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Surveying digital musical instrument use in active practice

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ABSTRACT

Digital musical instruments are frequently designed in research and experimental performance contexts but few are taken up into sustained use by active and professional musicians. To identify the needs of performers who use novel technologies in their practices, a survey of musicians was conducted that identified desirable qualities for instruments to be viable in active use, along with attributes for successful uptake and continued use of instruments based on frameworks of long and short term user engagement. The findings are presented as a set of design considerations towards the development of instruments intended for use by active and professional performers.

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Digital musical instruments; NIME; survey; engagement; design

1. Introduction

The field of novel digital musical instrument (DMI) design, and much of the music technology domain wherein it resides, relies on the existence of musicians that actively engage in musical practice. Simply put, new instruments need people to play them. In particular, DMI designers would seem to be especially dependent on performers who would take up novel instruments and engage with new technologies and methods of music-making. The relationship between design and musical practice can be mutually beneficial, as innovations in instrument design can inspire new musical practices, while evolving performance techniques and styles can inform design research in new directions.

However, scholars have repeatedly shown that most DMIs have short life spans, and many fail to make the jump from initial designs and prototypes to finished instruments put to service in real-world musical applications. Mamedes et al. (2014) proposed three primary reasons for the relative scarcity of established DMIs in use: new instruments lack established playing techniques; new forms of musical notation are needed to accommodate novel forms of musical output with new DMIs; established repertoires don't yet exist for new instruments. McPherson and Kim (2012) cited 'the problem of the second performer', highlighting the challenge of building a community for a new instrument beyond an initial single user. Furthermore, Morreale and McPherson (2017) found that within the NIME research community, the design of new DMIs is frequently carried out in service to specific research-based inquiries, resulting in technical probes and prototypes that are never intended to be put to real-world musical use.

1.1. What are DMIs, and who uses them?

The technical definition of a DMI is relatively straightforward, designated by Miranda and Wanderley (2006) as 'an instrument that uses computer-generated sound…and consists of a control surface or gestural controller, which drives the musical parameters of a sound synthesizer in real time' (p. 1). In practice, the term is most commonly associated with non-commercial, atypical musical instruments and interfaces that are not generally found in mainstream music performance. This constrained scope tends to be transferred to the prevailing research on DMI users as well, with most scholarship on DMI performance situated within academic and experimental music contexts. However, beyond these focused communities there is a diverse ecosystem of performers who use novel instruments and interfaces that may fit the technical definition of a DMI but not the typical social and cultural context associated with the term.

While studies of DMI-centric musical practice are valuable, they may fail to capture unique and diverse perspectives coming from other communities. For example, electronic dance music (EDM) and hip hop producers, DJs, experimental rock bands and modular synthesiser

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enthusiasts are just a few highly active areas of practice that rely heavily on existing and emerging digital technologies for performance but are not typically included in the discourse around DMI design and practice. Input from these groups can broaden the understanding of where and how new instruments and technologies are being used in different contexts, and ultimately inform the design and evaluation of new DMIs towards their successful and long-term use in more widespread active musical practices.

Here we report a study to identify and characterise DMI use across diverse musical practices via an online survey of musicians, with an aim to develop a set of design heuristics to aid the uptake of new instruments. We begin with a discussion of performance communities in Section 2, first focusing on research within and around the International Conference on New Interfaces for Musical Expression (NIME)[1] , then looking outward to consider DMI use in broader contexts. In Section 3, we review past DMI surveys, including a preliminary survey of our own. We then introduce the main contribution of this paper, the Electronic Musical Instrument Survey. The methodology is presented in Section 4. We report the results in Section 5, providing analysis on the respondents' impressions of the instruments they use, factors for uptake and continued use of DMIs based on frameworks for short and long term user engagement, and an extended analysis to relate findings to specific performance characteristics of musical style and level of activity. Finally, in Section 6, we consolidate our findings to present an updated report on DMI use across both NIME and popular music communities and offer suggestions for instrument designers to facilitate the uptake and long-term use of novel DMIs across diverse and active performance practices.

2. Communities of practice, communities of interest

2.1. NIME and DMI research communities

One of the most compelling attributes of the DMI design community is that it overlaps a great deal with the performance community. This is readily apparent in NIME, the annual International Conference on New Interfaces for Musical Expression, which is dedicated to scientific and artistic research on new musical interface design.

Though NIME is perhaps the most recognisable research community around design of, and creative practice with, novel musical interfaces and instruments, it is not alone. NIME began as a workshop at the 2001 ACM Conference on Human Factors in Computing Systems (CHI) (Jensenius & Lyons, 2017; Poupyrev et al., 2001), but prior to that the fields of musical interaction and interface design were already well established and documented. Volumes like the *Computer Music Tutorial* (Roads, 1996), *Electric Sound* (Chadabe, 1997), and *Trends in Gestural Control of Music* (Wanderley & Battier, 2000) contained a great deal of information on the topic, as did numerous contributions to conferences like the International Computer Music Conference (ICMC) and journals like the Computer Music Journal and Journal of New Music Research, which got their starts in 1974, 1977, and 1972, respectively.[2] Several other journals and conferences have been established with dedicated scholarship on musical interface design and artistic practice, such as Organised Sound, the Leonardo Music Journal, the Sound and Music Computing (SMC) Conference, the International Symposium on Computer Music Multidisciplinary Research (CMMR), and the International Conference on Live Interfaces (ICLI), to name just a few. Thus, while much of the review and associated research presented here explicitly references NIME, we may liberally extend our concept of this community to include these other associations of academic-based musical interface research and practice.

Historically, *community* has been frequently discussed in NIME literature without formal definition. As such, the term merely signifies some grouping of researchers or practitioners sharing a common pursuit or interest. Without a better framework for delineating and characterising different communities, we may lack the tools to adequately examine some of the key ways that communities form and interact, and to understand strategies for building and sharing knowledge.

2.1.1. Communities of practice

Communities have been a topic of considerable interest more recently. Marquez-Borbon and Stapleton (2015) examined the notion of community within NIME through the *community of practice* (CoP) framework. The term 'community of practice' comes from the social sciences and was first coined by Lave and Wenger (1991). CoPs are described as 'groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly' (Wenger & Trayner-Wenger, 2015, p. 1) and possess three essential characteristics: (1) the community's identity is defined by a shared domain of interest; (2) members of the community engage in joint activities, share information and knowledge, help and support other members, and learn from one another; (3) the community is composed of practitioners who share a repertoire of resources.

[1] https://nime.org

[2] The Journal of New Music Research was known as *Interface* from 1972 – 1993.

Of particular interest is how teaching and learning are carried out in CoPs and how this relates to the domain of DMI design and performance. The CoP model is closely related to the situated learning framework by Lave and Wenger (1991), in which 'knowledge is inextricably a product of the activity and situations in which it is produced' (Marquez-Borbon & Stapleton, 2015, p. 308), as opposed to *formal learning*, where the exchange of knowledge is separate from its actual use in practice and carried out in controlled teacher/class environments.

2.1.2. Communities of interest

While learning is a key component in characterising the community, another important consideration is the range of activities that goes on in the NIME community. In this regard, Marques-Borbon and Stapleton observe that NIME may alternately be characterised as a *community of interest* (CoI) (Fischer, 2001), a 'community of communities' in which a common task is approached by practitioners from different disciplines (e.g. human-computer interaction (HCI), design, computer science, engineering, hacking/making, music composition and performance, etc.).

However, the CoI structure may be problematic in two ways. First, when knowledge is tacitly distributed across different disciplines, a condition is formed where stakeholders each 'possess an important and yet incomplete understanding of the problem' (Fischer, 2001, p. 2), known as a *symmetry of ignorance*. Differing perspectives and vocabularies coming from different domains may further obfuscate the common task of a community. The interdisciplinary nature of NIME research, where practitioners freely operate across and between disciplines, may be susceptible to this condition.

Secondly, and perhaps more importantly, with so many different disciplines engaged within the NIME community, it is no surprise that there is no single common task. To this point, Cantrell (2017) extended the CoP/CoI analysis by identifying five distinct areas of NIME research practice: Practical Research, Artistic Performance, Hacking/Making, Commercial Production, and Self Reflexivity. Cantrell provides examples of several NIME projects that engage these different areas to greater or lesser extents, where scientific research mixes freely with creative practice, illustrating the wide diversity and interdisciplinarity found within DMI research.

