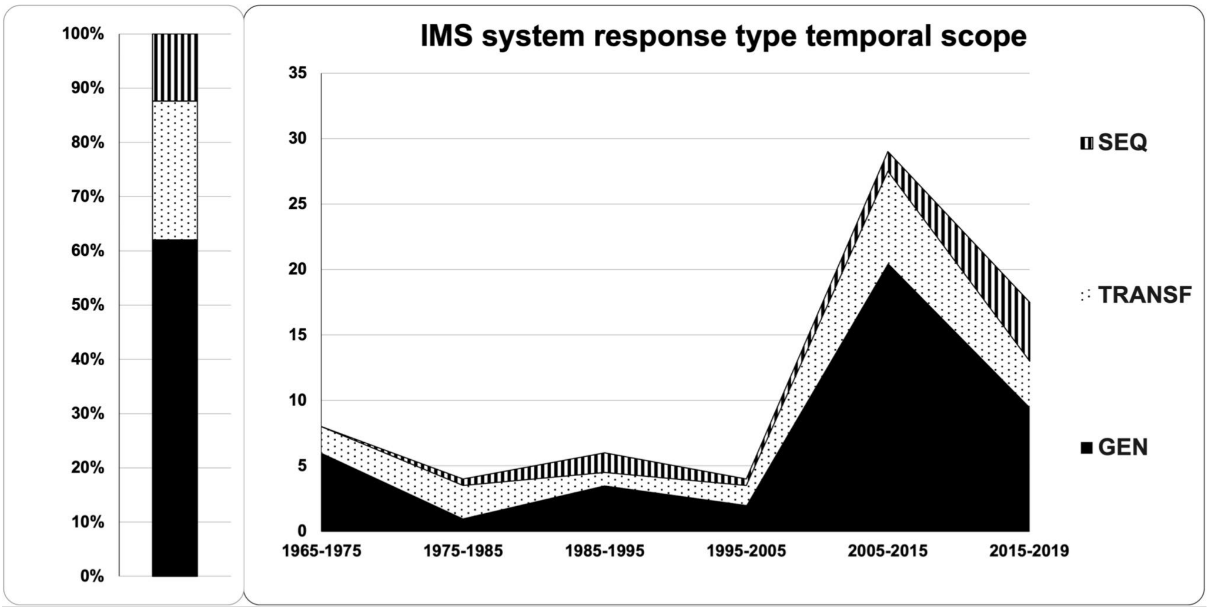

Figure 4. A global statistics visualization of the system response in biosensor-driven IMSs. Abbreviations: GEN (generative) implies the system's self-creation that is either independent of or influenced by an external input; TRANSF (transformative) suggests an underlying algorithmic processing model, including techniques such as filtering, transposing, delay, distortion, or granulation; and SEQ (sequenced) refers to the playback of predefined musical instructions.

response. We understand the rise of transformative types of response as a natural outgrowth of contemporary sophistication of algorithms for live sound processing that offer almost unlimited possibilities to design, create, and mix an outstanding real-time immersive experience.

Finally, Figure 5 shows the type of affordances a biosensor-driven IMS features. Of all IMSs analyzed, 55.7% were designed for one performer and one IMS. This expressive value highlights the advanced expertise required to develop these systems and their expressive appropriation to be confined somehow to the community of techno-fluent artists. Most artists opted for developing a biosensor-driven IMS for self-expression. Interestingly, we see that 21.4% of the analyzed works report an interaction between one system and the audience, meaning that a coshared control of the IMS presumably was due to the interest of IMS artists to include the audience in the understanding of the artwork. Thus, a multiperformer and a biosensor system had relevance in the cases analyzed, with 14.3%, especially those IMSs that included musical ensembles. Finally, 8.6% of all cases analyzed denoted an affordance of multiperformer/multisystem set up. We suggest the trend in Figure 5—with IMSs reflecting multiperformer with multisystems—probably indicates a growing interest of artists in performing pieces that can communicate remotely. Advancements in interconnectivity and bandwidth velocity promote IMSs that share control in a collaborative form, fostering the social impact that multiperformer and multisystem IMS artworks can have in the near future of musical practices.

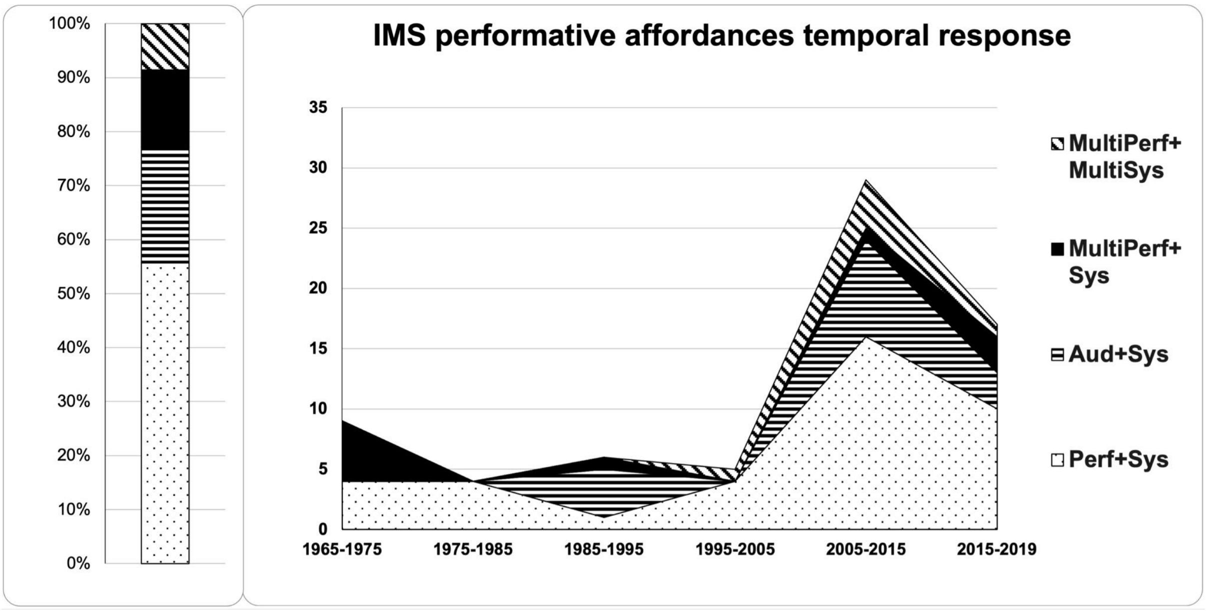

Figure 5. A stacked chart visualization of affordances in biosensor-driven IMS. Abbreviations: PERF+SYS (human performer plus computational system), AUD+SYS (audience plus computational system), MULTIPERF+SYS (multiple human performers plus computational system), and MULTIPERF+MULTISYS (multiple human performers plus multiple computational systems).

First Practices: 1965 to 1985

From 1960 to 1985, the first practices with biosensors in IMSs emerged. Through these early practices, composers sought to create incorporeal experiences of musical gestures by adopting as control structures the brain's electrical activity from electrodes placed in direct contact with the scalp. A direct translation of cortex waves into raw signals then was mapped to actuator parameters in physical and electronic music instruments, promoting feedback within IMSs. The prominent use of the EEG was to establish an immaterial connection between control and feedback. At that time, brain wave signals typically were mapped in a one-to-one fashion to actuators via electrical voltage control. Servomotors that actuate physical musical instruments and analogue synthesizers controlled via amplified brain wave signals were adopted. The biosensor technologies of that era were primarily medical setup devices that underwent several stages of customization to comply with performative musical settings such as *Music for a Solo Performer* (Holmes, 2012).

Lucier's *Music for a Solo Performer* [Item 1; 1965; Lucier, 1976; Straebel & Thoben, 2014] premiered in 1965 at the Rose Art Museum of Brandeis University in Waltham, Massachusetts, USA, and is the first musical piece composed and performed using brain waves, namely alpha waves in the range of 8-12 Hz. The artist's own brain waves controlled a series of servomotor actuators on percussion instruments, namely snares, cymbals, and gongs. Shortly after that, Teitlebaum wrote the improvisational musical pieces, *Spacecraft* [Item 2; 1967/68) and *In Tune* [Item 3; 1967/68], consisting of biofeedback circuitry to process amplified alpha brain waves. The signal was mapped to specific parameter controls of a custom Moog synthesizer via control voltages. Erkki Kurenniemi built the *DIMI-T Electroencephalophone* [Item 5; 1970], an electronic unit that registered a weak EEG signal from the user's earlobe. The biosignal was filtered, amplified, and used as a control source for a voltage-controlled oscillator. He later built the *DIMI-S Sexophone* [Item 7; 1971], a six-performer version of the DIMI-T, where handcuffs and wires connected the performers to the central electronic unit that measured the electrical resistance between all six performers. A sequence of musical tones was heard when two performers touched each other's hands repeatedly; the intensity of the music increased when skin moisture was elevated. Woody Vasulka and Richard Lowenberg created the *Environetic synthesiser* [Item 6; 1970] as a collaborative effort to incorporate the newest information technologies from biomedical engineering, psychophysiology, computer video display, and electronic music synthesis within a framework of a comprehensive art−communications system theory.

Henry and Lafosse collaborated on two experimental music albums, namely *Mise en musique du Corticalart I* and *Corticalart II* [Item 8; 1971; Arslan et al., 2005], consisting of the transcription of electric cortex waves into raw signals to control prerecorded audio samples. Between years 1974 and 1977, Teitlebaum and Rosenboom first produced *BrainWave Music* [Item 9; 1974], a piece informed by each of the performer's biosignal responses and, later, *On Being Invisible Pt.1* [Item 10; 1976−1977], a piece for a solo body, brain waves, and a computer-assisted music system. One common feature on these works was that a performer operated the system controls. However, in Teitlebaum and Rosenboom's earlier composition, *Ecology of The Skin* [Item 4; 1970], the system control was shared among the performer and the audience. Alvin Lucier created *Clocker* [Item 11; 1978], consisting of a contact microphone placed in a clock capturing the sound of the ticks. The audio then was routed through a digital delay unit that had a controlled delay time through the output voltage of an EDA. The changes in skin resistance produced corresponding changes in voltage, causing the ticks of the clock to slow down and speed up. *The Graphic Method Bicycle* [Item 12; 1979] is a Dick Raaymakers performance aimed at recording what happens when one tries to bring back to life a video-recorded movement—in this case, a man getting off a bicycle. Biosensors monitor his heart, breathing, and muscular and emotional activity during the dismounting action, and the acoustic signals were amplified and loudly transmitted to the audience. Chris Janney and Sara Rudner created *HeartBeat:mb* [Item 13; 1981]. Their biosensing device, developed by Transkinetics, Inc., captured electrical impulses of the performer's heart and surrounding muscles via wireless telemetry. The gathered data, amplified through filters and a sound system, provided a percussive track layered over music, such as a jazz scat, Indian tabla rhythms, and Chris Janney's recitation of medical texts.

Modern Practices: 1985 to 2005

Despite the increase in the computational power, storage capacity, and enhanced digital signal processing methods, we observed that, during the 1980s, few to none of the documented works appropriated biosensors as control structures in IMSs. The low adherence is possibly due to the musicians' awareness of the complexity of the brain signal and the limitations of the analytical tools in extracting relevant features from the noisy biosensor technology at the time. Drawing on the novel advances in brain-controlled interfaces, a new wave of biosensor-driven IMSs emerged in the 2000s. Interoperability among several computational and human agents within IMSs and the increased degree of transparency in the hardware components equally promoted new approaches to an established practice within IMSs. Computational power—and especially miniaturization—gave rise to several IMSs binding biosensors more seamlessly with more sophisticated mapping strategies. The technological context fostered the development of the

BioMuse system as a musical instrument based on physiological biosensing. The BioMuse system used EEG, ECG and EMG sensor data that became the human interface data as well as the articulation of computer processes such as digital audio and computer graphics (Lusted & Knapp, 1996).

The Bio-Muse system was used in IMS pieces such as Tanaka's *Kagami* [Item 14; 1991], which afforded a way to control music programs (and therefore compose) by tensing and relaxing the arm muscles. Addison developed an interactive artwork project, *Synesthesia* [Item 15; 1992], where the researchers employed individual ECG, RESP, and EMG measurements to create and drive a virtual reality environment. First, they acquired a participant's heartbeat and then fed it back to a sonification system and outputted it as a recognizable sound. Then they switched signals (auditory to visual). The project director's creative endeavor drew on her interest in brain trauma resulting from her injuries suffered in an automobile accident. Within the immersive, real-time virtual reality environments, participants could fill the multisensory "gaps" via "invisible" interaction/networking. Thus, some of the networking was energized through proprioceptive and kinesthetic dynamics.

Dunning and Woodrow developed a cycle of installations *The Mnemonic Body* [Item 16; 2002], *The Madhouse* [Item 17; 2001], *Derive* [Item 18; 2001], and *Body Degree Zero* [Item 19; 2004]. These authors invited participants to touch, stroke, and breathe upon particular locations of a life-size cast of a male human body to produce corresponding images and sounds in the main virtual world. In addition, electrodes gathered the participants' brain waves, which then were fed in real-time into a three-dimensional virtual reality environment. This process manifested visual and aural equivalents that then were projected onto a second screen and amplified into the physical space of the presentation.

The Conductor Jacket [Item 20; 1998; Marrin & Picard, 1998] was presented as a device able to collect and analyze data from conductors. The conductors recorded physiological and motion information from musicians with the goal of understanding better how they expressed affective and interpretive information while performing. Dave Everitt and interaction designer Greg Turner created an artwork driven by a heartbeat monitor, called *cubeLife* [Item 21; 1999]. This artwork was based in a virtual world populated by magic cubes (i.e., one kind of matrix in three dimensions) created through a heartbeat sensor of the participants' input either online or in the exhibition space. Each cube had a finite lifespan and associated sound and inhabited an artificial life environment where it could be made to flock with other cubes or follow various defined behaviors. Colors and variations were chosen from an inbuilt color harmony system or preprogrammed by the performers for particular effects. Media artist Marco Donnarumma (2001) presented *Music for Flesh I and II* [Item 38; 2001], an interactive sound art performance. The piece was performed in a concert setting with a circular array of subwoofers and loudspeakers. The work created a seamless mediation between human bioacoustics and algorithmic composition using the Xth Sense, a biophysical musical instrument created by Donnarumma.

The *BIOS—Bidirectional Input/Output System* [Item 22; 2002] collective involved participants in a collaborative project of interactive audio−visual and technological disciplines, resulting in several projects involving interactive 3D, audio−visual creations, and virtual reality. *Sensor Sonic Sights* [Item 23; 2003] was an audio−visual performance composed by Tanaka, Babiole, and Dailleau that explored gesture expressivity through the use of EMG sensors as a control structure for generating visual and sound synthesis. Overton's *Sitting Breathing [NOT Thinking;* Item 24; 2004] occurred during seven afternoons of seated meditation, with EEG, ECG, and RESP biosensors and interactive sound software. The performer's breaths, heartbeats, and brain waves manipulated digital sound in real-time, exposing the dynamic relationships between these continuously evolving, internal systems.

Contemporary Practices: 2005 to 2019

As the third phase generally started in 2005, the wide availability of numerous affordable EEG headsets increased the artistic experimentation with brain signals. Devices such as ThoughtTec, Neurotech's Emotiv Epoc, and Neurosky were delivered with proprietary software for estimating levels of meditation and excitement. Despite the weaker signal-to-noise ratio of these commercial devices as compared to medical biosensing devices, some IMS musicians appropriated noise as a control source of an IMS (Vavarella, 2015). For example, eye blinking when taking EEG measures is considered noise even though, in artistic contexts, this by-product can be turned into a control structure for a biosignal-driven IMS. Today, we have witnessed an increase in the level of information extracted from the biosensors. IMSs yield a high-level understanding from biosignals by evoking emotional, cognitive, and collaborative dimensions across participating agents.

More than two thirds of the IMSs identified in our study were created after 2005. Ortiz created *Díamar* [Item 25; 2007] as an Integral Music Controller (IMC) for compositional purposes. The IMC enables traditional musical control, such as singing and conducting, to co-occur with augmented and remote gestural interaction through EMGs. The artist continued exploring IMSs through biosignal interaction (Ortiz, 2021). *Carne* [Item 26; 2008] was written for an amplified violoncello and EMG sensors and was inspired by Terry Bison's 1991 short story, "They're Made Out of Meat." *S&V* [Item 27; 2008] was a piece that explored the non-real-time usage of biosignals to generate musical materials. In *S&V*, ECG signals were employed as an instrument to produce or manipulate sounds directly; in addition, prerecorded data sets of ECG signals were used to generate musical materials such as melodic and rhythmic patterns. The aim was to explore these signals in a more structured way while still using the heart as an instrument in real time. Ortiz also created *Dentro* [Item 31; 2010] as an IMS work composed for EEG and ECG as a homage to Alvin Lucier's *Music for Solo Performer*. The performer undergoes several emotional and cognitive states throughout the piece. In *Unsound* [Item 35; 2011], Ortiz teamed with the Sonic Arts Research Centre to develop a system for real-time tracking of audience members' emotional responses. Based on ECG and EDA measurements, the short film *Unsound* had both dynamic musical score and visuals according to the recorded biosignals. The *Multi-modal Brain Orchestra* [Item 28; 2009] explored the question of what creative content a collection of brains can generate when directly interfaced with the world, that is, bypassing their physical bodies. The orchestra members played virtual musical instruments through EEG interface technology while emotion analysis drove the affective content of a multimodal composition. The emotional input resulted in an interplay of the brain as both an actor and an observer of its actions. *The subConch* [Item 29; 2009] was an interactive installation by Sivertsen that addressed both phenomenological and textual aspects integrated with technology involving the use of EEG sensors to allow a participant cognitive control over sound and light, thereby producing a multidimensional aesthetic experience.

Music Sensors and Emotion [Item 30; 2009] was a study conducted by Knapp, Jaimovich, and Coghlan. Using physiological and kinematic sensors, the composers undertook a direct measurement of physical gestures and emotional changes in a live musical performance. These composers developed an IMC by using both motion and emotion to control sound generation. Long and Vines presented *Mind Pool* [Item 32; 2010] as an interactive BCI artwork that provided real-time feedback of brain activity to those interacting with it. Brain activity was represented sonically and physically via a magnetically reactive liquid placed in a pool in front of the participant; the liquid encouraged interaction and self-reflection by motivating participants to relate the ambiguous feedback with their brain activity. *Brain Machine* [Item 33; 2010] was a brain-controlled kinetic sculpture operated by mental energy, and the machine created a continuous stream of chaotic noise. When a high level of mental focus was detected, the device felt silent and remained in that state as long as the user could maintain focus. De Boeck created *Staalhemel* [Item 34; 2010], an intimate metaphor for the topography of the brain laid across a grid of 80 steel ceiling tiles as a spatialized form of tapping. The visitor experienced the dynamics of his/her cognitive self by, when fitted with a wireless EEG interface, walking under the acoustic representation of his/her brain waves. The accumulating resonances of impacted steel sheets generated penetrating overtones. The spatial distribution of impact and the overlapping of reverberations created a very physical sound space to house an intangible stream of consciousness.

MoodMixer [Item 36; 2011] was an interactive installation authored by Grace Leslie. *Mood Mixer* invited participants to navigate collaboratively a two-dimensional music space by manipulating their cognitive state and conveying this state via wearable EEG technology. Mann, Fungen, and Garten presented *DECOncert* [Item 37; 2011], a study in which participants immersed in water and connected to EEG equipment could create or affect live music by varying their alpha wave output. The authors explored the five states of matter—namely solid, liquid, gas, plasma, and quintessence—in the context of immersive media within a specific state of matter. Some of these immersive environments spanned multiple countries by way of networked connectivity.

Media artist Marco Donnarumma presented *Hypo Chrysos* [Item 39; 2011], *Omnious* [Item 45; 2012], *The Moving Forest* [Item 46; 2012], and *radical Signs of Life* [Item 47; 2013] as a series of pieces that explored interactive sound art performances for human bioacoustics and algorithms using the Xth Sense (Donnarumma, 2011), a biophysical musical instrument created by the author.

Eaton's piece *The Warren* [Item 40; 2011] employed an EEG machine and a technique called steady-state visually evoked potentials (SSVEPs), the natural response signals to visual stimulation at specific frequencies. In this artwork, SSVEPs allowed a user to select commands by looking at one of four icons on a computer screen that are flashing at different speeds. The more the user concentrated his/her gaze on an icon, the higher the brain signal reading for that command became. In turn, the signal was fed back to the icons to provide visual feedback to the user. The icons were mapped to musical parameters and commands relative to the composition. Through playing, ordering, timing, and sequencing how icons are played, the piece was controlled by the triggering sounds or individual parameters of controlled sound synthesis and effects. Knapp, Lyon, and DuBois conceived *Music for Sleeping and Waking Minds* [Item 41; 2011–2012], an overnight concert in which four performers fall asleep while wearing EEG sensors. The data gathered from these sensors were applied in real time to audio- and image-signal processing, resulting in a continuously evolving multichannel sound environment and visual projection.

Audiovisual installations, or performances, were very prominent in the years 2011−2013, with works such as Masaki Batoh's *Brain Pulse Music* [Item 42; 2012] and Vsevolod Taran's *The Escalation of Mind* [item 43; 2012]. In the former, the author realized a long-held dream of controlling the musical parameters via brain waves of several improvised pieces featuring traditional Japanese instruments. In the latter, the author conceived a performance in which the human brain served as a controlled voltage generator to render audiovisual transitions. At the heart of *The Escalation of Mind*, an actor cited fragments from Herman Hesse's *The Glass Bead Gam*e. During this process, the actor's brain wave activity, emotional state, and facial expressions are monitored in real time and combined with a synthesis of sound and video imagery, thus creating a unified environment in a virtual space. Whaley, Mavros, and Furniss presented a study, *Clasp Together: Composing for Mind and Machine* [Item 44; 2012; Whalley, Mavros, & Furniss, 2014] that explored questions of agency, control, interaction, and the embodied nature of musical performance within HCI. The piece was composed for small ensembles and live electronics. The composition departed from the traditional composer/performer paradigm by including both noninstrumental physical gestures and cognitive or emotive instructions integrated interactively into the score.

Combining neurofeedback training with participatory art and electronic music, Knut created *AlphaLab* [Item 48; 2013] to explore the possibilities of electronic art that entwined attention, experience, and compositional form. Participants rested on their backs on specially designed beds fitted with vibrotactile subbass speakers that augmented the biofeedback sound they heard in their headphones with low-frequency vibrations into the back of their bodies. Electronic soundscapes controlled by changes in alpha brain wave activity were used to guide participants to a place of intense but wakeful stillness.

The Space Between Us [Item 50; 2014] was a live musical performance in which the performers read an electronic score on a computer screen while the music this presented was generated by the emotions of a singer and an audience member. Both the singer and the audience member were wired to a BCI system. The system searched for emotional indicators in the brain waves and then predicted the participants' moods to control the musical score.

Conductar [Item 51; 2014] was an experience created by Crouse at Moogfest and afforded visitors an opportunity to physically wander the American city of Asheville, North Carolina and conduct a generative audio−visual world through movement and their neurological response to the environment. The audio−visual installation ran on a mobile app connected to a brain wave sensor. As participants strolled through the city, they would collectively compose new music with the electrical activity of their brains (via EEG data).

In Novello's *(un)Focused* [Item 49; 2013], brain waves were translated into laser shapes and sound; in *Fragmentation: A Brain-Controlled Performance* [Item 53; 2014], by the same composer, the performer controlled an avatar that was trying to escape a maze and whose movements generated visuals and sound. *Activating Memory* [Item 54; 2015] was a live music performance for a brain wave quartet and a string quartet codeveloped by Eaton and Miranda. *Activating Memory* was built as a BCI system to provide a new platform for users with motor disabilities to control musical instruments and to interact and communicate with each other through music.

Both Morozov's *eeg deer* [Item 52; 2014] and Prpa's *state.scape* [Item 55; 2015] were conceived as artwork installations where audio−visuals were generated from users' affective states (e.g., engagement, excitement, and meditation). The installations relied on an EEG interface-based virtual environment and sonification, both which served as platforms for the exploration of users' affective states in a responsive art installation.

In 2015, the Soundmachines BI1 braininterface was the first commercially available brain wave-to-synthesizer interface. The device was used in *Deep Profundis* [Item 56; 2015], created by Mancini in collaboration with the dancer Simona Lisi, to create the sound score for the dance choreography. Grace Leslie created two pieces. The first piece, *Vessels* [Item 57; 2015], was a brain−body performance that combined a flute and electronics improvisation with EEG sonification. The artist used recorded raw EEG, EDA, and ECG signals to actuate sound samples recorded from a flute and a voice. In the second piece, *Eyes Awake* [Item 58; 2015], created in collaboration with Carolyn Chen, Grace listened to her partner's guided meditation and, through the monitoring alpha rhythms pulsation, created a generative electroacoustic musical composition with a video overlay. *Emotion in Motion* [Item 59; 2015; Bortz, Jaimovich, & Knapp, 2015] was a framework created for the development of multiple emotional, musical, and biomusical interactions with collocated or remote participants. It was an open-source framework involving hardware-agnostic sensor inputs, physiological signal processing tools, a public database of data collected during various instantiations of applications built on the framework, and a Web-based application as front end and back end.

In 2016, Donnarumma presented *Corpus Nil* [Item 62; 2016], a performance for a human body and an artificial intelligence machine. In this piece, Donnarumma reflected the entire human body embodied with hardware and software through biosensing technology. Biosensors connected to the performer's limbs captured electrical voltages from the performer's body as well as corporeal sounds, all of which were mapped to various parameters of the IMS. Through a set of custom artificial intelligence algorithms, each bodily motion set was mapped to a sound and light event directed by the IMS.

Naccarato and MacCallum (2016, 2017) collaborated in a biosensing IMS artistic project that examined the use of real-time heart rate data from contemporary dancers to drive a poly-temporal composition for instrumental ensemble with live electronics. In *Choreography and Composition of Internal Time* [Item 60; 2016], the creators explored both the external expression and internal state of each dancer—physical, emotional, and psychological—in order to drive intentional arcs in heart activity over time. ECG data from the dancers provided an underlying clock for each musician, producing dynamic textures of time in the poly-temporal score. *Synchronism* [Item 65; 2016] was a participatory installation within a gallery involving three simultaneous invitations to the public: (a) a one-to-one performance where individuals joined the performer, one at a time, inside a private booth and shared via electronic stethoscopes and transducers the rhythms of their heartbeats in real time, stimulating sites of pulsation on their own and one another's bodies; (b) a multichannel, spatialized audio installation where bodies' cardiac, respiratory, and fluid sounds were rendered; and (c) a labyrinth-like paper kinetic sculpture installed in the public space. Several transducers were attached to the paper, sending real-time tactile interpretations of the audio from the stethoscopes throughout its surfaces. The public was invited to touch, embrace, and be enveloped by the architectural folds of the sculpture as it evolved in concert with the intimate performance and sonic-scape.

In *Behind Your Eyes, Between Your Ears* [Item 61; 2016], Knut used alpha brain wave rhythms to control an interactive soundscape and project visuals that traced the dynamics of attention as the participant moved between thinking and being. Participating visitors wore a wireless brain wave sensor and focused their attention on unfolding a delicate electronic soundscape in which different layers of sound were revealed according to the intensity and duration of their alpha brain wave patterns. Abstract geometric visualizations of the brain wave activity then were projected onto the audience.

Pearlman's 2016 installation *Noor: A Brain Opera* [Item 64; 2016] was a 360-degree immersive EEG-driven performance. An EEG wireless headset triggered video, a sonic environment, and a libretto through brain waves and interaction with the audience. Naccarato's *Tangent* [Item 66; 2017] was presented as a dance theatre in which dancers performed behind the audience, and the rhythmic section of the music was provoked by the heartbeat of the dancers. *Harmonic Dissonance* [Item 67; 2018] was an immersive experience composed by Oostrik as an ever-evolving network based on physical, physiological, and brain group synchrony on computer-mediated social networks feeding back audio content to a 4.1 channel speaker setup.

Donnarumma presented *Alia: Zu tai* [Item 68; 2018] as a piece that combined dance theatre and biophysical multichannel music diffusion with AI robotics, as well as *Eingeweide* [Item 69; 2018] as a dance theatre piece in which sounds from the performers' muscular activity were amplified and transformed by AI algorithms into an immersive auditive experience. Finally, the piece *Vrengt* [Item 70; 2019], developed by Erdem, was based on EMG-shared instruments for music–dance performance, with a particular focus on sonic microinteraction.