2.2. Focus on communities of performance

So far our review of NIME and related research shows a strong interdisciplinary community actively involved in many facets of DMI design and performance. In the next section, we review how surveys have been used in these communities to identify and illuminate DMI practice, in preparation for our own survey. We make a general initial observation here, and a key distinction in the aims of our own study: while design and performance roles are deeply interrelated in research-based communities like NIME, this is largely not the case in more active and professional music communities that are not research-based. Generally speaking, performing musicians perform, and leave the design and development of new instruments to others. Therefore, as we prepare our own survey that might inform a performance-centred DMI design methodology, we are interested to isolate performance from design, and focus specifically on these aspects of communities using DMIs.

3. Past surveys

In the interest of providing designers with better tools and more information to aid the creation of new instruments, researchers have utilised questionnaires to survey performers about the use of DMIs in their musical practice. In this section, we review methods and results of several previous surveys, which provide a basis for the formulation of our own survey in Section 4.

3.1. Dual performer-designer roles

An online survey was conducted by Magnusson and Hurtado (2008) to investigate the embodied connections between performers and their instruments, and contrast between acoustic and digital instruments. A call for participation was circulated across several audio programming mailing lists and by the time of first publication, the survey had received over 200 responses. Given the focus on audio programming, which included an optional evaluation section on the authors' own audio software, *ixi*,[3] questions around digital instruments were mainly focused on software and excluded specific discussion about hardware such as physical input devices or embedded instruments.

Two particular findings of the survey highlight the specialised nature of the DMI user community that was investigated. First, respondents prize the ability to easily create and modify digital instruments, mainly via editing software and writing code, according to specific needs of a performance or composition. These 'easy' designs and modifications require advanced non-musical skillsets, most importantly computer programming skills, that are not possessed by many musicians. Furthermore, it shows that many of the respondents identify as instrument designers as well as performers.

Second, the respondents tended to be more critical of digital instruments than their acoustic counterparts.

[3] http://www.ixi-audio.net

Entropic (non-deterministic) characteristics of digital instruments were generally considered to be flaws or errors in the system, whereas entropy in acoustic instruments was regarded favourably as giving the instrument character leading to the discovery of new sounds or playing techniques. This outlook indicates a *design-centric* evaluation of an instrument, understandable given that most respondents were instrument builders themselves and well-versed in the craft of the field.

The Taxonomy of Realtime Interfaces for Electronic Music Performance (TIEM) was a survey that was subsequently conducted by Paine (2010) in partnership with the Electronic Music Foundation[4] , Infusion Systems[5] and the Input Devices and Music Interaction Laboratory.[6] The survey consisted of an online questionnaire for DMI designers and performers to submit information about the instruments they had designed or used in practice. At the time of first publication (Paine & Drummond, 2009), 70 complete responses had been received and a public website was created containing a database of the submitted DMIs.[7]

As with Magnusson and Hurtado's survey, respondents identified as both performers and designers. Furthermore, they varied in how they thought of, or referred to, the systems they were discussing: instruments, interfaces, compositions, or something else. The authors observed that the 'notion of interface/instrument considered also in terms of a composition, while familiar to those working in the area, is of course radically different from the concept of a traditional acoustic instrument' (Paine & Drummond, 2009, sec. IV para. 6). Again this illustrates how select and idiosyncratic typically studied DMI performance communities are.

3.2. Surveying the NIME community

A pair of surveys by Morreale and McPherson (2017) and Morreale et al. (2018) elucidate some of the limitations around performance and the continued use of DMIs over time. The first surveyed instrument makers whose instruments had been presented at the NIME conference over several years. This was followed by a survey of NIME performers to explore and understand the roles of DMIs in their practice and understand common values among performers. They confirmed that a majority of new DMIs fail to be developed or used beyond their initial design and infrequent use in actual performance, and identified a few primary factors contributing to this trend: DMIs are often designed as research probes or works-in-progress not intended for real-world use; instruments are most frequently used by only one or two performers (and most often the primary/only performer is the designer); instruments frequently suffer from maintenance and reliability issues; perspective performers lack the opportunity to use them in performance.

Common themes that were identified around the use of DMIs included the desire for bespoke instruments that could meet personalised and idiosyncratic needs most commonly associated with performing experimental and exploratory styles of music. Consistent with the other surveys discussed in this section, they also found that most (78%) of the performers who responded had designed their own instrument.

3.3. Investigating DMI performance beyond NIME

The studies discussed above illustrate an active, engaged, and highly skilled community of performers, researchers and designers moving frequently and fluidly between these roles. As such, they embody both the technical/engineering and creative artistic roles of DMI practice, and contribute greatly to innovation in both instrument design and expanded musical practice.

These types of practices are well represented in the literature and in the academic research community at large, most notably NIME. However, the use of novel digital instruments and technologies in performance is common beyond these typically surveyed communities as well. Whether by virtue of certain instruments' mass appeal and commercial availability, or their appropriation by more conventional and mainstream music styles, perspectives from more populous and highly active communities of digital instrument users are seldom included in DMI user research.

In a previous study, the first author (Sullivan, 2015) conducted a preliminary survey about musicians' use of technology across different performance communities. Musicians of all kinds were invited to complete the survey, with a call for participation circulated across several different academic and community mailing lists and social media platforms. One hundred valid responses were collected, mostly from professional and recreational musicians, with fewer from academic circles

Table 1. Musician roles of respondents from our preliminary survey. There were 100 total respondents.

Musician roles	Respondents
Professional	43
Hobbyist/recreational	38
Student	11
Instructor/educator	7
no response	1

[4] https://emfinstitute.org/
[5] https://infusionsystems.com/
[6] http://idmil.org
[7] The TIEM website and database are no longer online.

Table 2. The most common musical styles played *(left)* and primary instruments used *(right)* by respondents from our preliminary survey. Respondents could give multiple answers in both categories.

Musical styles played	Responses
Rock/popular	39%
Experimental/avant-garde	24%
Classical	14%
Jazz/blues/R&B	7%
Acoustic/folk/country	7%
Electronic/EDM/House	5%
…5 other styles	< 5%

Primary instruments	Responses
Guitar	66%
Piano/keyboards	64%
Drums/percussion	35%
Bass	33%
Voice	22%
Computer/synthesiser (tie)	11%
…39 other instruments	< 11%

(Figure 1). The survey contained questions about respondents' background, instrument choices, musical styles performed, as well as experiences with, and attitudes towards, new DMIs. Overall the participants represented a diversity of musical styles, and their primary instrument choices were highly conventional, illustrating a trend toward more popular modes of music performance (Table 2).

The objective of this survey was to gain a general overview of trends in DMI use among different performance communities in order to identify areas of focus in preparation for our current survey. The questions were mostly closed-ended (multiple choice and numerical) to allow for efficient quantitative analysis. However, some of the free-format answers provided especially useful and provocative information for further study in two particular areas.

First, performers' integration of digital musical instruments and related technologies varied dramatically based on musical style. More specifically, a clear distinction was shown between users of noncommercial technology (including DIY instruments and interfaces, user-programmed software, research-based prototypes, and experimental instruments) and commercially available mass-marketed hardware and software instruments. In contrast to previously mentioned surveys, in which most participants used noncommercial instruments, we found that in our survey with rock and popular music styles more heavily represented, commercial instruments and interfaces were much more predominant.

Second, responses showed that basic issues of instrument *stability*, *reliability*, and *compatibility* (with other instruments, performers and industry standards) are primary factors that lead to the abandonment of new instruments and technologies. This motivated a separate study in which a meta-review of DMI design literature was conducted that identified fifteen key design areas to be addressed for DMIs to be viable for use in professional performance situations, such as build quality, versatility, timing and latency, sustainability and product support (Sullivan & Wanderley, 2018).