TOWARD AN EMBODIED CONTROL STRUCTURE IN IMSs: FUTURE CHALLENGES

Historically, the notion of the interface has evolved significantly with the emergence of HCI studies and the rapid development of more complex black-boxed computing apparatuses that require comprehensible mediators between humans and machines. Biosensing control structures can be envisioned and framed as central nodes for new forms of communication or "dialogues" within an artistic perspective between the humans' bodies and brains and the machines. The assemblages of bodies, brains, and media conjure up new enactments for synchronicity, communication, wholeness, control, augmentation, and awareness that impact the general understanding of these intersections. Embodying one or more biosensing applications as a structural element of the artwork facilitates the integration of new media with music and composition, cinema, and performance arts to generate experiences that can enable a sense of magic within and inspire the audience.

Biosignal-driven IMSs serve as catalysts for potentially new musical expressions, body−instrument relations, sound in space technology, and performer−audience relationships of contemporary musicking in a network of reciprocal relationships. Personalizing technology through biosensing approaches can benefit musical studies, in that music presents a unique and highly intensive performance form (i.e., in terms of numbers of parameters, bodily training, timeliness, and embodiment). IMSs are cultural artifacts that are fluid and dynamic—never resting and continually opening up for new definitions and usages.

In this context, we discuss future challenges at the intersection of biosensing technology and IMSs. We envision several guidelines for future work based on the historical perspectives presented in earlier in this paper. Moreover, a need exists for a transdisciplinary approach toward art and technology to envision the future of biosignal-driven IMSs.

In Figure 6, we present our proposal for a biosignal-driven IMS roadmap for the next 5 years. The light gray outer blocks represent the foundational conditions guiding the appropriation of biosensors as control structures in IMSs, both in technological and artistic perspectives: interconnections, sensor technology, industrial standards, appropriation, control structures, and interaction. The inner gray blocks represent the foundational blocks' design and implementation in terms of technological and manufacturing developments. These biosensor advances encompass new materials engineering, such as electronic textiles (eTextiles); miniature electronics, such as those embedded in eTextiles; computing and communications that promote or facilitate interaction among several systems; systems engineering; and industrial design in developing the biosensing technologies. On the IMS side, the criteria are integration, efficiency and efficacy, information retrieval, open access, and musical practices. The left panels—materials and manufacturing methods—and the right panels—biosensing technologies and musical creativity—represent key roles in cementing the foundational blocks together and making biosignal-driven IMSs a physical manifestation. The interdependence across blocks can be understood as a techno-artistic ecosystem. The several blocks that compose the ecosystem are interdependent and ultimately influence future biosignal-driven IMS developments. From all standards presented above, we highlight three key ones that can inspire future applications of biosensor-driven IMS: integration, information retrieval, and accessibility of open-access hardware and software.

Concerning integration, the already existing low-cost biosensing wearable devices intertwine natural and artificial realities in pervasive and unobtrusive fashions. Hardware miniaturization, increasing processing power, and enhanced digital signal processing tools have expanded the depth of environmental awareness and biosensing across the multiple layers of human and machine communication. Biosensing is a particular signal manifestation at the front of the most exciting breakthroughs in this area of knowledge. Wireless biosensor textile integration can provide the ability to explore the design space and interactions this technology holds. Seamless integration with textiles can foster the creation of tools for techno-fluent artistic practices and advance transparent and personalized channels for the intercommunication of human activity within a broader context of an IMS. Interaction through an interconnected musical

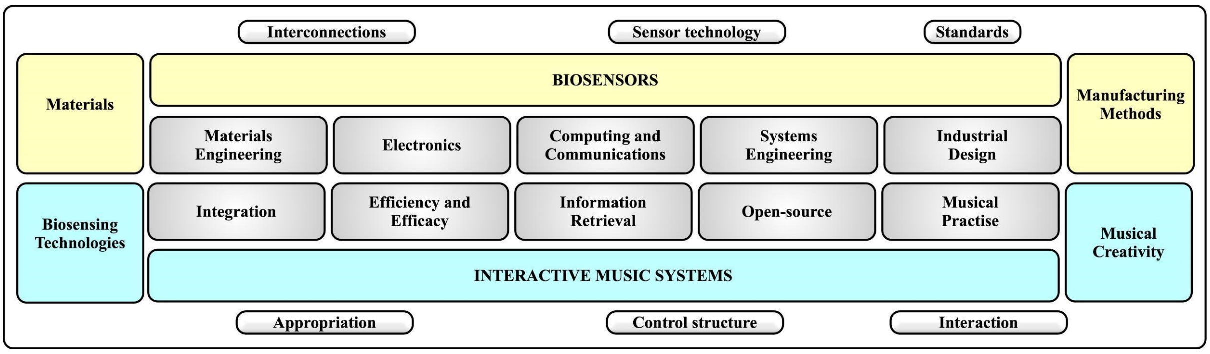

Figure 6. A roadmap for a transdisciplinary approach for biosensing technologies within IMSs, adapted from S. Park, Chung, & Jayaraman (2014). The light gray rounded blocks at the top and bottom represent the foundations that guide appropriation of biosensors as control structures in IMSs. The dark gray boxes provide criteria that affect the foundational blocks' design and implementation. The yellow blocks represent continuous technological developments concerning novel materials and manufacturing methods and the blue blocks present key roles in cementing methods when creating IMSs such as new forms of appropriation of biosensing devices for musical creativity.

instrument can foster ecosystems of interoperable musical devices and connect musicians and audiences, musician and musician, and audience and audience interactions. Beyond integration in textiles, biosensors could be placed on objects and in the environment, such as adding sensing capabilities to everyday life artifacts, thereby converting them into musical interfaces.

Concerning information retrieval, critical work involving congruent mapping between the categorical audio feature and context-mapping remains to be done. The integration of biosensing technologies as control structures in IMSs can be seen as a possible control structure for recalibrating music and sound in various contexts. Possible scenarios for augmenting biosensing technologies include health and well-being, video game soundtracking, and perceptual evaluation of auditory stimulus (e.g., noise annoyance, concentration and attention, relaxation, and mindfulness). Biosensor-driven IMSs can transform emotions into music and may help people recognize and understand their feelings and actions and those of other people. IMSs open the possibility of leveraging music—something HCI researchers seldom focus on—as one innovative way of expressing emotions to facilitate social interactions and augment performance.

Recent studies on brain-to-brain interfaces (BBI) were conducted on collaborative problem solving (Jiang et al., 2019). BBIs allow for technology-mediated direct communication between two brains without involving the peripheral nervous system. They consist of two components: an EEG that detects neural signals from one brain and translates them into computer commands and a computer–brain interface (CBI) that delivers computer commands to another brain. By combining EEG and magnetic stimulation, future IMSs could embed BBI features open to control by two humans telekinetically, thus promoting cooperation to achieve a desired musical goal. For example, a nonverbal musical instruction can be packed by a sender's brain to a receiver brain that would execute the desired motor response for performing the corresponding musical gesture. In societal terms, BBIs can be assembled as a sizable cloud-based network of individuals, both performers and audiences, who cooperate in unfolding an interactive musical piece. Other applications of BBIs include game music, sound enhancement, and user-state monitoring by sonification means.

In the ever-growing field of biosensing devices, we highlight the emergence of open-source brain–computer interfaces as the primary element of disruptive change in the significant adoption of the signals by a broader community of artists, most notably for interactive creations. Such devices include the Open-BCI (Durka et al., 2012) and the highly powerful, small, and low-cost biosensing toolkits BITalino (Da Silva et al., 2014). The convergence toward off-the-shelf technological solutions for biosensing is essential in enabling more comprehensive access and more successful practices with biosignals as control structures in IMSs. They ultimately could be embraced by a community of techno-fluent artists to be rooted in the artistic approach rather than the engineering focus. In this context, novel hardware devices and related software can promote more ready-to-use frameworks for interactive artists in extracting multidegrees of information, from continuous physical properties to high-level semantic information from the vast array of existing biosignals. Furthermore, low-cost, portable and ready-to-use devices can enlarge the scope of the biosensing spectrum in artistic applications toward more extensive audience participation within IMSs, thus engaging social experiences through a collective body.

CONCLUSIONS

Several taxonomies have been proposed in prior research for the emerging practice of bionsensor-driven IMSs. These proposals have focused on either the potential interactions with IMSs (Drummond, 2009; Ortiz et al., 2015; Prpa & Pasquier, 2019) or the characterization of biosignal data sources in HCI studies (da Silva, 2017). However, the interplay between the above in bionsensor-driven IMSs taxonomies is lacking in the literature, namely the emerging interaction of a musical system with the HCI affordances of the biosignal. To this end, we proposed a novel taxonomy for biosensor-driven IMSs that integrates both functional and empirical categories and allows their interrelated analysis. With our taxonomy, we offer IMS musicians a blueprint for mapping strategies in a more informed way and the ability to better predict their designs.

The novelty of our taxonomy relies on providing a viable framework for both analyzing and designing IMSs. A description of the biosensing system in terms of HCI and signal processing intertwined with a description of potential musical interactions fosters a better understanding of biosensing as a control structure in IMSs. We applied the proposed taxonomy to a curated catalog of 70 biosensor-driven IMSs spanning the 1965 biosensor-driven IMS by Alvin Lucier's *Music for a Solo Performer* until 2019. Each catalog entry was categorized according to the functional and empirical dimensions of our taxonomy, from which we extrapolated representative historical trends to critically verify our working hypothesis that biosensing in IMSs is expanding the array of control structures within IMSs.

We computed global statistics from the catalog data to extrapolate representative historical trends on three dimensions: type of sensor, response type, and performative affordances. The results revealed an extensive appropriation of EEG as a control structure in IMSs, although more recently other sensors have been appropriated, such as the case of the EMG. IMS musicians tend to seek a generative response in their systems. However, we identified the rise of transformative types of response possibly as a natural outgrowth of the increasing sophistication of algorithms for live sound processing, which in turn offer almost unlimited possibilities to design, create, and mix sounds in real-time. Finally, the performative affordances of analyzed IMSs historically denote higher prevalence of single performers. However, a growing trend reflects multiperformer with multisystems IMSs. We believe the advancements in interconnectivity and bandwidth velocity have fueled this recent trend.

Furthermore, the results showed three representative historical trends across all examined dimensions denoted as first practices (1965–1985), modern practices (1985–2005), and contemporary practices (2005–2019). The first historical practices involved a small group of early adopters of biosignal-driven IMSs, explained by the novelty of biosensing as a means of control and interaction within IMSs. The modern practices were marked by a decrease in the use of biosensors during the late 1980s and the resurgence of the practices in the 1990s. Finally, the contemporary practices encompass a larger set of biosensors at the disposal of the musician. The healthy growth in the availability of open-source devices, especially from the 2000s, allows for the artistic exploration of biosignals by a larger community of musicians.

Based on the recent trend observed in the collected data, we discussed the impact of smart and wearable biosensing technologies and the future challenges for their continuous appropriation as embodied control in IMSs. Technological developments such as new textiles with electronics embedded, miniaturization and computation power of novel devices accompanies the evolution of interactive systems, namely IMSs. New perspectives emerge from this dialogue, from designing IMSs with higher levels of understanding, such as emotion recognition, to distributed systems that communicate with each other, fostering collaborative, interactive musical compositions.

A possible limitation of our current analysis is its short-temporal span. The need for future reassessments of the historical periods is instrumental. As verified in other phenomena domains (Mollick, 2006), the fast pace at which technology evolves calls for constant revisions of the inner temporal trends. A future perspective may consider the three identified historical periods as belonging to a single phase, as their changes may become irrelevant in comparison with possible future endeavors of biosignal-driven IMSs.

Although advancing the connection and critical relation between empirical and functional dimensions of biosensor-driven IMSs and despite the statistical evidence supporting our findings, our study does not consider some inner mapping practices emerging in this context: of note, the impact of current machine learning and artificial intelligence algorithms for decoding and mapping biosignals to musical parameters of IMSs. Therefore, in future, such techniques should be considered as possible extensions of the taxonomy. Currently, the lack of a representative number of IMS is still scarce.

IMPLICATIONS FOR THEORY AND APPLICATION

The implications of our findings impact both future knowledge about and implementations of IMSs. By integrating functional and empirical dimensions, our proposed taxonomy permits the review of IMSs in a more integrated way. Supported by our taxonomy, IMS musicians can relate the sonic feedback with a description of biosignals in HCI. And with ongoing technological advances, the future applications of and research into IMS can open innovative practices and performances.

Another implication of our study is to provide critical analysis of historical trends of appropriation of biosignals as a control structure allowing practitioners and researchers to have a sharper picture of the historical developments of biosensing driven IMSs. From this foundation, further refinement in the taxonomy can allow the flexibility and dynamism necessary for ongoing research and practical advances in music performance.

ENDNOTE

1. Devices and sensors are equally considered in the obtrusiveness dimension, as they both can be worn and impose constraints to the physical experience of the user.

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Authors' Note

This research has been funded by the Portuguese National Funding Agency for Science, Research and Technology [FCTPD/BD/142892/2018] and by the project "Experimentation in Music in Portuguese Culture: History, contexts and practices in the 20th and 21st centuries" (POCI-01-0145-FEDER-031380), which is cofunded by the European Union Through the Operational Program Competitiveness and Internationalization, in its ERDF component, and by national funds, through the Portuguese Foundation for Science and Technology.

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Human Technology
ISSN 1795-6889
www.humantechnology.jyu.fi

HUMAN TECHNOLOGY

ISSN: 1795-6889

www.humantechnology.jyu.fi

Volume 17(1), June 2021, 81–112

NOVEL AND EXPERIMENTAL MUSIC TECHNOLOGY USE IN THE MUSIC CLASSROOM: LEARNING PERFORMANCE, EXPERIENCE AND CONCENTRATED BEHAVIOR

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Abstract: *In recent years, music technology in the classroom has relied on general devices such as the iPad. In the current study, we used a mixed-methods approach to examine the learning performance, learning experience, and behavior of two class groups of primary school music students (*N *= 42), using established music technology (i.e., the iPad with the Keyboard Touch Instrument app) and novel music technology (KAiKU Music Glove). Results show a significant difference of change in test scores during learning (*p *= <.01) and a medium effect-size is found (*d *= .75), indicating use of the iPad and Keyboard Touch Instrument app contributed to increased learning when compared to the KAiKU Music Glove. Perceived ease of use ratings of both technologies and observable levels of concentration exhibited by the students are also discussed in the paper. Implications provide insights into the usage and development of embodied music technology in the music classroom.*

Keywords: *music education, music technology, learning experience, learning.*

https://doi.org/10.17011/ht/urn.202106223979

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INTRODUCTION

The creative use of information technology (IT) in the music classroom rarely is associated with concepts found in human–computer interaction (HCI) research. Thus, HCI, IT, and music education are peripheral disciplines that have not been bound together adequately to understand student behavior when engaged with embodied music technology. This represents a missed opportunity for understanding the phenomenon. In the present study, we sought to investigate the research gap among these peripheral disciplines by using HCI and IT research to understand children's behavior in the music classroom while students used embodied music technology as part of their music class. IT is a widely integrated aspect of teaching and learning in today's Nordic childhood music class. For the students, IT affects their learning performance and, crucially, their experience of music. For the teacher, IT can support the teaching of music education with technology's advanced technical capabilities (e.g., data storage, access to the Internet, variety of applications, gamification), enabling activities that are engaging to children. IT can also help the teacher to manage the students' learning performance.