4. The Electronic Musical Instrument Survey

Following our previous work, we were interested to conduct a more comprehensive online survey that again targeted performers across a wide variety of performance practices and focused on factors that contribute to uptake and long-term engagement with new DMIs in performance. Additionally, we wanted to understand what types of performers were using DMIs and how behaviours and preferences vary between different communities.

To do this, we created the Electronic Musical Instrument Survey, an online survey for performing musicians. To encourage participation by performers from diverse musical practices, we chose to use the term *electronic musical instrument* (EMI) as a generic and inclusive name for various overlapping terminologies used in the field such as DMI, NIME, computer-based instrument, interface, controller, etc. By avoiding domain-specific jargon we hoped to make the survey accessible and applicable to anyone who might choose to take it.

4.1. Participant criteria and recruitment

The survey was open to all performers, with no specific requirement that they use electronic musical instruments (EMIs) in performance. The questionnaire was conditionally formatted so only those who reported using EMIs were directed to the relevant sections. Participants were required to be 18 years of age. Beyond that, the only requirement was that respondents identified themselves as 'active musicians'. As an incentive for participating, respondents were invited to enter a drawing for a $100 CAD gift certificate to an online music retailer.

The call for participation was sent via the following channels:

- McGill University Schulich School of Music Student mailing lists
- University of Montreal Music Faculty Student mailing lists
- Centre for Interdisciplinary Research in Music Media and Technology (CIRMMT) regular and student member mailing lists

- Eastern Bloc New Media and Production Centre[8] mailing list and social media
- New Music World[9] mailing list
- social media (Facebook, Twitter and Instagram, shared and reposted by friends and colleagues in music performance circles)
- circulated by colleagues in academic and music performance communities in North America and Europe

4.2. Questionnaire

As mentioned before, our previous survey had used mostly closed-ended and short-answer questions to both minimise the length of time to complete the survey (and in doing so, maximise the number of respondents) and to optimise and automate analysis of the data. For this survey we chose to ask more open-ended questions and used more qualitative methods of analysis for the free-format responses to collect richer data about performance practices. The questionnaire is included as Appendix A (see supplementary material).

The questionnaire was organised in two parts. In the first part, Sections 1.A and 1.B collected demographic and background information about the respondents and their musical training, including how long they had been playing music, details on formal training, areas of focus, and experience with computer programming and electronics. Section 1.C asked for details about their performance practice: primary genres and sub-genres of music that they perform, frequency and types of performance, what kinds and sizes of venues, if they play solo or with groups/ensembles, and what kinds of instruments and setups are used.

Part two of the questionnaire was dedicated to the use of electronic musical instruments and controllers. Because the survey was open to all performers, Section 2.A started with a filter question, 'Do you use electronic musical instruments in performance?' If a respondent answered no, the survey concluded at that point. If they answered yes, they survey continued. In Section 2.B, respondents were asked to describe and answer several questions about a specific instrument or controller they frequently use. They could repeat the section up to three times to give information on multiple instruments. Section 2.C contained several open-ended questions asking for the respondents' opinions on acquisition and continued use of EMIs in general. Section 2.D contained a few concluding questions. Respondents were invited to write any additional comments they had, and were asked if they wanted to opt-in for the gift certificate drawing. Additionally, they were asked if they would be interested in participating in a follow-up interview, though the interviews we ultimately cut from the study given the large amount of data collected from the survey itself.

In total the survey contained 32 questions, though the exact number a respondent might answer varied, based on conditional logic that would skip or reveal additional questions depending on respondents' answers to certain questions. Respondents were allowed to skip any questions they didn't care to answer, and we estimated it would take between 10 and 30 minutes to complete.

4.3. Data collection and processing

A website was built to host the survey and put online at the domain emisurvey.online.[10] The survey was open for two months. While it ran, responses were saved to a database on the web host server.

Before beginning the study, the entire survey protocol had been reviewed and approved by the Research Ethics Board of McGill University.[11] The identities of respondents were kept anonymous: names and other personally identifying data were not recorded on the survey. Email addresses (collected if they opted in for prize drawing or interview availability) were removed from the dataset before analysis.

When the survey concluded, the full dataset was downloaded from the website database as a .csv file and imported into Microsoft Excel for initial processing and data cleanup. The data were visually inspected and any invalid entries (including abandoned or nonsense entries) were removed. Any email addresses that were collected were moved to a separate key file and associated with a corresponding participant ID code (P01 – P*n*).

4.4. Analysis methods

The initial intent for analysis was to use grounded theory (Strauss & Corbin, 1994). In grounded theory and other similar qualitative approaches, a fundamental activity is *coding*, where incidents in the data are first identified with a code, or simple short description. As the data are reviewed, incidents are either assigned an existing code or a new code is created. Similar codes are grouped together and, depending on the exact methodology used, they are iteratively reviewed and classified into hierarchical categories or themes. While this process of coding and classification was appropriate for our needs, The formal

[8] https://easternbloc.ca/.

[9] New Music World was a community-based online resource for global new music events and content, founded by Joel Chadabe and affiliated with the Electronic Music Foundation Institute (https://emfinstitute.org/).

[10] The survey website is presently archived at https://emisurvey.johnnyvenom.com/.

[11] McGill University REB II Certificate # 254-1117.

methods of grounded theory felt too rigid and prescriptive for our desired exploratory analysis of the survey responses. Instead, we chose a more flexible thematic analysis approach presented by Braun and Clarke (2006), which uses similar methods but is adaptable to the specific contexts for which it is applied.

The analysis was organised into three parts. The first part of the analysis focused on the respondents' descriptions and impressions of the electronic and digital instruments they use in performance. Responses were coded and grouped using an *inductive*, or bottom-up, approach (Creswell & Creswell, 2018), where the groupings developed naturally as the codes were generated. Subsequent review and classification of the codes yielded several themes around what types of performers use EMIs, characteristics of their performance practice, instruments used desirable features and attributes of EMIs. Braun and Clarke (2006) characterise this part of the analysis as *semantic*, in that the themes were drawn directly from the data and we did not attempt to interpret the participants' responses or make implicit assumptions about their meanings beyond what they had written.

Part two of the analysis identified factors that influence uptake, long-term use, and retirement of instruments. Responses to this specific section of the survey were coded using a top-down, *deductive* approach (Creswell & Creswell, 2018) to contextualise the results within a conceptual framework based on two models of user engagement found in the literature: We characterise the first as short-term, comprised of the following stages: *initial engagement*, *sustained engagement*, *disengagement*, and *reengagement* (O'Brien & Toms, 2008). The second pertains to long-term engagement, which was developed by Wallis et al. (2013) in a study of instrument use by amateur musicians and based around intrinsic motivations of *mastery*, *complexity*, and *purpose*.

In part three, as a follow-up to our main thematic analysis and investigation for future work, we crosstabulated the results from the previous steps across different respondent attributes to explore variations between performance communities.

The analysis was carried out using Nvivo qualitative data analysis software (version 12 for Mac, by QSR International)[12], with additional steps carried out in Excel. The thematic analysis codebooks and crosstabulation sheets are included in Appendix B (see supplementary material).

[12] https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home

Table 3. Overview of sections and questions in the EMI Survey. The full questionnaire is included in Appendix A (see supplementary material).

Survey sections	Questions
1. Information about respondents	
A. Background info	1 – 3
B. Musical training and experience	4 –6
C. Performance practice	7 – 12
2. Electronic musical instruments	
A. Use of electronic musical instruments	13 – 15
B. Description and functionality	16 – 24
C. Acquisition and continued use	25 – 30
D. Conclusion	31 – 32

5. Results

An overview of the survey is shown in Table 3. Where applicable, the relevant survey sections and questions are indicated next to the corresponding results in the text.

5.1. Information about respondents

5.1.1. Demographics (Sec. 1A, 1B)

A total of 85 people responded. 73% of respondents ($N = 62$) reported that they use EMIs in their performance practice, while 27% ($N = 23$) stated that they do not.[13] Respondents were primarily North American and European, reflecting the main geographic areas where the survey call was circulated. The total number of respondents was short of our goal of 100, however given the diversity of responses and qualitative methods used for the analysis, we felt that the number was sufficiently adequate to gain many clear insights about the overall population of EMI users. We reflect further on our survey reach and respondent diversity in Section 6.2.

Figure 1 shows age, musical training, and performance experience distributions for respondents who use EMI and those how don't. Overall the survey population is highly experienced. 89% of all respondents reported that they have been performing for more than 10 years (64% more than 20 years). 85% have received formal training, with more than 40% having studied music at or above graduate level. The distributions vary somewhat between EMI users and non-users, though overall they are largely consistent.

5.1.2. Performance practice (Sec. 1C, q9-11)

As shown in Figure 2, there was a wide range of diversity in the frequency and type of performances across respondents. Over half perform 10 times or less per year. Average audience size varies from less than 100 to over 1000, with EMI users more likely to perform for smaller

[13] We note that this was self-reported and was subject to the respondents' interpretations of what constitutes an EMI, something that we revisit in later sections.

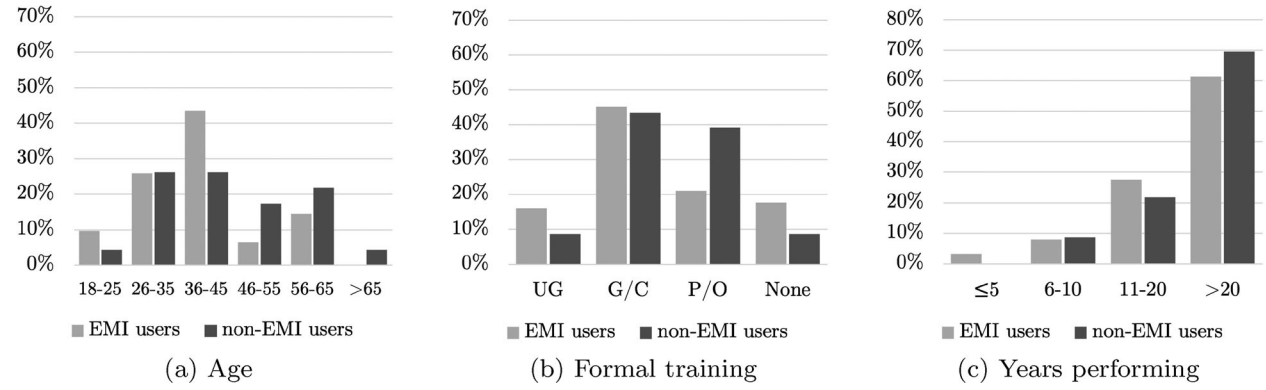

Figure 1. Percent of respondents by age, formal training and years of experience performing for EMI users ($N = 62$) and non-users ($N = 23$). Categories of formal training for Figure (b) are: *UG: undergraduate, G/C: graduate or conservatory, P/O: Private instruction or other, None: self taught*.

audiences and much less likely to perform for large audiences. Most respondents perform in groups, at least part of the time. Only a small percentage of respondents perform solo exclusively, while EMI users are somewhat more likely than non-users to perform in both contexts.

5.1.3. Musical style (Sec. 1C, q7 & 8)

To classify musical style, we used a list of genres from AllMusic, an online music database,[14] with some revisions to reflect some of the anticipated nuances and particularities of our expected respondents. For instance, *electronic* may mean very different things to popular or experimental musicians, so we separated it into *EDM* (electronic dance music) and *electroacoustic*. Respondents were asked to select up to two main styles from the list and could write in other styles or sub-genres in an additional open text field. To facilitate our analysis, the totals for musical styles were adjusted to include any sub-genres or written-in styles that we felt belonged to the given categories if they hadn't already been reported by the respondent. Examples included assigning *'house, drum'n'bass, jungle, progressive techno'* to EDM and *'alternative, post-rock, indie'* to pop/rock. Figure 3 shows the musical styles reported by EMI users and non-users.

There are two important things to note around the selection and categorisation of performance styles and ramifications for our study. For one, while our list of styles adapted from AllMusic aims to be comprehensive, it is admittedly Eurocentric in both scope and categorisation, and a comprehensive list of styles originating from a different geopolitical worldview would likely look much different. Furthermore, self-identification of musical style and genre is highly subjective and similar musics may be assigned to different categories by different respondents. We keep these points in mind throughout the analysis, and return to the topic of musical style in Section 5.4.

[14] https://www.allmusic.com/genres

5.2. Use of electronic musical instruments (Sec. 2A)

In the second half of the survey, participants were asked if they use electronic musical instruments (EMIs) in performance. Of the 85 total respondents, 23 (27%) answered that they do not, bringing them to the end of the survey. The remaining 62 participants continued to the second half of the survey, where they identified and gave information about their primary electronic instrument(s) (up to 3), and responded to general questions about instrument uptake and longitudinal use. The instruments were categorised and are shown in Figure 4.

The 62 respondents who use EMIs comprise a diverse group of performers active in a variety of different types of practices. All play multiple instruments, and most play a mix of conventional instruments and digital/electronic instruments and interfaces, as well as using computers extensively for their performance setups. While many respondents play infrequently and to smaller audiences, several reported having active practices that include more frequent performances and larger venues. There is a wide musical diversity as well. Most perform avant-garde and experimental styles ; however, this varies widely from one performer to the next. The other reported styles fall across a range of genres from art and folk to popular musics. The topics of active performance and musical style are further addressed in the final stage of our analysis (in Section 5.4).

5.2.1. Instrument qualities, features and issues (Sec. 2B)

In the first part of our thematic analysis, we analysed responses to questions about the EMIs that performers

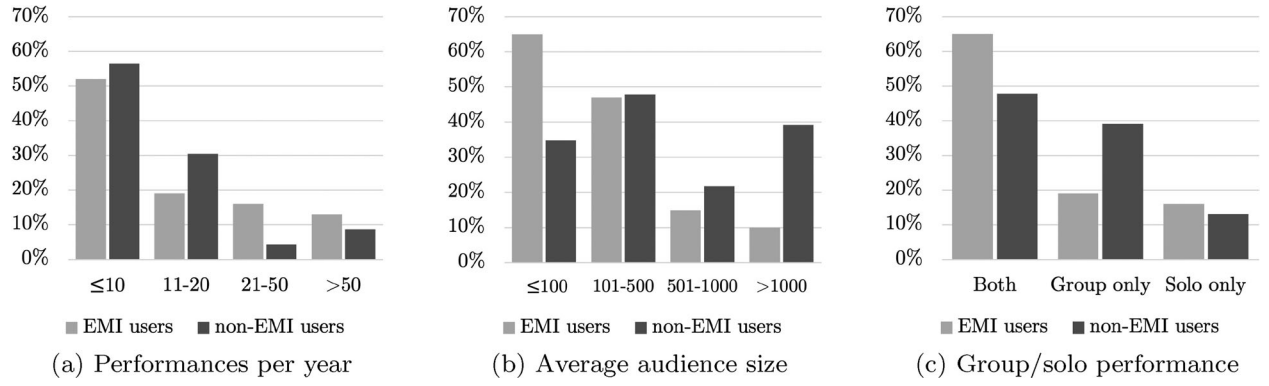

Figure 2. Percentage distributions of EMI users ($N = 62$) and non-users ($N = 23$) for three performance metrics. Multiple answers could be chosen for Figure (b).