In this study, we aimed to understand better novel and experimental music technology use and interactions in childhood music education. For this, we employed a mixed-method approach to examine quantitative and qualitative data. The quantitative data derived from learning performance tests and the qualitative data emerged from subjective experience surveys and behavioral observations. A mixed-methods approach appropriately supported the purpose of this study, which was to understand established and experimental embodied digital music technology usage in childhood music education. We achieved this by examining students' learning performance, their experience of using the technology in the context of music learning, and their behavior while using either the iPad with the Keyboard Touch Instrument app or the KAiKU Music Glove, a tactile wearable device that activates musical notes via touch. The three research questions directed this study:

RQ1. What is the difference in musical knowledge before and after using the iPad with the Keyboard Touch Instrument app and the KAiKU Music Glove connected to the iPad in children's music classes?

RQ2. What are the students' ratings of perceived ease of use before and after using the iPad only or the KAiKU Music Glove in the music classroom?

RQ3. What is the difference in concentration-related behavior patterns of the student's while interacting and playing the iPad or KAiKU Music Glove in children's music classes?

Within this paper, a review of related literature will be presented first, which discusses concepts in embodiment and cognitive concentration in particular. Having established a theoretical background for this research, an empirical investigation of two student groups assigned either the iPad or the KAiKU Music Glove as the primary device for music learning is carried out. These devices were used in the music classes over a 6-week period

PRIOR AND RELATED RESEARCH

Historically, technology use in the music classroom has been associated with IT from broader society, as computers and, in particular, MIDI (musical instrument digital interface) sequencing stimulated a musical revolution (Gall & Breeze, 2007). Accordingly, the following section looks at tablet computer use in education, specifically how tablet computer integration has impacted childhood music education. The subsequent section provides an overview of experimental hand-sensor music technology included and used in this study, KAiKU Music Glove, and then placing it into a HCI theoretical paradigm we have called human music technology interaction. Play and concentration in childhood music education are discussed, in addition to a theoretical concept from the original technology acceptance model (TAM; Davis, 1985) reviewed and used in the study.

The Tablet Computer in Education

As a result of the physical properties of tablet computers in terms of their screen size, lightweight design, multimedia support, ease of use, and long battery life, they can serve as optimal devices for encouraging student engagement in multiple actions and activities in many classroom subjects and learning situations (Churchill, Fox, & King, 2012; Henderson & Yeow, 2012). Studies have shown that tablet usage in learning situations encourages high levels of student productivity, creativity, engagement, autonomy, and self-regulation in class situations (Clark & Luckin, 2013; Henderson & Yeow, 2012).

Over recent years, substantial technological developments in music classrooms have involved integrating innovative devices as part of the learning process in order to encourage interaction through tactile input and haptic feedback. The most established of these innovations is the iPad, a tablet computer manufactured by Apple. The iPad has been widely integrated into contemporary classrooms. Burnett, Merchant, Simpson, and Walsh (2017) stated that the iPad's integration into the classroom has been less problematic than other similar devices, past and present. Studies by Wario, Ireri, and De Wet (2016), Wang, Teng, and Chen (2015), and Heinrich (2012) demonstrated that iPad use in classroom settings has a positive impact on learning. Rowe, Triantafyllaki, and Pachet (2016) reported that the creative utilization of the iPad, as well as its playfulness, transfers seamlessly into the experimentation involved in the creation of music. Flewitt, Kucirkova, and Messer (2014) found evidence that the iPad was useful to children in the classroom, reporting that children were motivated to use the technology and held concentration for longer periods of time when using the technology. In addition, a diverse range of music apps (for the iOS and Android operating systems), often readily available on tablet computers and iPads, allows the teacher and student access to creative music educational experiences (Hillier, Greher, Queenan, Marshall, & Kopec, 2016). The sensory interface of the tablet computer's touch screen facilitates student interaction with the digital interface of its apps in an intuitive way, (e.g., pressing on a piano key shown via the user interface or enabling gestures during music creation). To that end, Burton and Pearsall (2015) found that children as young as 4 years old preferred playing music in apps that required very little musical manipulation—meaning the apps were mostly open-ended in user interaction and allowed the children freedom in music making. Consequently, the 4-year olds preferred music-making apps that made them the source of music making rather than the apps' output. With this in mind, Burton and Pearsall (2015) claimed that apps used in childhood music education should have qualities that enable play and open music creation.

However, evidence is inconclusive regarding usage of tablet computers in the childhood music classroom, as Hutchison, Beschorner, and Schmidt-Crawford (2012), Ruismäki, Juvonen, and Lehtonen (2013), and Stretton, Cochrane, and Narayan (2018) stated. They reported that research on tablet computer technology in childhood music education is relatively unexplored.

Observations of tablet computer use show overuse in the classroom, misuse, and lack of user confidence. In addition, Heinrich (2012) found that young students using tablets as part of their learning curriculum may require support or familiarization with the device's features and functionality before actively using them.

The KAiKU Music Glove Device

The KAiKU Music Glove is a musical MIDI controller with touch sensors (see Figure 1). The glove fits on one's hand, while the sensors embedded within the glove's fingers are pressed with the other/opposite hand. The manufacturer, Taction Enterprises Inc., has organized the sensors within a practical and ergonomic perspective, and the devices are produced specifically for pedagogical use in teaching music theory (see, Danso, 2019; U.S. Patent No. 9,905,207, 2018).

The positioning of two rows of touch sensors is presented as a potentially effective method for teaching the musical scale. It also is effective in the teaching interval and chord structures when both the teacher and students are wearing the glove. This approach is an attempt to optimize the process of music teaching and learning (Paule-Ruiz, Álvarez-García, Pérez-Pérez, Álvarez-Sierra, & Trespalacios-Menéndez, 2017) based on the Kodály method (Harrison, 2021) that emphasizes the use of the hand during singing lessons. A theoretical premise behind the KAiKU Music Glove is that the glove encourages the embodied learning of music (Myllykoski, Tuuri, Viiret, & Louhivuori, 2015). Children can learn music utilizing different modalities (visually, auditorily, and kinaesthetically, or by combinations of these; Burton & Taggart, 2011; Persellin, 1992). Acknowledging the integration of multimodality into the embodied learning of music through the hands is a design principle of the KAiKU Music Glove device (Myllykoski et al., 2015). Targeting

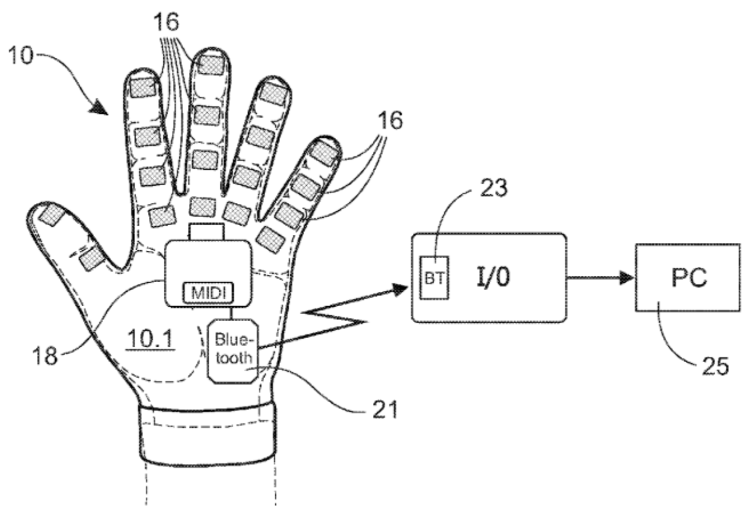

Figure 1. A diagram of the KAiKU Music Glove with a musical instrument digital interface (MIDI) and Bluetooth (BT) connected to a personal computer (PC). The KAiKU Music Glove generates musical data through a glove embedded with touch sensors and electronic units. It connects via Bluetooth or Universal Serial Bus (USB) to a host device (i.e., laptop or personal computer) to produce musical sound.

The numbers in the diagram correspond to the hardware that the KAiKU Music Glove implements: 10. A Glove device. 16. Touch sensors. 18. Central MIDI electronic unit. 21. Bluetooth transmitting MIDI code. 23. Bluetooth receiver. 25. Personal Computer (host device) (U.S. Patent No. 9,905,207, 2018).

the hands for musical knowledge and instrument development is not exclusive to the KAiKU Music Glove device (Voustinas, 2017). Other technologies recently developed also focus on the hands for use in a performance setting.

Human Music Technology Interaction: Placing KAiKU in Paradigm

User interfaces may be seen as embodiments, or “skins,” of technological systems (Sampson, 2019). At this level of design, the user encounters, affects, and is affected by the system. Moreover, the interface represents how data is made meaningful to the user through design (O’Brien & Toms, 2008). From a phenomenological perspective, how the user encounters these designs is always through the body and its senses (Höök, 2009; Höök & Löwgren, 2012; Rousi & Silvennoinen, 2018). This is furthered by how the body connects the sensory design of the technological interface to human action (Bødker, 1989; Dewey, 1934/2005; Gayler, Sas, & Kalnikaite, 2019). Music is intrinsically connected not only to the evolution of human cultural activities but also is tightly coupled with the development of language—the most permeating and fundamentally cognitively defining communication technology there is (Justus & Hutsler, 2005). Thus, the multitechnological layering of music and its associated instruments or tools are connected with human action and interaction. From this perspective, music can be understood as linguistic and/or expressive communication technology. Musical instruments are tools facilitating music expression, and IT-enabled devices may serve as instruments in their own right or extend (augment) the capabilities of traditional instruments, such as the electronic violin or piano, to name a few. Furthermore, in addition to being one of the most embedded technologies throughout human evolution, music and its instruments have always been fully embodied and multisensory (Lee & Noppeney, 2011, 2014; Zimmerman & Lahav, 2012), involving several human sensory channels simultaneously.

Both the tablet computer and the KAiKU Music Glove, for instance, integrate the tactile and haptic experience of music making with IT. These directly connect multiple senses (touch, sound, sight, perhaps even smell, depending on the device materials) to digital interaction, strengthening the link between the mind (thought) and the body (physical movement, control, and sensations) within digitally facilitated music production. Although embodied multisensory experience always has been one of the main characteristics of the body–music experience (production and consumption), IT extends the traditions and nature of tool/instrument-assisted music making through its informational layering. This informational layering refers to the nature of IT where form does not always follow function and, through informational manipulation, some sensory characteristics of the devices (i.e., sound and haptic feedback) may change entirely. When considering the connection between people and technology, or people and musical instruments, one may ponder the augmented nature of the tool. We use *tool* here to highlight the characteristic of instruments and technologies as enablers for human action, while simultaneously alluding to Heidegger’s (1927/1962) ideas of tools (i.e., technologies are “ready-to-hand”) as augmentations of the human body and cognition (see also Harman, 2011). Furthermore, musical instruments may be seen as augmented human capacities to act and affect: Engagement with a musical instrument also is an embodied interactive activity among multiple human actors (Leman, 2008; Yu, 2013). In other words, music and its instruments can be seen as tools for social experience and collective cognition, linking the embodied consciousness of multiple individuals through sound and other sensory effects (Himberg & Thompson, 2009). Leman (2008) supported a premise called “transparent technology,” a means of musician-based technology integration whereby the instrument/technology becomes seamless in its use and experience from the perspective of the music maker. Thus, conscious cognition of the instrument and its properties gradually become embodied and automatized in the musician's practice, transferring the coupling of musician and instrument from thought to feeling (emotional and sensory–motoric).

Play and Concentration in Childhood Music Education

Play provides experiences and opportunities for learning. This has formed a much-discussed basis for research in the context of educational technology (Said, 2004). Moreover, from an HCI perspective, the concept of play has been associated with increased frequency of and satisfaction in system use (Atkinson & Kydd, 1997). Additionally, researchers have attributed play to increased motivation, challenge, and positive affect (e.g., Woszczynski, Roth, & Segars, 2002). Other studies have shown that playing increases players' concentration in their experience of the activity (Huizinga, 2004). "Play has a deep biological, evolutionarily important, function, which has to do specifically with learning…. Many scientists think of much of their work as play, often linking the idea of play with high creativity" (Prensky, 2001, pp. 5–6).

People learn from experience, and learned matter influences how individuals subsequently experience phenomena (see constructivist views on learning, e.g., Steffe & Gale, 1995; see also Helfenstein & Saariluoma, 2006; Putnam, 2012; Rousi, 2013; Saariluoma, 2003; Symeonidis & Schwartz, 2016, regarding apperception). "An experience" in terms of an event (see, e.g., Batterbee & Koskinen, 2005) may be understood as a narrative with a beginning, middle, and end. How this experience unfolds, however, is determined by how the minds of those involved (or observing) make meaning. The engagement with devices and software for the purposes of producing something new—whether music, a performance, and/or an interactional engagement—can be likened to play. It is a constructive process in which creative expression or representation is produced (McArdle & Wright, 2014).

Through play, new literacies are realized and involvement in the process encourages concentration (Koo, 2009). Concentration refers to a sustained period of attention. From the perspective of concentration, meaningful learning can be achieved, as long as one of three forms of interaction (i.e., student–teacher, student–student, student–content; Tsang, Kwan, & Fox, 2007) is of a high level. Concentration derives from genuine engagement in learning as the student cognitively and affectively is attuned to acquiring, integrating, assimilating, and applying the information and other content presented within the lesson time (Dansereau, 1985). Bester and Brand (2013) argued that the amount of time and effort spent in a classroom is worthless unless the students are learning, and this process happens within the concentration span of learners.