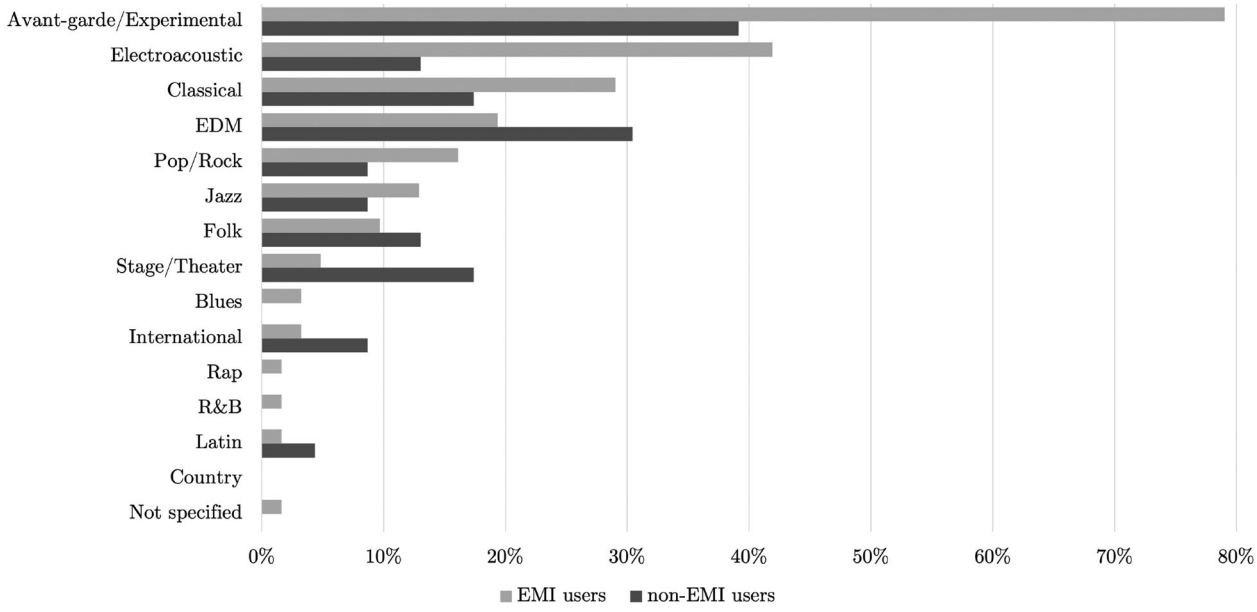

Figure 3. Percentage distributions of EMI users ($N = 62$) and non-users ($N = 23$) by musical styles performed.

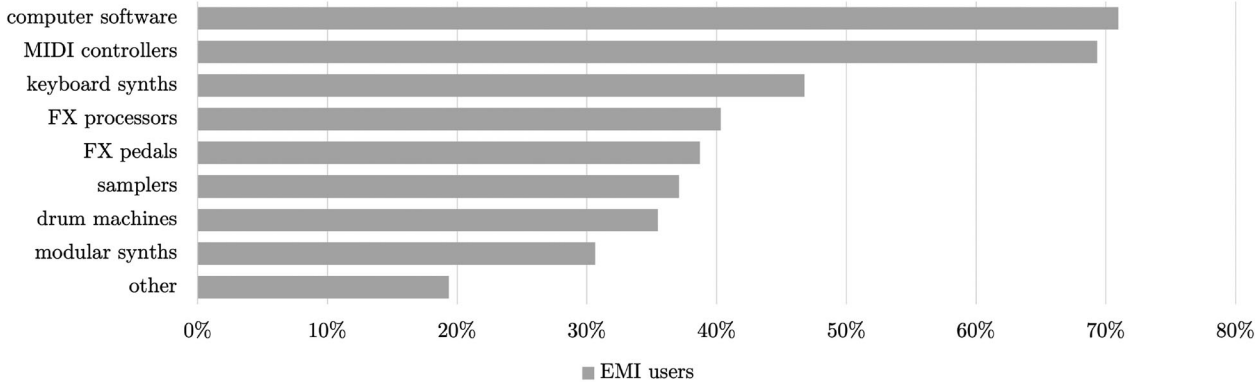

Figure 4. Percent of EMI users ($N = 62$) who use each type of electronic musical instrument (EMI).

use: likes and dislikes, desirable and undesirable features, how they configure and use their instruments, overall satisfaction and suggested improvements. The first round of analysis yielded an initial set of codes, which we organised into similar groupings. The coding process was repeated, checking our initial codes and revising them where appropriate. Once complete, we were able to further organise our findings into broader categories out of which we could identify several emergent themes.

For this section of the survey, we classified the coded responses into three groupings: (1) recurrent quality attributes, (2) requested features, and (3) instrument issues. The first grouping was further classified into four general categories: *handling complexity*, *accommodation*, *appropriation*, and *other qualities*. Table 4 shows the most frequently mentioned qualities, features and issues. (See supplementary material, Appendix B.1 for the full analysis codebooks.)

Handling complexity: The most commonly cited quality mentioned was flexibility and versatility, mentioned by 48% of respondents. This means different things to different performers. For some the reasons are economical: *'A machine that does one thing very well is half as good as something that does 10 things reasonably well' (P84).* For others, flexibility and versatility affords greater creative freedom and expression in performance: *'The highly flexible modular design … allows me to build many possibilities out of the same instrument' (P35).* Also mentioned was the ability to configure or program the instrument more deeply: *'… versatility to add any code and modify the instrument's behaviour' (P13).*

On the other hand, 21% of respondents value simplicity, citing the effectiveness, ease of use, and dedicated functionality of an instrument: *'It's all very simple and, dare I say, primitive, which is why I like it' (P59).* These differing points of view were also reflected in a separate question that asked whether respondents preferred computers or dedicated hardware. Responses were divided between those who favour the versatility and configurability of computers and those who favour dedicated hardware, while many replied that it depends on a number of different factors.

Accommodation: 53% of respondents specifically commented on the way their instruments accommodate their performance practices. Size and portability were most frequently mentioned, by 29% of respondents (also making it the 2nd most frequently mentioned attribute): *'It's compact, lightweight and versatile' (P73)*; *'… can go inside my bassoon case' (P58)*. Playability was second most common in accommodation (19% of respondents), which included mentions of expressiveness, articulation, control and ergonomics. Additional accommodation qualities were compatibility and interoperability with other instruments, software and setups, and ease of setup and use.

Appropriation: Two general categories of appropriation were frequently mentioned: embodied connections (24%) and personalisation (23%). For embodied connections, respondents spoke favourably of tactile and physical interactions with their instruments, citing control, material connection and 'muscle memory' with an instrument that enhances their performance. For personalisation, many mentioned configurability and programmability of their instruments that leads to 'ownership' of highly customised instruments and multi-instrument setups. Some respondents expressed deep appreciation and even affection for their instruments:

> *'It's just part of my family. I love it unconditionally for it's qualities which both assist me in achieving a sound and for it's limitations which push me to think about things critically and inspire me to solve problems and become a more versatile and capable artist' (P21).*

Other qualities: Three additional qualities were frequently mentioned that did not fit the themes above: sound quality (26%), cost and affordability (15%), and overall pleasing aesthetics of an instrument such as its look and feel (10%).

Requested features: Responses in this category were mainly focused on incremental enhancements to performers' existing instruments – adding or extending specific functionality, adding to or improving the quality of controls and adding connectivity to interface with other instruments and systems: *'The only thing I would add would be more detailed control of the LFO (low frequency oscillator) [such as] controls for the attack, decay, sustain, release, and a better synchronisation of the LFO with the internal sequencer' (P88)*; *'I would like the option of outputting control voltages' (P84).* Nearly all requests involved features that currently exist on other instruments, though some described highly specific and technical needs:

> *There are small, modern functionalities that I would very much like to incorporate into the instrument's design. Thankfully third-party hardware engineers have created options available, such as the 208 Toolbox*[15] *which unlocks additional functionality without requiring modifications to the original hardware. I am presently working with an engineer to further expand the possibilities offered by the 208 Toolbox to suit my needs (adding a noise source and voltage controlled LFO) (P35).*

Instrument issues: Respondents described a wide variety of issues with their current instruments. The most common issue was broken or unstable knobs, buttons,

[15] The 208 Toolbox is a third party expansion board for the Buchla Easel Command and 208C synthesisers. www.portabellabz.be/toolbox.html

Table 4. Most frequently mentioned EMI recurrent quality attributes, requested features and instrument issues. Percentages refer to percent of total respondents ($N = 62$) with responses coded at each item.

Recurrent quality attributes							
Handling complexity		Accommodation		Appropriation		Other qualities	
flexibility/versatility	48%	size/portability	29%	embodiment	23%	sound quality	26%
simplicity	21%	playability	19%	personalisation	24%	cost/affordability	15%
		compatibility	16%			aesthetics	10%
		ease of use	13%				

Requested features	
added features/functionality	19%
more/improved controls	19%
more/improved connectivity	18%
high-level programming	6%
better feel/ergonomics	5%
feedback	5%

Instrument issues	
broken bits, knobs, keys, etc.	18%
software issues	15%
limitations of hardware	10%
cables and connections	6%
poor overall quality	6%
general computing devices	5%

keys, and similar parts. Cables and connections were also points of failure. However, most described putting up with – and working around – these issues and continuing to use the instruments. While software issues (and crashes in particular) were the second most mentioned issue (by 15%), some were particularly sympathetic and forgiving of software: *'Since 2000 I've had exactly 6 crashes on stage' (P46).*

5.3. User engagement: Uptake and continued use of new instruments and technologies (Sec. 2B; q25 & 28)

Following our previous survey (summarised in Section 3.3), we were particularly interested in identifying factors that motivate performers to take up new instruments in their practices, and factors that contribute to the long term success, or alternately abandonment, of new EMIs. Following initial open coding, we investigated two previous models of user engagement to see how we could contextualise respondents' views within a more formal understanding of both short- and long-term engagement with technology.

The survey included two specific questions related to engagement:

25. What factors influence you to take up a new electronic instrument?
28. On average, how long do you typically use an electronic musical instrument before retiring it? What factors influence you to stop using certain electronic instruments?

Initial open coding yielded a list of themes that we associated to the three stages of EMI use referred to in the questions: *uptake*, *longevity* (continued use over time) and *abandonment* (discontinuing use of an instrument). The survey didn't ask a specific question about the factors for longevity, and when mentioned, they were often closely connected (or in opposition to) factors for abandonment. Therefore the themes for this step of analysis are shown in Table 5 with these two categories combined, followed by our initial observations.

Uptake: Factors related to taking up new instruments primarily fell into three groups. Novelty and variety were most frequently mentioned with respondents seeking out new sounds, exploring new musical possibilities and expanding their setups. Second, respondents look to upgrade to acquire specific functionality or improve certain qualities of their instruments. Third, respondents cited a number of practical concerns that would influence their choice of a new instrument, such as cost and availability, and how it would integrate into their current setup with other instruments.

Beyond these main groups, differing outlooks between hardware and computers/software were apparent. Towards hardware, most respondents reported seeking our new instruments that provide dedicated functionality and impose constraints. In contrast, one respondent highlighted the ephemeral nature of their computer-based instrument:

> *'In a sense, I can say that I haven't taken a new instrument in years because I've been performing with a computer for more than a decade. In another sense, I may say that I often change instruments, as every time I develop a new patch my instrument is fundamentally transformed' (P24).*

Longevity and abandonment: Many respondents showed great loyalty to the instruments they use, with several stating that they never retire an instrument. In the case of computer-based performance (well conveyed in the previous quote), this brings into question the blurred lines between instrument and composition as discussed

Table 5. Identified factors for uptake, and the combined categories of longevity and abandonment of EMIs. Percentages refer to percent of total EMI users ($N = 62$) with responses coded at each item.

Uptake		
Novelty & variety	new or improved sounds, exploration, expand or diversify performance practice	44%
Upgrading	acquire specific functionality and new features, improve interaction or control	44%
Practical concerns	cost and availability, integration with setup, quality and reliability, size and portability	40%
Influence	saw/heard the instrument played, recommendation	8%
Constraints	simplification, constraints of hardware	3%
Other factors	flexibility and versatility, learning curve and ease of use, same computer/new patches	19%

Longevity & abandonment	
never retire instruments	21%
broken or unreliable	21%
loss of interest or usefulness	16%
replace with better or more suitable	16%
obsolescence, incompatibility	15%
constant change	7%
streamline setup, eliminate redundancy	7%
vibe, flow, balance	3%
newer prototype	2%

in Section 3.1. Consistent with previous survey findings (Sullivan & Wanderley, 2018), issues of quality, reliability and compatibility were important contributing factors in the abandonment of instruments. Beyond this, many other factors were consistent with the factors for uptake: loss of interest or usefulness (complementary to acquiring new instruments with new features, sounds, etc.), upgrading and seeking novelty or change.

5.3.1. Models of user engagement

The notion of *engagement* is an important concept in HCI, and more generally interaction design, and can be conceptualised in similar terms as our inquiry how EMIs are taken up and used by performers. To provide a formal framework for analysis, we associated participant responses for this part of the survey with related concepts of user engagement from HCI literature.

Short-term user engagement: A prevalent model of user engagement with technology was formulated by O'Brien and Toms (2008). They propose that engagement is a process that moves through four distinct stages: an initial *point of engagement*, a sustained *period of engagement*, ending in *disengagement*, and may eventually be followed by *reengagement*. Along with these four stages, they also recognise the possibility of *nonengagement*. This model for engagement came out of a review of previous domain- and context-specific frameworks around engagement, and an exploratory user study of individuals participating in four different computer-based activities: Web searching, online shopping, Webcasting and video gaming. Across the four stages of engagement, O'Brien and Toms identified several attributes, leading to a conceptual and operational definition of engagement as *'a quality of user experiences with technology that is characterised by challenge, aesthetic and sensory appeal, feedback, novelty, interactivity, perceived control and time, awareness, motivation, interest and affect'* (O'Brien & Toms, 2008, p. 949).

We characterise this type of engagement as *short-term*, as it is concerned with engagement at the event level (for example, a single practice session or performance). Because of this scope, it was difficult to apply this model directly to our survey responses, which are concerned with the entire lifespan of an instrument (or at least the complete life of use by an individual performer) and not a single sitting.

On the other hand, we identified many of the same short-term engagement attributes in the respondents' attitudes towards uptake, longevity and abandonment of their EMIs. We explored this by re-coding the responses to our two questions on this topic, this time classifying them according to O'Brien & Toms's list of engagement attributes. The results are shown on the left of Table 6.

Long-term engagement: Prior research has examined long-term engagement with musical instruments. Drawing from psychology, Wallis et al. (2013) applied the *self-determination theory* (SDT) of motivation by Ryan and Deci (2000) to identify attributes of musical instruments and music-making activities that inspire long-term engagement by amateur musicians. SDT classifies three intrinsic motives that regulate behaviour: *mastery*, *autonomy* and *purpose*. Wallis et al. specifically link these intrinsic motives to amateur musical practice as opposed to professional practice which might also be motivated by extrinsic motives (such as the need to make money). Furthermore, intrinsic motives are more closely related to the sense of enjoyment, i.e. playing music for pleasure rather than out of duty. Out of their analysis, Wallis et al. derived seven conceptual and abstract attributes of intrinsic motivation that can be seen to facilitate long-term engagement with musical instruments. We re-coded the corresponding survey responses along these attributes, which are listed in Table 6 (right).

5.3.2. Attributes for engagement with EMIs

Both models correlate closely with our responses. Short-term attributes, despite focusing on a much narrower time scale than the survey questions, effectively described

Table 6. Attributes of user engagement. Left: Short-term as defined by O'Brien and Toms (2008). Right: long-term as defined by Wallis et al. (2013). Percentages refer to percent of total EMI users ($N = 62$) with responses coded at each item.

Short-term engagement (O'Brien & Toms)	
novelty	44%
control	18%
aesthetic & sensory appeal	16%
challenge	15%
interest	15%
motivation	8%
interactivity	6%
affect (negative/positive)	5%
attention	3%
awareness (external/self)	3%
feedback	3%
perception of time	0%

Long-term engagement (Wallis et al.)		
Mastery	complexity	34%
	immediacy	32%
	incrementality	10%
Autonomy	ownership	39%
	operational freedom	15%
Purpose	demonstrability	6%
	cooperation	3%

many of the themes identified in our initial coding (in Table 5), especially the factors for *uptake*. On the other hand, the long-term attributes, while more theoretical, explicitly address the aspect of longitudinal use, which is missing from the short-term model and is an important aspect of our investigation. Therefore we found them both beneficial and they are both included in our engagement analysis.

We conclude this stage of analysis by comparing attributes between the models of long- and short-term engagement and the results of our exploratory analysis. Table 7 shows all of the attributes and their associations. While there are many interrelated concepts across the three groupings, we highlight three main classifications that were most frequently mentioned by respondents and discuss how the models and data intersect.