Ready-to-learn: A Tool View to Information Technology in Musical Education

The theory of reasoned action (TRA) is a model developed to represent the reasons people behave in an intentional way (Davis, Bagozzi, & Warshaw, 1989; Fishbein & Ajzen, 1975). An adaptation of TRA is the TAM (Davis, 1985). TAM provides the general reasons for technology acceptance, clarifying the user behavior involved in choosing to use and then using a technology. Davis (1989) argued that not only was TAM originally designed to predict user acceptance behavior but also to explain it. Thus, TAM fundamentally helps researchers and those working in the IT industry understand why a particular system may be either acceptable or unacceptable to the user. Such information then could be used as a basis to pursue corrective development action.

TAM contains two factors critically relevant for computer acceptance behaviors: perceived usefulness and perceived ease of use (Davis, 1985, 1989; Davis et al., 1989; Venkatesh, 2000). Perceived usefulness is the user's own perception that using technology improves task performance. This may indeed be likened to what social psychologist James Gibson (1977) referred to as "affordance," whereby designs and their qualities are understood for what they may afford the user—that is, how they assist in the attainment of goals that align with intention. Perceived ease of use is the degree of effort that the user expects to place into interaction while using the technology (Davis et al., 1989). Behavioral intention represents a person's attitude toward and perceived usefulness of a system. This makes the concept slightly different within TAM than in TRA. An attitude and behavioral relationship implies that a person may form the intention to carry out behaviors that have a positive affect (Davis et al., 1989). TRA and TAM have been used widely in the social sciences and information systems research communities and include extended versions, such as TAM 2 (Venkatesh & Davis, 2000), TAM 3 (Venkatesh & Bala, 2008), the unified theory of acceptance and use of technology (UTAUT; Venkatesh, Morris, Davis, & Davis, 2003), and UTAUT2 (Venkatesh, Thong, & Xu, 2012). The latter models expand on the dimensions of affect and emotion, adding detail to the expectational components of technological engagement (i.e., performance expectancy and social influence) in addition to greater importance placed on the role of context (i.e., facilitating conditions).

Theoretical Concept: Perceived Ease of Use

We chose perceived ease of use from the original TAM as a theoretical concept to examine the degree of effort the students expected to place into technology interaction within the music classroom. Accordingly, perceived ease of use as a concept is a good fit for providing theoretical and practical insights relative to this study's purpose and research questions. We applied perceived ease of use to the analysis of the study's results to capture the relationship between the participants' behavior, learning performance, and report of their experiences with their assigned technologies. Figure 2 presents the original TAM theoretical framework (Davis, 1985).

METHODS

We conducted an exploratory, descriptive mixed-method study involving two elementary school classes in Central Finland. One class was assigned only the iPad with a music-producing app as the device to use within their music class. The other class was assigned the KAiKU Music Glove as a device, but also used the iPad with the app as an apparatus to generate sounds only.

Participants

Participants comprised two classes of 21 students each ($N = 42$). All participants were students, aged 8 to 9 years, enrolled at Jyväskylän Normaalikoulu in Central Finland and participating in regular music classes. The average age of students was 8.3 years ($SD = 0.5$). To protect the students'

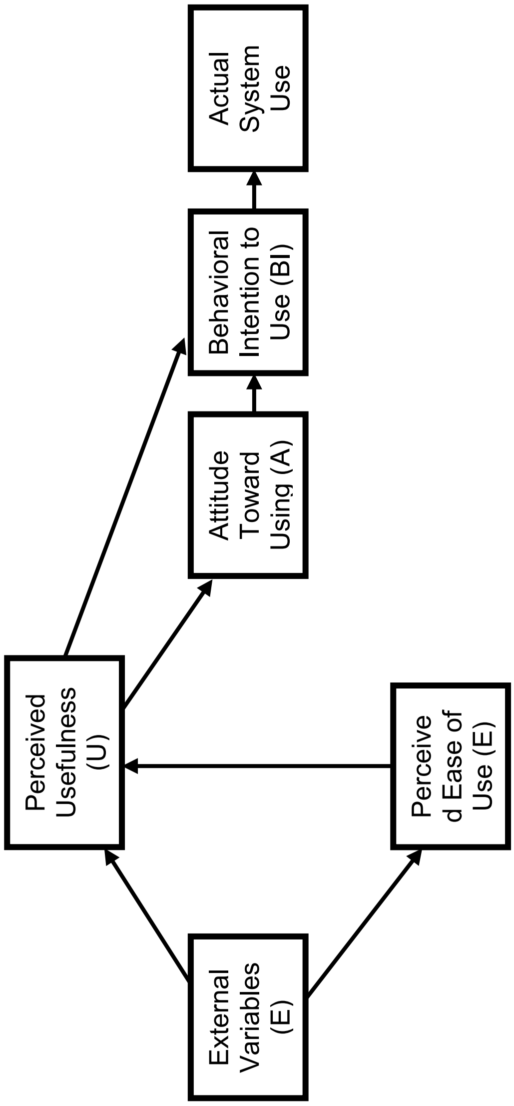

Figure 2. The technology acceptance model (TAM; Davis, 1985). The use of technology is determined by the person's behavioral intention to use (BI) the system, which is influenced by the user's attitude (A), described as an emotional response or a positive/negative experience when using the technology. Feeding into A is the perceived usefulness (U) and perceived ease of use (E). U also directly influences the user's BI. External variables may include social norms, such as an institution's access to technology and infiltration of use (Davis, 1985; Davis et al., 1989).

anonymity, each child received a number from 1 to 21 (each class separately) so that he or she could be identified consistently across the three data gathering processes.

Convenience sampling was used to address the specific aims related to our research questions. Specifically, the sampling method used in the current study is referred to as concurrent mixed method sampling (Teddlie & Yu, 2007) in that our sample serviced the requirements of our quantitative and qualitative strands of data. The quantitative and qualitative data were collected simultaneously, and the analysis of the quantitative data informed the analysis of the qualitative data (and vice versa). The procedure was convenient in that gaining access to the school to study both classes was made readily available by the existing common collaboration between the University of Jyväskylä and the Jyväskylän Normaalikoulu. Serving as a teacher training school for the University of Jyväskylä's Faculty of Education students, the Jyväskylän Normaalikoulu also collaborates with various departments at the university as an accessible location to conduct research. In addition, all of the subjects were willing to participate.

We obtained ethical clearance to conduct this research with children prior to commencing the study by receiving signed parental consent forms for each child that granted us permission to video record and use any data produced by the minor students in this study. Following the completion of the study, we researchers destroyed all video recordings.

Context

The study was carried out in two music classrooms at the Jyväskylän Normaalikoulu based in Jyväskylä, Finland. The school is responsible for educating students enrolled in Grades 1 to 9. Parents of the students attending the school typically permit their children to participate in associated research as well as work with student teachers.

Materials

iPad

The iPad is a multitouch screen tablet that runs on the iOS operating system. The device can serve as a platform for a variety of programs. In the case of this study, it was fitted with a music-producing app; the iPad created the audio output from the app. Students used headsets to hear the output.

Keyboard Touch Instrument App (iPadOS)

The Keyboard Touch Instrument app provides access to various MIDI-based keyboard instruments. For this specific music class—and thus this study—the app was set to the grand piano keyboard instrument, which was accessed via the iPad. The range of keys on the MIDI-based grand piano keyboard on the app was similar to the physical piano used in class by the teacher as well as emulates a standard piano sound. Thus, this digital instrument was deemed practical by the classroom teacher for the students to use. Tactile input from the both the iPad's screen and KAiKU Music Glove's sensors (see below) triggered the Keyboard Touch Instrument app to generate specific sounds.

KAiKU Music Glove

The KAiKU Music Glove device is a musical MIDI controller, fitted with touch sensors and an electronic unit. On the glove, touch sensors form more than two rows to format a musical scale (see Figure 3). To work the sensors, the user presses them with a finger from the other hand. The sensors are connected to an electronic unit that produces musical data.

The touch sensors are arranged from the index finger to the little finger. The tips of the fingers correspond to the notes of a first octave, C, D, E, F, so that semitone E-F is located between the ring finger and the little finger. The data signal created by touch on the glove transfers an output

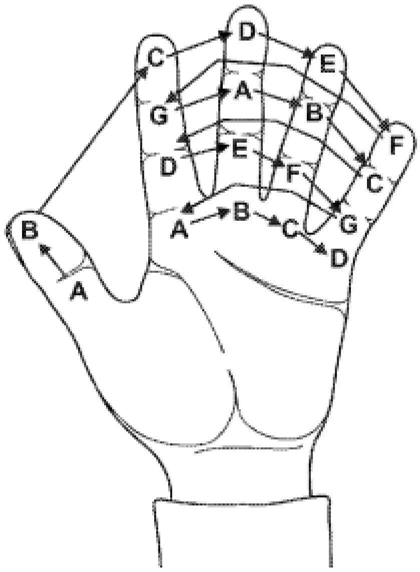

Figure 3. The progression of the music scale on the hand via the KAiKU Music Glove. The arrows show the position of the notes in relation to the fingers (U.S. Patent No. 9,905,207, 2018).

to a selected external device, for example, a MIDI device, a PC, or a computer tablet. In the current study, the glove's output was facilitated by a USB-connected iPad. The iPad functioned as a host device to the glove, decoding MIDI-information and producing sound accessed by headphones.

Study Design

This exploratory, descriptive mixed-method study involved two elementary school music classes. One class was assigned only the iPad as the device to use, which allowed students to play music from the Keyboard Touch Instrument app accessed via the iPad. The other class was assigned the KAiKU Music Glove as the primary music-creating device. However, this class also used the iPad with the Keyboard Touch Instrument app, but only as an apparatus to generate sounds. Because we compared the outcomes of the students using the KAiKU Music Glove device to the students using the iPad for learning, this quantitative aspect of the study can be considered quasiexperimental.

This mixed-methods approach served to address the multiple research questions. First, we worked with the music teacher to create a pre- and posttest assessment tool to measure any growth related to the participants' knowledge of music and musical listening abilities. This provided quantitative data on all students participating in this study and addressed RQ1. We also created an instrument to determine the participants' user experience associated with their assigned technology, employing a Likert-type scale. Students were asked to undertake these tests daily, before commencing use of their assigned devices and then once again after they used them. The responses to these user surveys were analyzed to answer RQ2. Thus, this survey provided both quantitative and qualitative information. Finally, we video recorded the 6 weeks of lessons so that we could analyze the behaviors of selected students regarding their concentration behavior, the analysis of which would address RQ3. These data were analyzed in light of perceived ease of use data results to draw inferences to generate a better understanding of the implications of utilizing established and experimental embodied digital music technology in childhood music education. This process provided our qualitative data. Figure 4 provides a visual summary of the research design. Each of the processes and materials are described more fully below.

Familiarization with KAiKU Music Glove and Researcher Integration Sessions

Two researchers were present in the classroom during the data collection phase of this study. Cozby and Rawn (2012) explained this allows the researchers to immerse themselves fully within the research setting, while Bogdan (1983) proposed this approach allows researchers to develop an understanding of complex social situations. Using the participatory observation method raises the problem of participant reactivity to being observed, known as the Hawthorne effect (Croucher & Conn-Mills, 2014). To account for this, we conducted familiarization sessions for each class so that we were able to integrate ourselves into the environment and introduce the KAiKU Music Glove technology into the experimental classroom. These pre-experiment sessions also allowed the researchers to pilot the data collection processes (i.e., test the Likert-type user experience survey questions and responses with the students and test the video recording process).

We researchers held two familiarization sessions before the prestudy test of knowledge was given to the students as well as Week 1's user experience survey. These sessions fulfilled a two-fold purpose: (a) to allow the children to learn and experience the equipment before the actual study, and (b) to allow children and researchers to become acquainted with one another. This important aspect of conducting research with children develops a trust relationship in which children are more willing to express themselves in the ways they normally would (Barley & Bath, 2014).

We structured the familiarization sessions similarly. The sessions started with the researchers introducing themselves. One class was given five KAiKU Music Gloves connected via USB to an iPad (with the Keyboard Touch Instrument app used on a iPad to generate sounds only) to interact and play music with, and the other class only used iPads with the Keyboard Touch Instrument app to interact and play music with. The class assigned the KAiKU Music Glove had five students at a time using the technology. This was timed closely by the class teacher, with four groups of students in total using the technology for approximately 10 minutes (total = 40 minutes). Five KAiKU

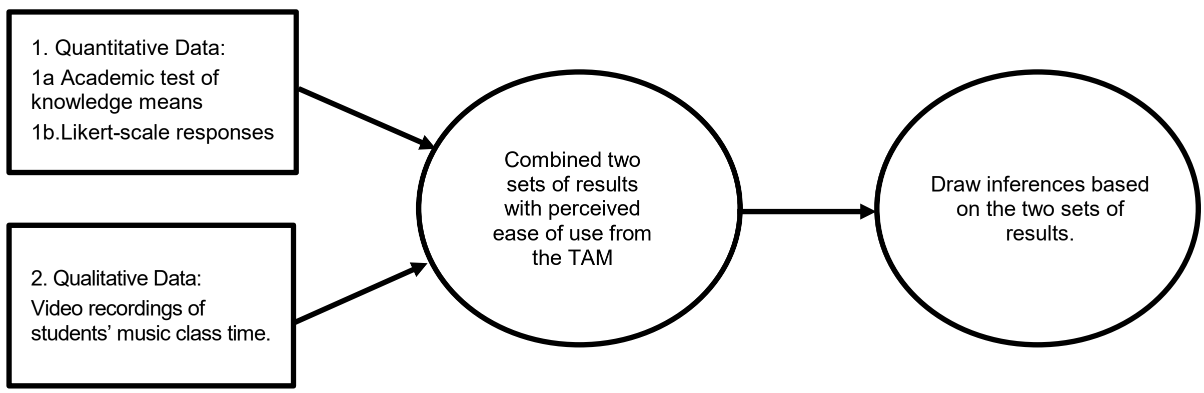

Figure 4. Mixed method study design of qualitative and quantitative data.

Music Gloves were deemed ready for use by their manufacturer before the study commenced, which is why we choose to use a limited number of them during these familiarization sessions. The students interacted and played with their KAiKU Music Gloves by touching the sensors of the glove to trigger and generate sounds in the Keyboard Touch Instrument app. When the students were not using the KAiKU Music Glove for their 10 minutes, they were instructed by the classroom teacher to complete musical exercises using an assigned iPad with the Keyboard Touch Instrument app. In the class assigned only the iPads, students played music by touching the iPad's screen to activate the sounds in the Keyboard Touch Instrument app for the entire class period. In both groups, the audio generated from the Keyboard Touch Instrument app played back through headphones plugged into the iPad and worn by each student. The familiarization sessions included small amounts of content, such as students playing four-bar simple rhythms, whole notes, half notes, quarter notes, and whole rests using one note.

After these familiarization sessions were completed, the KAiKU Music Glove manufacturer provided 22 of the gloves to the experimental class for the study's 6-week data collection period: 21 for all the students and one for the teacher to use. Additionally, in the week following the final familiarization session, the 6-week data collection period began with the following measures: the test of knowledge, the user experience survey to assess the students' perceived ease of use, and the qualitative video analysis.

Measures

Test of Knowledge

The students in both classes completed a test of musical knowledge at the beginning and end of the study. The pre- and posttests examined the students' musical knowledge retention and learning growth before and after using their assigned technologies. The classroom teacher (i.e., the teacher of all the students' subjects) and researchers discussed the nature of the test of musical knowledge, and the teacher developed the instrument. We researchers considered the teacher an expert at determining the validity of the content of the test because the teacher had taught primary and childhood music education classes at the Jyväskylän Normaalikoulu since 2012. The teacher designed the content of the test based on a Finnish childhood music education curriculum and teaching syllabus. The curriculum and syllabus integrates theoretical and practice-based music learning (Ruismäki & Ruokonen, 2006).

The development of the test of knowledge encompassed three stages. The first stage involved the researchers planning and discussing with the teacher the structure of the test and defining the content of the test. Following this, the teacher designed five open-ended questions in the Finnish language (see Table 1; these questions were answered by the participants in Finnish language and, for the purposes of this paper, have been translated by the classroom teacher from Finnish to English) based on the music class syllabus to examine theoretical (e.g., an examination of musical notation names) and practical questions (e.g., an examination of music listening skills). The test of musical knowledge consisted of five questions: one each testing the children's aural skill, pitch identification (these two were achieved by the teacher playing a musical notation by using a piano; the subjects listened to the notation and answered questions related to aural recognition of rhythm and pitch identification of melody), remembering musical notation names, and identifying piano keys and rhythmical markings. The second stage established face validity

Table 1. The Five Questions and Maximum Points from the Test of Knowledge.

Question	Maximum Points
What is the correct rhythm listened to?	1
In what order do you learn to play these melodies?	4
Name the piano keys.	8
Name the note names on the stave.	8
Identify the musical symbols from listening and match them to the phrase.	10

Note. The maximum points from the test are 31 and the minimum points are 0. The questions here were translated from Finnish to English by the music teacher.

of the test with the researchers. The researchers agreed that the test appeared to examine theoretical and practical questions. During the third stage, the teacher assembled the test in paper form. The students would complete their tests by using a pencil. The test—created in the Finnish language, one of two main official languages of Finland, which students of the age of the participants typically are able to read and write sufficiently—was administered by the music teacher before and at the completion of the 6-week study. The teacher also assessed the students' responses to the tests at both collection points and provided the results to us researchers.

User Experience Survey: Perceived Ease of Use

To examine how the two classes of students experienced using their respective technologies during their music class, the students completed a subjective experience survey each class, before and after using their assigned iPad or KAiKU Music Glove (see the Appendix for the survey in English). This user experience survey included one question on perceived ease of use; the balance of the survey presented questions not related to the scope of this paper and thus we focus only on Question 2 during the analysis in this paper.

We developed the questions for this user experience survey instrument thematically, based on Gasparini and Culén (2012), who explained that the perceived usefulness and ease of use of the iPad in the classroom are important factors for their acceptance. The Likert-type scale was designed pictorially in line with Kano, Horton, and Read (2010), who found that a thumb-scale employed for children's self-reporting on computer experience was effective with children as young as 7 years old. As a result, the students' responses to the statements on user experience required them to circle Likert-like scale thumb pictures (two thumbs down = *Not at all* to two thumbs up = *Very much*) to reflect their perspectives.We created this user experience survey employing the thumb scale in English, which the teacher then translated into the Finnish language. Again, all the participants were sufficiently skilled in Finnish.

We piloted the survey for reliability during the familiarization sessions (see below). Students responded to the test statements by circling thumb pictures. We then reviewed the initial responses between the familiarization sessions and at the start of the experiment to identify any inconsistencies in the intended response. For instance, we could determine if students from either class was responding incorrectly to statements (i.e., by writing numbers instead of circling thumb pictures to indicate their response, per instructions, or by drawing on the page arbitrarily). We did not find such inconsistencies in their responses to the user experience survey, indicating preliminary validity.

Qualitative Video Analysis

To observe the differences in students' concentration-related behavior patterns while using both music technologies, we conducted a qualitative video analysis of the recordings of the students using their assigned technologies in class. These data were collected and analyzed by two researchers (the first author of this paper and a master's graduate who is a classroom teacher), qualitatively observing the students using the technologies in the form of qualitative video analysis. To record each of the six classes, we set up a stationary video camera in the classroom in a position to capture the widest angle and the largest number of students possible. The camera setup recorded both audio and video. From the audio data, we could determine the students' verbal communications (i.e., a discussion with his/her peers related or unrelated to the music class activities, see Figure 5, or asking the teacher for help). We started the camera recording as the students entered the classroom and left the device to record without any action for the duration of the class. The qualitative video analysis was completed after the 6-week study was complete.

The general inductive approach for qualitative data analysis involves a research methodology suited for many research purposes. In the current study, we extended the approach to analyze video recordings of participant behavior. The primary goal of the inductive analysis was to allow research findings to emerge from the recurrent and prevailing themes in the data (Thomas, 2006). In inductive analysis, an iterative process, the raw data is read multiple times with codes, themes, and categories continually defined, refined, clarified, and amended (Braun & Clarke, 2006). The inductive analysis was driven by our interest in determining any differences in the concentration level of students using each of the devices, as articulated in RQ3. Thus, in our study, because our data comprised video recordings, we employed the iterative process by repeatedly viewing video clips containing behavior of interest.

We analyzed the behavior of four participants, two from each study condition, to identify concentration-related behavior patterns as the students' played and learned with their assigned technology during each lesson. The restricted camera angle used in the study and the quality of video that could be observed consistently for analysis limited our ability to expand beyond the four students. We focused our analysis on the four participants' nonverbal behaviors, such as looking around the classroom, and verbal communications, such as asking for help from the teacher or asking for help from another student. Criteria for selecting the four study participants involved (a) the student must be within the video frame consistently throughout the class, (b) the student must be present in class for the entire duration of the study, and (c) one student in each class scored high in learning performance (above median in the pre- and postlearning test of knowledge) and the other low on the same measure. Students 7 and 12 from the iPad class and Students 3 and 10 from the KAiKU Music Glove class were selected for observation via the videotaped data. However, both students selected for video analysis from the KAiKU Music Glove class scored below the median in the prelearning test of knowledge. Considering the limitations apparent in both the technical and selection challenges and because both students fully met the first two selection criteria and Student 3 scored above the median in the postlearning test of knowledge, the researchers agreed to modify the requirement of the third criterion and observe these students for the video analysis. In this instance, the high quality of behavioral observation that could be made via the videotaped data was considered of primary importance. We acknowledge this exemption in the study's limitations.

The two researchers chose lessons from Weeks 1, 3, and 6 for video analysis (as these lessons represented a beginning, middle and end point of the study for analysis), employing a three-stage process for the analysis of the video recordings. The first stage of analysis involved a first-pass inductive coding of the data to place identified data into preliminary analytic categories. In the first stage, the two researchers worked independently to identify segments of the video recordings with occurrences of student verbal and nonverbal behaviors suggesting a lack of concentration. Following this, the researchers negotiated and agreed on the following codes: boredom, no attention, task focus, and raising hand for help. In the second stage, the researchers concurred on a subset of the video recording sections where specific student verbal and nonverbal behavior was observed. The results of the second stage were lists of segmented descriptions, along with time codes; these were identified individually and entered into a shared spreadsheet. This stage of analysis led to the refinement of the previous identified codes. From this second stage, four themes emerged: looking away from technology, looking around the classroom, teacher–student interaction, and students discussing the task with fellow students. In the third stage, classifications for student verbal and nonverbal behaviors regarding their concentration-related behavior in the classroom were further revised. After independent analysis, we agreed upon two classifications at this selective coding stage: off-task behavior and on-task behavior (see Table 2). Patterns in off-task and on-task behavior have been the focus of much research (see, e.g., Baker, Corbett, Koedinger, & Wagner, 2004; Baker, D'Mello, Rodrigo, & Graesser, 2010; Cozby & Rawn, 2012; Ziemek, 2006).

Off-task behavior relates to the users' cognitive–affective states as they interact with technology. These include boredom (Csikszentmihalyi, 1990; Miserandino, 1996) and engaged concentration. Engaged concentration is a state of engagement with a task that is intense. During this state, attention is focused and involvement is complete. However, it does not involve the various task-related aspects that Csikszentmihalyi associated with flow (e.g., clear goals, balanced challenge, direct and immediate feedback). Baker et al. (2010) identified these cognitive–affective states as looking at or away from the object or looking around the room for something other than the user interface. Meanwhile, Ziemek (2006) associated off-task actions with disruptive behaviors, such as talking about things not related to the activity and disrupting their classmates. On-task behavior is identified by Baker et al. (2004) as asking for help from the teacher or another student and commenting on achievements. For our study, the frequencies of the occurrences of the students' nonverbal responses and verbal communications were considered indicators of their concentration during class.

Classroom Activities

The process of the music instruction conducted was typical for this teacher and this age group of students, other than the introduction of an experimental condition in form of the KAiKU Music

Table 2. Actions of On-Task and Off-Task Behaviors.

Off-Task Behavior	On-Task Behavior
Looking away from, the screen	Asking for help from the teacher
Looking around for something other than the user interface	Asking for help from others
Talking about things unrelated to the activity or disrupting others.	Commenting on achievements

Note. Based on the research of, e.g., Baker et al., 2004; Baker et al., 2010; Cozby & Rawn, 2012; Ziemek, 2006.

Glove and the data collection processes (i.e., measurement instruments and video recording). This 6-week period of time was blocked off during the students' academic semester, and as such the students had music education with this classroom teacher prior to our study. This classroom teacher is specifically a music teacher in this school and thus teaches music subjects only. All 42 students participating in this study have specific teachers in the following subjects: special needs teachers, language teachers, craft teachers, physical education teachers, class teachers, music teachers, and religion teachers. The class assigned the iPad had class on a Monday; the class assigned the KAiKU Music Glove had class on a Thursday. The teacher was the same for both music classes; the same classroom activities were assigned to the iPad and the KAiKU Music Glove classes. The teacher integrated both technologies into the existing curriculum of the lesson plans, ensuring students who participated in this study did not fall behind in the level of education they received. As the technology was incorporated into the lessons, the students were able to participate in the study without sacrificing the amount of material covered. Figure 5 briefly provides information on the content of the weekly lessons. The weekly classes followed the same procedure, as shown in Figure 6.

Week 1	The teacher instructed the class about incorporating three notes, C-D-E, into four-bar melodies. The teacher then demonstrated the location of the musical note positions, C-D-E, on the keyboard (or, in the class assigned the KAiKU Music Glove, on the device). The students incorporated three notes, C-D-E, as part of four-bar melodies while using and playing their iPad or KAiKU Music Glove.
Week 2	The teacher instructs the class about different note names found on the musical stave. Following the new instruction, the students then continued practicing playing three notes, C-D-E, as part of four-bar melodies while playing their iPad or KAiKU Music Glove.
Week 3	The teacher instructed the class on the location of the musical note positions found on the keyboard (or the KAiKU Music Glove) as well as the note names of *Twinkle, Twinkle Little Star*. The students learned, and practice playing the melody of *Twinkle, Twinkle, Little Star* while using their iPad or KAiKU Music Glove. The classroom teacher accompanied the students' by playing *Twinkle, Twinkle, Little Star* on the electric keyboard or on the KAiKU Music Glove.
Week 4	The teacher instructed the class on the note positions found on the keyboard or on the KAiKU Music Glove as well as the note names of a traditional Finnish Christmas carol (*Joulu on taas; It's Christmas Again*). The students learned and practiced the melody of *Joulu on taas* using their iPad or KAiKU Music Glove. The students sang to accompany the melody and harmony of the Christmas carol. This was the first-time students accompanied the use of their technologies with singing.
Week 5	The teacher instructed the class on the theoretical background of time signatures and ¾ time. The students learned about time signatures, and ¾ time playing. The students continued to practice the *Joulu on taas* using their iPad or KAiKU Music Glove. Also, the students sang *Joulu on taas* while playing it simultaneously on their technologies.
Week 6	The students continued to practice *Joulu on taas* using their iPad or KAiKU Music Glove. At times, the young musicians were accompanied by the classroom teacher on the electric keyboard, no matter which technology they were using.

Figure 5. An Overview of Activities in Both Music Classes.

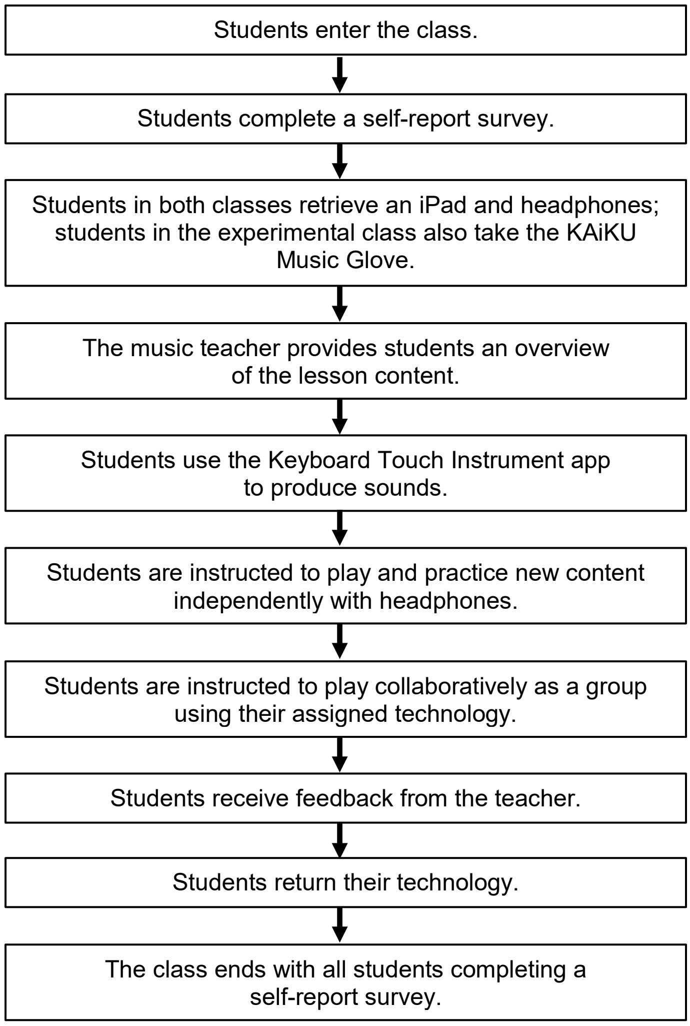

Figure 6. The session procedure during the 6-week-long experiment. Each box represents an essential component in the organization of each music lesson, observed and agreed on by researchers. The weekly lessons maintained a regular schedule and were held in the same room.