Ownership and Novelty: The primary qualities shared between the three rounds of coding are closely associated with *ownership* (long-term attribute) and, more narrowly, *novelty* (short-term attribute). In summary, the most compelling factors for the acquisition of new instruments, and long-term use of existing instruments, is that they afford novel and ongoing creative and expressive possibilities and allow for embodied and highly personalised connections between instrument and performer. There are divergent views on how to achieve novelty though. For many, this is an external process of experimenting with and acquiring new instruments, for others, it is a matter of deep exploration and customisation that comes with working with a single instrument or setup for many years.

Complexity and challenge: A related quality that was commonly mentioned is the ability of instruments to facilitate *complexity* and successfully navigate the *challenges* associated with assembling and performing with elaborate and highly specific assemblages and instrumental setups that allow for rich and dynamic musical output. Most references in this group referred to acquiring new instruments, in particular seeking out instruments and interfaces that afford improved interaction and control or provide a particular indispensable features.

Immediacy, incrementality and reliability: The third common category we identified characterises qualities that support the successful and functional operation of instruments, while minimising or removing obstacles that would prevent operation. Three related qualities are recognised, roughly moving from short to long term periods of engagement. First, *immediacy* comprises properties that allow for easy and direct use, such as ease of setup, portability, and affordability. Second, *incrementality* refers to the learning curve of an instrument that will ideally afford a gradual manageable progression from simple operation to mastery and expert operation. Finally, *reliability* pertains to qualities that allow for successful and sustainable operation like an instrument's overall quality, stability and compatibility with other instruments and systems (or conversely, unwanted characteristics like instrument breakage, failure and obsolescence).

Interestingly, there was little mention of *purpose*, the third intrinsic motive of long-term engagement. This motive, as defined in SDT, is 'evoked by activities containing a social element or an element of relatedness with other people' (Wallis et al., 2013, p. 56). While it factored strongly in Wallis et al.'s framework for engagement by amateur musicians, there were few mentions by our respondents. Those that did mainly spoke to seeing or hearing an instrument played as inspiration for acquiring it. Regarding cooperation and playing with others, only two mentions were made and in fact one highlighted the desire for better technology to facilitate *less* cooperation: *'[I would start using a new instrument] if the concept of performing the instrument myself is more favourable than collaborating with someone who is already proficient on that instrument' (P21)*. The lack of comment on the social aspect is somewhat surprising, as fully 85% of EMI users in the survey report that they perform in ensembles or groups at least part of the time.

Table 7. Associations of long- and short-term engagement attributes with our coded themes for EMI uptake, longevity and abandonment. The most commonly identified items are highlighted in boldface (mentioned by more than 20% of respondents).

Long-term		Short-term	Coded themes
mastery	complexity	challenge	**acquire specific functionality** improved interaction, control newer prototype integration with the rest of setup eliminate redundancy, streamline setup same computer, new patches
	immediacy incrementality	attention feedback	quality, reliability **breakage, unreliability** incompatibility, obsolescence cost and availability size and portability simplicity constraints (of hardware) learning curve, ease of use
autonomy	ownership	novelty interest motivation affect awareness aesthetic appeal sensory appeal	**new or improved sounds** **do not retire instruments** loss of interest or usefulness exploration expand or diversify performance practice new features constant change vibe, flow, balance (or imbalance) never pick up new instruments movement around stage
	operational freedom	control	replace with better, more suitable options, versatility, flexibility
purpose	demonstrability cooperation	interactivity	heard the instrument played recommendation

5.4. Understanding performance communities

For the third and final section of our analysis, we extend our results of the first two sections by returning to our earlier discussion on DMI use (Section 1.1) and communities of performance 2. We were interested to see if musicians different performance communities prioritise different qualities for instruments that they would want to use in their practice. Furthermore, through our review of previous surveys in Section 3.1, we found that existing scholarship on DMI performance tends to be self-reflective of its own research-oriented communities (such as NIME), and there is a lack of information about more popular and widespread practices.

To establish some basic distinctions between different types of practices we looked at two attributes of respondents that use EMIs: frequency of performance (to differentiate between active professionals and amateurs who perform less often), and performance of 'NIME' versus 'non-NIME' musical styles.[16]

Frequency of performance was quantified directly from question #9 of the survey: *'How many times per year do you perform in public?'* EMI users ($N = 62$) were roughly split between two groups: frequent performers who perform more than 10 times per year (48%), and infrequent performers who perform 10 times or less per year (52%).

To associate reported musical styles with typically 'NIME' and 'non-NIME' modes of performance, we referred to the most common styles reported in the survey of NIME performers by Morreale et al. (2018), shown in Figure 5: experimental, electronic, noise, acousmatic, and classical, which were selected by between 19% and 82% of their respondents. In our own survey we ascribed analogous musical styles as NIME styles, and the others as non-NIME (as shown in Table 8), then classified respondents accordingly: NIME (42%), non-NIME (13%), and those who play both (44%). One respondent who didn't answer questions about musical style was removed. The classifications are shown in Table 9, along with further subclassification of both attributes. These are, of course, imprecise categorisations that were self-reported and somewhat subjective. But they do allow us some draw some general designations around types of practices that may be helpful to our analysis. Additionally, we use the term 'NIME' in a loose and inclusive sense, referring not only to the community directly associated with the NIME conference and organisation, but to all related communities engaged in research-based practices around musical interface design and performance.

[16] We started with a third, performers who also design instruments versus those who do not; however, the survey lacked specific data for this and all of the respondents who could be identified as designers were included in the NIME performance category already, making the classification largely redundant.

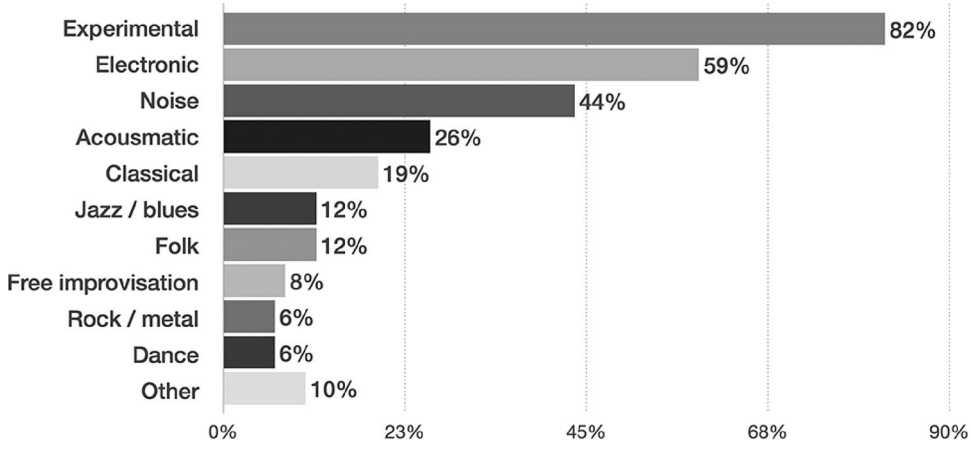

Figure 5. Musical styles reported by NIME performers in Morreale et al. (2018). Used with permission.

Table 8. NIME and non-NIME musical styles from the EMI Survey.

Category	Musical styles
'NIME' styles	Avant-garde/experimental, electroacoustic, classical
'non-NIME' styles	EDM, pop/rock, jazz, folk, stage/theatre, blues, international, rap, R&B, Latin, country

Using these two respondent classifications we computed a crosstabulation of the identified recurrent quality attributes (from Section 5.2.1, Table 4) and primary attributes of uptake and long-term engagement with DMIs (Section 5.3, Table 7). The crosstabulation results are shown in Appendix B.2 (see supplementary material). A detailed discussion of the results is withheld here, as this additional analysis is offered as a supplement the main results already reported and an indication for future continued work. We can, however, point out a few noticeable contrasts between frequent and infrequent performers of NIME and non-NIME musical styles:

5.4.1. Performance frequency

- Infrequent performers (which we associate with amateur musicians and hobbyists) prioritise flexibility and versatility in an instrument, while more frequent performers (active and professional musicians) spoke more favourably about simplicity and constraints.
- Infrequent performers seem to be more likely to seek out novelty and change instruments more often than active performers.
- Frequent performers engage in deeper levels of customisation and personalisation of their instruments, and prioritise reliability and quality over novelty and variation.