RESULTS

The results from the test of knowledge are presented first, followed by the responses on the perceived ease of use question of the user experience survey, and finally, qualitative observation tallies. The results report and compare learning outcomes between the iPad and KAiKU Music Glove classes and perceived ease of use responses before and after each time the students used their assigned technologies. Statistical analysis in the form of a Mann-Whitney U test was used to examine whether or not the difference in change in test scores between the student groups is significantly different after using their assigned technologies during the study's duration. To analyze the change in perceived ease of use responses before and after the students used their assigned technologies, we used a Wilcoxon Signed-ranks test to examine their perceived ease of use survey responses. The qualitative observation tallies were made by the researchers viewing video recordings of the classroom lessons. The observation tallies were the result of behaviors coded by both researchers. Observation tallies were made by both the researchers. Following the comparison of tally totals, both researchers negotiated and agreed upon final codes for behaviors and the total instances of each observed behavior.

The test of knowledge was completed by all students in both classes. Before the students used their devices, the test of knowledge established a baseline measurement of the students' knowledge regarding the musical syllabus. After using the technologies, the same test of knowledge was completed by the students to examine whether the use of the technologies had increased or decreased their musical knowledge.

Pearson's correlation coefficient was carried out to assess the relationship between the group of students using only the iPad for music learning (n = 21) and the group of students using the KAiKU Music Glove ($n = 21$) for the same purpose. We also computed test of knowledge scores at the beginning of the experiment (Week 1) and retest scores (Week 6). The Pearson's r data analysis revealed a moderate positive correlation between the test and retest scores for both groups, with an r of .73 (iPad only group) and an r of .77 (KAiKU Music Glove group). Results from the test of knowledge before and after using the technology are in Figure 7.

We performed a statistical analysis of the posttest of knowledge scores using a Mann-Whitney U test. The purpose was to compare whether the change between the two groups from pre- to posttest scores was significant. The Mann-Whitney U test indicated that the difference in change in test scores between the students after using their assigned iPad (*Mdn* = 7) and KAiKU Music Glove (*Mdn* = 0) technologies is significant, U = 115, z = 2.641, p = .008 two-tailed, and a medium effect-size was found d = .75.

As shown in Table 3, results from the daily survey indicate the technologies were rated similarly before they were used in perceived ease of use, as Week 1, Week 3 and Week 6 report median results of between 4 and 4.50, and a small effect size (d = .20) was found. After the technologies were used, the daily survey results indicate that both technologies were rated lower in perceived ease of use, as Week 1, Week 3, and Week 6 report median results of between 3 and 1.50, and a small effect size (d = .20) was found. In addition, results from the daily survey indicate that both devices were rated similarly in perceived ease of use, post-use, at Week 6 (iPad, *Mdn* = 2.00, KAiKU Music Glove *Mdn* = 1.50) and a small effect size (d = .31) was found.

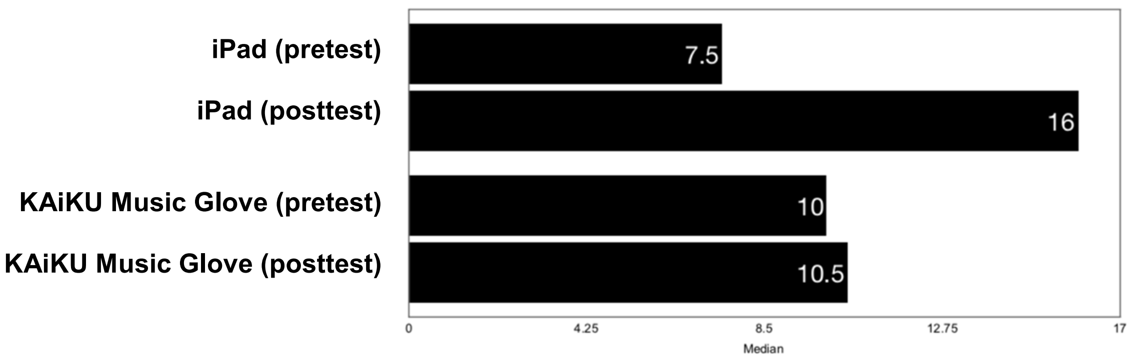

Figure 7. Medians comparing the pre- and postlearning test of knowledge results from the iPad and KAiKU Music Glove classes. The maximum test score is 31.

Table 3. Descriptive Statistics of the Perceived Ease of Use Responses During Weeks 1, 3, and 6 for the iPad and KAiKU Music Glove Classes.

	Week 1			Week 3			Week 6		
Item	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
I think the iPad will be easy to use today (iPad)	3.84	4.00	1.12	3.50	4.00	1.43	3.76	4.00	1.25
Today I found the iPad easy to use (iPad)	2.84	3.00	1.07	2.80	3.00	1.28	2.53	2.00	1.55
I think the glove will be easy to use today (KAiKU Music Glove)	4.30	4.50	0.95	3.95	4.00	0.95	3.70	4.00	1.17
Today I found the glove easy to use (KAiKU Music Glove)	2.80	3.00	1.06	2.35	2.00	1.82	2.10	1.50	1.21

We performed a Wilcoxon Signed-ranks test on the change in perceived ease of use ratings. The Wilcoxon Signed-ranks test indicated the change in perceived ease of use rating before using the iPad at Week 1 (*Mdn* = 4.00) and after using the iPad at Week 6 (*Mdn* = 2.00) is significant, $T = 118$, $z = -2.5854$, $p = .009$; a large effect-size was found, $d = .80$. The Wilcoxon Signed-ranks test indicated the change in perceived ease of use rating before using the KAiKU Music Glove at Week 1 (*Mdn* = 4.5) and after using the KAiKU Music Glove at Week 6 (*Mdn* = 1.5) was significant, $T = 214$, $z = -3.4236$, $p = .001$, and a large effect-size ($d = .80$) was found.

To analyze the difference in change between the students' ratings in perceived ease of use of both the devices from Week 1 to Week 6, a Mann-Whitney U test on the ratings was performed. The Mann-Whitney U test indicated the difference in change of perceived ease of use ratings between the students who used the iPad (*Mdn* = 0) and the students who used the KAiKU Music Glove (*Mdn* = 2) across the 6 weeks of study was not significant, $U = 165$, $z = -1.384$, $p = .168$ two-tailed; a small effect size ($d = .40$) was found.

To analyze the difference in perceived ease of use ratings of both the devices between the two groups of students, after rating their devices at Week 6, we performed a Mann-Whitney U test on the ratings. The Mann-Whitney U test indicated the difference in the two groups of students perceived ease of use rating after using the iPad (*Mdn* = 2) and after using the KAiKU Music Glove (*Mdn* = 1.5) at Week 6 is not significant, $U = 217$, $z = -0.07547$, $p = .936$ two-tailed, and a small effect size ($d = .31$) was found.

We conducted a video analysis to understand the students' behaviors while using their assigned technologies. Video of the classes was recorded at 2-week intervals during the survey period (i.e., Weeks 1, 3, & 6), and the observations were of two students from each class, selected by specific conditions. The students' coded behaviors refer to their concentrated-related behavior while using their assigned technologies. These were labeled as Off-task Behavior and On-task Behavior.

Two researchers rated and coded behavior of the selected students at each observation point independently. Interrater reliability was measured to ensure that the data collected in the study were represented correctly. We completed statistical analysis in the form of Cohen's kappa (k)

to examine the reliability between the observed scores of the researchers. The results of the kappa were $k = .81$, indicating strong agreement between the researchers on their coded categories.

Tables 4 and 5 display the tallies of the researchers' analysis of the two representative students' behavior in the iPad-using and KAiKU Music Glove-using classes. Each student in both the classes were designated a number (from 1 to 21). Within the iPad-using class, students numbered 7 to 12 were selected for video analysis of their behavior, and within the KAiKU Music Glove-using class, students numbered 3 to 10 were selected for video analysis of their behavior.

Table 4. Tallies of the Researchers' Analysis of Two Representative Students' Behavior in the iPad Class.

Week	Student Number	Instances of Off-Task Behavior	Instances of On-Task Behavior
1	7	3	0
	12	2	0
3	7	0	0
	12	0	0
6	7	1	0
	12	4	0
Total		10	0

Note. Each student in the iPad-using class was designated by a number (from 1 to 21). Students 7 and 12 were selected for video analysis of their behavior.

Table 5. Tallies of the Researchers' Analysis of Two Representative Students' Behavior in the KAiKU Music Glove Class.

Week	Student Number	Instances of Off-Task Behavior	Instances of On-Task Behavior
1	3	0	0
	10	0	0
3	3	0	0
	10	0	0
6	3	0	3
	10	0	3
Total		0	6

Note. Each student in the KAiKU Music Glove-using class was designated by a number (from 1 to 21). Students 3 and 10 were selected for video analysis of their behavior.

DISCUSSION

The current study found that the students using, playing, and learning music with the iPad-only scored higher in their test of knowledge posttest result. When analyzing the difference in change between the students' posttest results during the 6 weeks of lessons, a Mann-Whitney U test showed a statistically significant result. When the change in perceived ease of use responses is analyzed before using both technologies, statistically significant results were found. The results of the qualitative video analysis tentatively suggest that concentration-related behavior may have been observed to be higher in the two students using, playing, and learning with the KAiKU Music Glove, than the two students using the iPad-only. The results above provide evidence for discussion of the study in terms of the three research questions.

RQ1. What is the difference in musical knowledge before and after using the iPad with the Keyboard Touch Instrument app and the KAiKU Music Glove connected to the iPad in children's music classes?

As indicated in the analysis of the posttest differences, the students who used the iPad with the Keyboard Touch Instrument app improved more in their musical knowledge after using the technology over the 6 weeks of lessons as compared to the students who used the KAiKU Music Glove. When the posttest results comparing the difference in change are compared to one another, the difference was significant and the effect size was medium. These findings suggest that use of the iPad with the Keyboard Touch Instrument app contributed to increased learning more so than the KAiKU Music Glove. The findings in this study are in line with a previous research that also used these data (Danso, 2019). However, a distinct difference in this study's use of the data is the analysis of change in posttest score after the students used their technologies, which highlights the potential significance of the iPad with the Keyboard Touch Instrument app's contribution to the students' increased learning. In addition, the increased learning of the students who used the iPad with the Keyboard Touch Instrument app supports the literature of Wario et al. (2016), Wang, et al. (2015), and Heinrich (2012), who found interacting with the iPad in the classroom may have a positive impact on learning. On the other hand, the difference may have resulted from students being more familiar with the iPad device and thus able to use its touch screen more efficiently, helping their learning performance.

Moreover, the students using the iPad as their music-education platform learned with the piano keys presented via the Keyboard Touch app. Touching the piano keys presented in the app may have supported the students' learning better than the students assigned the KAiKU Music Glove due to familiarity from prior lessons in understanding how notes are positioned on a keyboard. In addition, the Keyboard Touch Instrument app has a wider range of musical notes (27 keys in total) available for the students to play compared to the KAiKU Music Glove (17 sensors in total). This may have encouraged more freedom for the students in the iPad group to express themselves musically. The KAiKU Music Glove has a fixed mapping system placing notes across the fingers (see Figure 3), which may have presented a practical challenge for the students playing music and their subsequent learning. In this instance, the Keyboard Touch Instrument app used by the student group assigned the iPad could be seen as unrestrictive to the students' musical expression while supporting their learning outcomes. The unrestrictive nature of the app as the primary learning tool supports the findings of Burton and Pearsall (2015), who stated that apps used in childhood music education should allow children freedom in music making. To achieve a similar positive learning outcome, the KAiKU Music Glove may benefit from future development in placing additional sensors on the device and allowing users similar access to the range of musical notes the Keyboard Touch Instrument app provides, both which may encourage freedom in music making.

Consequently, the KAiKU Music Glove may have been a hindrance to learning in the music class. This could be due to the fact that it was too unfamiliar, thus diverting attention from the music learning in general. We had identified this potential obstacle already before the study's implementation and attempted to mitigate it with the familiarization sessions. Despite two familiarization sessions, we must acknowledge that the children assigned to the KAiKU Music Glove condition already had prior experience in using the iPad with the Keyboard Touch app that mirrored the piano keyboard and thus were presented with a significantly different musical interface when we entered the classroom. Although the question about how prior experience with iPads (or other tablet computers) and specific software programs may have contributed to the lower test scores for the KAiKU Music Glove condition is an important issue to explore more deeply, it is out of the scope of this current study.

RQ2. What are the students' ratings of perceived ease of use before and after using the iPad only or the KAiKU Music Glove in the music classroom?

We asked the students at the start and conclusion of each lesson about their anticipated and post-use perceived ease of use for their assigned technology. The students' rated both technologies higher in perceived ease of use across Week 1, Week 3 and Week 6 before using the devices, and rated them lower after they were used across Week 1, Week 3, and Week 6. This is indicated by two sets of results. First, the descriptive statistics reporting medians of between 4 (iPad-only pre-use Week 1) and 4.50 (KAiKU Music Glove pre-use Week 1) before the technology were used, and medians of between 3 (iPad-only Week 1, and Week 3 post-use) and 1.50 (KAiKU Music Glove Week 6 post-use) after they were used. Second, the analysis of the change of score between the students' rating their anticipated ease of use of the iPad and KAiKU Music Glove use at Week 1 and the final rating at Week 6 are statistically significant, in part due to their higher ratings before use at Week 1, and lower final ratings post-use at Week 6.We speculate the higher ratings before using the iPad-only may have been due to the familiarity of using the device prior to the study, and the lower ratings after they used the device may have been due to having to play music by using the Keyboard Touch Instrument app interface while completing the lesson content. On the other hand, the students rating the KAiKU Music Glove high before using it in perceived ease of use may have been due to the novel design of the KAiKU Music Glove, as it places musical notation across the hand in the form of sensors. Consequently, the children anticipating playing music on their hand may have influenced these responses in a positive manner. However, the lower ratings in overall perceived ease of use after the KAiKU Music Glove is used show that the device may have impeded playing music while completing the lesson content.