5.4.2. NIME and non-NIME musical styles

- Performers working in non-NIME styles value compatibility and interoperability between instruments and across their instrumental setups, while at the same time prioritising ease of use and size/portability. This suggests that they tend to use instruments that individually provide more constrained functionality, but incorporate many together into elaborate setups.
- NIME musicians prioritise the embodied connections they have to their instruments, and necessitate greater control for carrying out complex musical performance.
- Non-NIME musicians commented more frequently about the importance of their instruments' sound quality and aesthetics than NIME musicians. They are also highly motivated to acquire and create new sounds. While this was not highlighted in the NIME musicians, this may also be a fundamental difference in the musical styles themselves, where NIME-style music often operates on a more organic level of sound production (often working with lower-level synthesis

Table 9. Classifications of EMI performers by musical style (NIME/non-NIME/both) and performance frequency (+/− 10 performances per year).

		Musical style			
		NIME 42% ($N = 26$)	non-NIME 13% ($N = 8$)	both 44% ($N = 27$)	not specified 2% ($N = 1$)
Performance frequency	Frequent 48% ($N = 30$)	27% ($N = 17$)	8% ($N = 5$)	11% ($N = 7$)	2% ($N = 1$)
	Infrequent 52% ($N = 32$)	15% ($N = 9$)	5% ($N = 3$)	32% ($N = 20$)	–

parameters), where non-NIME styles, especially pop and dance music, are more likely to acquire and use pre-recorded or programmed samples, presets, etc.[17]

6. Discussion

6.1. Considerations for the design of DMIs for performance

In consideration of the challenges that designers face towards the creation of new DMIs that would be viable and appealing for active musicians to work with in real-world performance practices, we summarise our results as a set of considerations for DMI designers. The bold-faced items reference the elements defined and discussed in the previous section.

(1) We define three primary desirable sets of qualities for DMIs to be viable for use in real-world performance practice: (a) the instrument's ability to ***handle complexity*** that is appropriate to the user and context; (b) its capacity to adequately ***accommodate*** the unique requirements of a performer's practice; and (c) its suitability for ***appropriation*** by its user, that can facilitate long-term growth and enjoyment.
(2) Additionally ***sound quality***, ***cost and affordability***, and the ***look and feel*** of an instrument are important characteristics that contribute to performers' positive impressions of their instruments.
(3) While acquiring new instruments and retaining existing instruments depends on a number of factors, performers consistently show interest in acquiring new instruments that provide ***improved features, controls and new sounds***.
(4) ***Instrument reliability*** is a persistent concern for most performers, yet many put up with minor problems and continue to use a particular instrument despite ongoing issues. In this regard, ***performers often exhibit great loyalty and even affection for their instruments***.
(5) We identify three sets of user engagement attributes that contribute to the successful uptake and long-term use of DMIs: (a) ***ownership and novelty***, through deep exploration and customisation of existing instruments as well as acquiring and experimenting with new instruments, that facilitates ongoing creative and expressive performance; (b) ***complexity and challenge***, the ability for instruments to accommodate elaborate and highly specific musical setups and processes, allowing for rich and dynamic output; and (c) ***immediacy, incrementality and reliability***, which support the successful, functional and long-lasting operation of instruments while minimising obstacles that would prevent their use.
(6) Lastly, and perhaps most importantly, we take note of diversity across performance practices and between performers. While the high-level considerations listed here are meant to be applicable to all performers, they will be exhibited in different ways depending on a variety of factors. We propose two general ways of classifying performers and types of practices: by frequency of performance (frequent/infrequent, which suggests a contrast between amateur and professional practice) and musical style (which we categorise between 'NIME' and 'non-NIME' styles, characteristic of the DMI design and research community.)

6.2. Limitations and future work

This list of considerations is far from exhaustive, and additional insights will be revealed with continued investigation and analysis around DMI performance. However, we hope that these findings shed new light on what it means to perform with novel instruments, especially across and beyond previously studied communities including those surveyed here.

6.2.1. Capturing diversity and widespread performance practices

It was hoped that the EMI Survey would reach a number of different performance communities, however we found that many respondents fit into typical NIME-style types of practice. More than two-thirds of respondents come from formal training and academic backgrounds, are involved in experimental music practices, and are highly computer literate. As this study was carried out in an academic research environment and the call for participation was distributed across several university networks, accordingly many of the respondents can be recognised as operating in or adjacent to academic practices. Therefore, we recognise the limitations of our survey distribution and attempts to capture wide diversity across performance communities. We did, however, find significant variation in the survey population which collectively represented a range of different approaches and perspectives to performance.

We can envision a future survey that could extend our current work in a few key ways. First, recruitment efforts can target diverse types of performance communities based on specific attributes such as professional versus amateur musicians; performers of popular, classical

[17] This characterisation of performance style shares some similarities to the three levels of music interaction and performance contexts identified by Malloch et al. (2006) based on a model of information processing by Rasmussen (1986) which moves from *skill-* to *rule-* and *knowledge-based* modes of interaction.

and experimental styles of music; designers versus non-designers; academic researchers versus non-academic researchers; and skill versus rule and knowledge-based levels of musical interaction (based on the model by Malloch et al. (2006)). Crosstabulation analysis could be extended across all different community attributes to provide a more detailed comparison of DMI trends by performance type and identify corresponding implications for design. However, to generate meaningful results a much larger survey population would be required to provide a sufficient sample size for each group.

The survey has also exposed other topics of interest that will be beneficial to explore in more detail. For one, previous literature has shown the important function of community and socialisation towards the success of a new instrument, and it has also been shown to be a factor for long-term engagement. However in the survey, little was mentioned about social aspects of performance despite most respondents reporting that they perform in groups at least some of the time.

6.2.2. Application in design

The survey analysis and results presented here are largely performer-focused, and have intentionally eschewed discussion of specific instruments or instrumental features except at an abstract level. However, it is important to direct our findings back into tangible instrument design and evaluation. In a parallel project, we have run design studies leading to the development of novel new instruments (Sullivan et al., 2020). We can envision new prototypes or even entirely new instruments that attempt to directly incorporate some of the suggestions we have proposed, and the resulting designs tested with musicians in actual musical settings to gauge the usefulness of the various considerations.

7. Conclusion

This article has reported on an investigation to understand how musicians across different communities use DMIs in their performance practice. We began by conceding that many DMIs see limited use in performance for a variety of reasons. We then reviewed previous work that has examined DMI performance, which have frequently risen from, and been oriented towards, more academic- and research-minded communities like NIME. As such, these investigations have served to highlight the dynamic interdisciplinarity of such communities, in particular the trait of individuals who operate across and between traditionally defined roles of designer, composer and performer. Previous survey-based studies have shown that, while common among NIME-style performance communities, this blending of design and performance may be predicated on additional non-musical proficiencies like computer programming or electronics design, that performers from other communities may be less likely to possess.

Thus we were motivated to examine how DMIs, and more generally what we have termed *electronic musical instruments* (EMIs), are used across more diverse and widespread performance practices, and especially those that are not closely involved with instrument design as well. To investigate this, we carried out the Electronic Musical Instrument Survey, an online survey on musicians who use digital and electronic instruments in live performance. We conducted a thematic analysis of the responses that yielded several of high-level insights about important qualities for DMIs to taken up into use.

We hope that our findings can be helpful for designers and researchers at multiple levels. At a theoretical level, we identified several factors that contribute to performers' initial and lasting engagement with DMIs, and related them to existing models of user engagement found in previous HCI research. At a methodological level, we have presented a structured approach to the analysis of qualitative survey data that uses both bottom-up and top-down methods of thematic analysis, as well as crosstabulation to observe variations between different types of respondents in our survey. This methodology could be suitable for other analyses where both inductive and deductive approaches are called for. Finally, at a practical level, we provide a summary of considerations for the design of new DMIs based on the direct input of performing musicians, which may be helpful for designers whose instruments are intended for real-world musical use. It is our belief that thoughtful consideration of the factors that we have identified here can improve the overall quality of designs and viability of new instruments for use in real-world, professional performance practices.

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