In line with Davis et al.'s (1989) conception of perceived ease of use, we can observe that students may have anticipated less effort in engaging the technology before using their assigned devices at Week 1 but then perceiving more effort was necessary in using them after the course at Week 6. Regarding the iPad, some of the students' high ratings in perceived ease of use before and after its use is in line with the works of Henderson and Yeow, (2012), Churchill et al. (2012), and Clark and Luckin, (2013), who indicated that tablet computers are supportive for use in classroom settings. Regarding the KAiKU Music Glove, some of the students' high scores before use suggest that novel hand-sensor technology is seen as easy to play music with.

RQ3. What is the difference in concentration-related behavior patterns of the student's while interacting and playing the iPad or KAiKU Music Glove in children's music classes?

Several explanations are possible in analyzing the difference in the concentration-related behavior of the students while using, playing, and interacting with their assigned iPad or KAiKU Music Glove. The teacher interacted more frequently with the two observed students who used the KAiKU Music Glove, as requested by these students. This was coded in the observation tallies as on-task behavior, in line with Baker et al. (2004). Thus, a tentative association with KAiKU Music Glove usage encouraging the students' to remain on-task might be identifiable, as they were asking for support from the teacher. Crucially, these data must be interpreted with caution because the students using the KAiKU Music Glove may have found the instructions from the teacher needed clarification, prompting a request for help and corrective guidance about the lesson content and how the lesson content was associated with playing on the KAiKU Music Glove.

It follows that the students using the KAiKU Music Glove may have needed additional help and support from the teacher because of the novelty of the technology and the technical difficulties students experienced while using it. Evidence of this can be seen from the results discussed in RQ2, where the KAiKU Music Glove was rated lower in perceived ease of use. But these circumstances also were noted clearly in the observations of the researchers. For example, the researchers observed that both students using the KAiKU Music Glove experienced practical difficulty in strapping the device to their wrists, making the glove properly cover their hands. In these cases, the wrist strap was slightly too large and the students requested the teacher's help in tightening the wrist strap appropriately. These difficulties can be seen to impede the embodied learning experience of the children by preventing—or at least delaying—them from engaging in the immersion of the music-making interactions. As the user interface skin (Sampson, 2019) of the KAiKU Music Glove did not always fit the students' hands easily, the sensory design of the technology prompted the students to interact more with the teacher instead of playing music with the sensory aspects of their hand (Höök, 2009; Höök & Löwgren, 2012; Rousi & Silvennoinen, 2018). This observed difficulty in usability of the KAiKU Music Glove also may have been embodied in the students' actions, as the improperly fitted technological design prompted the request for help (Bødker, 1989; Dewey, 1934/2005; Gayler, et al., 2019). Naturally, from this arises the importance of social interaction and experience from not only the perspective of music but also those of educational (music) instruction and technological usage. These are issues that deserve full attention in their own right.

In addition, the differences in observed concentration-related behavior of the two students from each group may have been due to the students observed being more familiar with the iPad and less familiar with the KAiKU Music Glove. As noted above, all participants in this study had used the iPad with the Keyboard Touch Instrument app in their music classes before we initiated this experiment. Thus, on-task and off-task behaviors could have been complicated—or perhaps even caused—by the students' struggle or unfamiliarity with their assigned technology.

The comparatively high off-task behavior of the students using the iPad only that we observed may have relevance to the evidence in RQ2. Because the iPad device and software were easier to use and more familiar than the KAiKU Music Glove, the off-task behavior may reflect that these students were freer to interact with one another more often (peer-to-peer) and provided opportunities for them to play with one another. This freedom in play and social interaction may have encouraged the students to concentrate more in the process of the lesson (Koo, 2009), which contributed to genuine engagement with the classroom activities and educational content (Dansenreau, 1985). As an effect of the iPad's design, the technology may have enabled the iPad-only students more opportunity for a social experience with the learning content. This social experience is described as coexperience by Batterbee and Koskinen (2005), who noted that children experienced music while using and playing with the technology together, as well as being engaged in play and social experience with one another. Hence, the iPad may have enabled a creative (McArdle & Wright, 2014) coexperience of playing music for these students to be occupied completely in.

This corresponds to a simultaneous creative coexperience of music enabled through design of the iPad, perhaps evidenced by its high ratings in perceived ease of use by the students and their familiarity with the device from prior use. In this class, this could be viewed as a benefit in using the iPad further, as it fostered coexperience between the students while maintaining their concentration on classroom activities. The familiarity of technology and coexperience may go hand in hand, and having the students become more familiar with the KAiKU Music Glove may have enhanced this. In addition, the KAiKU Music Glove's slightly lower ratings in perceived ease of use compared to the iPad-only after it was used, suggest it was practically difficult to use, somewhat hindering interaction with others. For this reason, the role of social learning in relation to the introduction of both established and new technologies in the music classroom should be explored in greater detail in future studies.

Moreover, concentration-related behavior was quite similar across both classes of students' using their assigned technology as evidenced by their overall low off-task behavior tallies. Speculatively, the respective low off-task behavior recorded by both classes of students' using their assigned technologies may associate with literature by Huizinga (2004), who suggested that students can be engaged in classroom task activity while using, playing, and interacting with their devices during class even if this involves peer interaction and other behaviors that might reflect loss of concentration.

As the students used their assigned devices, one must remember that they were engaged in an embodied music experience. Thus, the experience itself may be seen to extend beyond the human−device interaction toward the larger scope of the musical engagement per se. Because of the overall respective high concentration-related behavior, these findings resonate with findings by Huizinga (2004) by reporting that play supports children in concentrating on learning when engaged with the interaction of objects.

Associating perceived ease of use data with the current observation data indicates that the students' expectations of the studied technologies may have affected concentration-related behavior, which in turn resulted in their actual system use. It follows that the higher performing class in the test of knowledge (the class who only used the iPad with the Keyboard Touch Instrument app) may have perceived their technology as easy to use, which resulted in less effort invested in interaction while using the technology. Indeed, the data show the students observed for concentration-related behavior while using the iPad only engaged in more off-task behavior than the students using the KAiKU Music Glove, suggesting the students using the former technology were not concentrating as fully as the students using the latter during the 6-week study. We suggest that, in the current study, higher perceived ease of use corresponded to less interaction effort while using the familiar technology (i.e., the iPad), resulting in lower levels of concentration-related behavior. On the other hand, the higher concentration-related behavior recorded by the students using the KAiKU Music Glove most likely is linked to their increased effort toward interaction while using the technology. Consequently, applying the perceived ease of use conception from TAM (Davis, 1985) illustrates the students' strong intentions to anticipate how easy to use both device interfaces appeared before playing music, while their concentration-related behavior may be an instance of how challenging these technologies are in action.

LIMITATIONS AND FUTURE STUDY

The current study found practical information about novel and experimental technology use in the music classroom, particularly the strengths of the iPad regarding academic performance and overall ease of use during interaction. The current study also provides new insights into the use of experimental hand-based sensor technology in the childhood music classroom, finding the students had strong intentions about using it to play music throughout the duration of the class. Both technologies helped the students' learning performance, and the observed students appeared to concentrate in class. However, several limitations with the study design and implementation are apparent and thus the results should be considered preliminary and used with caution.

The current test of knowledge did not control for the effects of the students' history, maturation, and familiarity with the iPad device (see, e.g., Dimitrov & Rumrill, 2003); these aspects of student knowledge should be built into the development of any future iterations of the test of knowledge. Additionally, more sophisticated quantitative measures (such as ANCOVA) on the pre- and posttest data may produce a truer analysis of the scores than what was used in this study. Finally, the current study's duration was quite short. The 6 weeks represented a short component within a larger, ongoing class. A longer study period with both technologies, and particularly more time for the students to use the KAiKU Music Glove and practice with the technology in advance of research measurements, may provide more reliable interpretations about student usage of their respective technologies in their childhood music class.

Regarding the perceived ease of use items (adapted from TAM; Davis, 1985), we see a threat to the internal validity within the current study. Although the use of the perceived ease of use investigation was used only descriptively in this study, the current study's findings cannot provide distinct evidence that perceived ease of use was accurately measured as this has been determined less subjectively using construct validity scales. To provide clear evidence of TAM concepts in our data (such as those sought through our perceived ease of use survey), construct validity tests should be completed to ensure that the instrument is measuring the associated trait accurately.

In addition, the study itself is limited in its measurement of student concentration-related behavior. The qualitative video analysis used to analyze concentration-related behavior was problematically influenced by a fixed video camera angle. More video angles or a wider angled device is necessary to repeat a similar analysis, which would have helped us to adhere to our conditions for selecting subjects for observation. A larger population (or sample) of observed participants would also be beneficial. To further increase the reliability of the study, stratified sampling could be used to represent a larger swath of the population for analysis (e.g., test of knowledge scores). Moreover, we believe that the students' familiarity—or lack thereof— with the devices used in this study may have skewed the observation data. Thus, having students' equal familiarity of their respective devised would be important for future study. Furthermore, testing and analysis of a sample that uses KAiKU Music Gloves of the same physical size is necessary to draw more precise conclusions about its usage in the music classroom.

Other factors affecting learning experience, particularly in the music education context, were not accounted for during this study, such as the role of social experience and social learning in relation to music learning and technology usage. One worthwhile theory to investigate in relation to the function of the devices within the learning process would be Albert Bandura's (1977a) social learning theory (SLT). This theory significantly relates to behaviorist traditions in which researchers understand or investigate how people behave in specific ways to achieve specific outcomes (e.g., attain direct reward—e.g., financial, food, etc.—or achieve social acceptance). SLT is a complex construct in that it helps researchers understand not only how humans behave in ways to influence specific social outcomes but also to attain states of influence and agency within themselves. For instance, self-efficacy alludes to one's own experience of being able to do (capabilities) and affect (agency) in various circumstances (Bandura, 1977b). According to Bandura, these social and intrapersonal outcomes may be exercised through media and objects in relation to group dynamics. Thus, the social learning dimension of an iPad or KAiKU glove study could open interesting perspectives to examine in further studies. Within these further studies, attention could be placed on the devices as, for instance, boundary objects within the facilitation of music education and social interaction in the classroom.

CONCLUSIONS

The purpose of this study was to explore established (e.g., iPad) and experimental (e.g., KAiKU Music Glove) embodied digital music technology usage in childhood music education. We pursued this by examining students' learning performance, their experiences of using the technology in the context of the music classroom, and their behaviors while using either the iPad only or the KAiKU Music Glove. Concepts such as concentration, experience, and play while learning music through technology in childhood music education were discussed. Overall, we found in the current study that the student group who used the iPad with the Keyboard Touch Instrument app improved more in their learning performance compared with the student group who used the KAiKU Music Glove with the iPad and Keyboard Touch Instrument app (for sound output). In addition, the study found that students using both technologies rated higher perceived ease of use before they engaged the devices and lower ratings after 6 weeks of use. Furthermore, the study found that both devices were rated similarly in perceived ease of use toward the end of the study period. We observed concentration-related behavior to be respectively high in both groups of students using their devices. Specifically, concentration-related behavior was found to be higher in the two students using the KAiKU Music Glove compared with the students who used the iPad only. When the concentration data is associated with perceived ease of use (from the TAM; Davis, 1985), it explains that both technologies were anticipated strongly in their ease of use to play music, yet the iPad required less effort during play compared with the KAiKU Music Glove. Specifically, less effort may have been exerted by the students using the iPad only as compared with the KAiKU Music Glove, primarily because of their familiarity with the iPad in their music education. As IT is a widely integrated aspect of teaching and learning in today's Nordic childhood music classes (Christophersen & Gullberg, 2017), the current study provides practical insights into the creative use of music technology in the childhood music classroom.

IMPLICATIONS FOR RESEARCH, APPLICATION, OR POLICY

As technologies, particularly tablet devices, are becoming more prevalent in childhood education, and particularly in music learning, this research provides a foundation for future research as well as application considerations. Our finding that unfamiliarity with a technology may impede learning will help future researchers and teachers think through their introductions of new technologies and take the necessary steps needed to avoid any negative impact of the actual device on their evaluations of technology-enhanced learning. The same is true in regard to perceived ease of use and its impact on successful use of a learning technology. Finally, although our results are somewhat preliminary, our research contributes important considerations regarding what constitutes on-task task and off-task behaviors during the introduction of unfamiliar technologies.

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Human Technology
ISSN 1795-6889
www.humantechnology.jyu.fi

Appendix: Likert-type Scale for Student Self-Report on User Experience

(BEFORE THE LESSON)

Student Name: ______________________________ Date: ______________________

Assigned Student Number: ______________

	not at all	no	maybe	yes	very much
1. I am very excited to use the iPad/Glove today.					
2. I think the iPad/Glove will be easy to use today.					
3. I view the iPad/Glove as a musical instrument. just like the recorder and piano.					

(AFTER THE LESSON)

Student Name: ______________________________ Date: ______________________

Assigned Student Number: ______________

	not at all	no	maybe	yes	very much
1. Today, I found the iPad/Glove easy to use.					
2. Making music on the iPad/Glove today was easy.					
3. Today I viewed the iPad/Glove as a musical instrument Just like the recorder and piano.					
4. I think I could teach my friends to play the iPad/Glove.					

HUMAN TECHNOLOGY

ISSN: 1795–6889

www.humantechnology.jyu.fi

Volume 17(1), June 2021, 113–115

ACKNOWLEDGING OUR REVIEWERS

(December 1, 2019–April 30, 2021)

Human Technology, as an interdisciplinary, online scholarly journal investigating the multiple facets of humans in interaction with technologies, consistently has sought out experts from around the world in a variety of fields related to the field of human–technology whose fields of expertise align with the topics of the papers submitted to our journal. Over the last 2 years, dozens of scholars—from universities, research organizations, and technology-based businesses—have kindly and graciously completed a review of one of the dozens of manuscripts submitted for publication consideration in *Human Technology*. We are deeply grateful for the time, effort, and wise recommendations these individuals have provided to the editorial staff of *Human Technology* in assessing the submissions' suitability for publication and in helping improve the manuscripts that remained under consideration.

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