Encumbered Interaction: A Study of Musicians Preparing to Perform

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ABSTRACT

Guitars are physical tools (for making music) that require skillful two-handed use. Their use is also supported by diverse digital and physical resources, such as videos and chord charts. To understand the challenges of interacting with supporting resources at the same time as playing we conducted an ethnographic study of the preparation activities of working musicians. We observe successive stages of individual and collaborative preparation, in which working musicians engage with a diverse range of digital and physical resources to support their preparation. Interaction with this complex ecology of digital and physical resources is finely interwoven into their embodied musical practices, which are usually encumbered by having their instrument in hand, and often by playing. We identify challenges for augmenting working tools like this by supporting interaction that is encumbered, contextual and connected, and suggest a range of possible responses.

Author Keywords

Working Musicians, Design Ethnography, Artifact Ecology, Encumbered Interaction, Embodied Interaction, Augmented Instruments

CCS Concepts

• Human-centered computing→Ethnographic studies
• Applied computing→Sound and music computing

INTRODUCTION

There have been many calls to augment everyday objects with digital capabilities as seen in research on the Internet of Things (IoT) [23] and smart objects [2]. IoT projects have explored a range of potential uses such as industrial automation [11], social communication between collections of objects [2] and following the data footprints of war-gaming miniatures [10]. We are interested in how physical tools can be connected to the diverse resources that people require, assemble and prepare in order to use them – in the moment of use.

We turn to the guitar as a good example of such an object. Using a guitar to a high level of proficiency, as is the case with many other tools, requires skill, dedication, and physical dexterity. Guitars are often used together with other devices, and there is a broad and enthusiastic community of users who share knowledge and resources related to their use [43]. Unlike other research to augment guitars, our interest is not in augmenting their sound [27] or extended playing techniques [35]. We are interested in the use of guitars as working tools and how future augmentation might support their mundane and everyday use. We therefore conducted an ethnographic study with a group of working musicians actively engaged in public performance, to better understand their working practices, how their guitars are used and especially how they relate to various digital and physical resources that they encounter.

We observed these musicians progress through a sequence of individual and collaborative preparatory work, which included the sourcing and creation of digital and physical resources, to support the preparation of performance material. These working practices are typically encumbered, in that the instrument is almost always 'at hand' and often being played. In response to these emerging themes we outline the implications and opportunities to augment the guitar – or other physical tools – in ways that can support their working practices.

RELATED WORK

Activities of Working Musicians

The activities of working musicians have been previously examined by [14], who provide an observational and participatory account of how proficient musicians skilled in a variety music styles perform at various kinds of social events (e.g., parties, weddings, dance clubs, bars, etc.). Likewise, [17] assessed the series of *informal music practices* generally associated with playing popular music. They noted a reliance on music notation resources (often referred to as 'charts'), as well as a widespread tendency to learn songs by listening and copying from recordings or by observing other musicians, as is also the case in other music communities such as traditional Irish music [5,42]. An ethnographic study of 'Irish sessions' by [5] addressed the spontaneity with which Irish musicians assembled to play traditional 'tunes' on the spot, in addition to the use of supporting 'props', such as notebooks. Multiple authors [1,5,14,17,26] detail a common tendency amongst working musicians to dedicate extensive amounts of time towards building and maintaining an evolving collection of performance material. Possessing an individual repertoire

also functions as an entry point for future collaborative activities [14]. In this sense, [5,14,17] have reported how musicians may learn from each other, either explicitly or implicitly as they play music together. We also focus on active musicians playing popular music styles who are proficient and perform publicly, and consequently are required to learn and prepare new musical material regularly.

Digital Tools to Support Musical Practice

Besides using chord charts and audio recordings to learn new material, musicians also make frequent use of online materials from websites like YouTube and Ultimate Guitar (UG) [43], as well as more specialized content, such as video lessons, backing tracks and multimedia interactive notation, among others (see [8] for a review). Furthermore, in [5], Irish musicians reported using specialized online communities and social networks to support their individual preparation process prior to performance. In a related study [42] Irish music learners appeared to merge multiple online resources, such as YouTube videos and chord charts with other offline activities, such as playing along other musicians resulting in a unique learning experience tailored by each musician.

Other music performers such as disk jockeys (DJs) [1] and electronic Grime artists [26] have also been observed to heavily support their practice with the use of social networks and other websites to share materials and connect with their audiences. Incidentally, these online tools have also been reported to facilitate the self-promotion of working musicians as well as their collaboration with other artists [20]. However, it should be noted that our paper focuses on working musicians, specifically guitarists and bassists, who are proficient performers with musical instruments.

Augmented and Smart Instruments

The NIME community (New Instruments for Musical Expression) actively explore the creation of new instruments, or the augmentation of existing instruments. Examples of new instruments often concern 'instrumenting' digital technologies such as mobile devices [33,38]. Whereas examples of augmentation include interventions into an instrument's mechanism, for instance the magnetic resonator piano [27], or the integration of sensors into electric guitars to manipulate the performed sound [6,35]. The Sensus Guitar [44] integrates sensors and gesture tracking to control digital audio workstations (DAW). It is also IoT equipped, enabling the user to connect and share directly from the instrument or even control other performance media, such as stage projections or lighting. All of these examples focus on the performed sound of the instrument. A contrasting approach can be found in [3] where the decorative inlay on the body of a guitar is harnessed as scannable image recognition markers that link to an online record of the instruments history of engagement. Turchet et al. [40] highlights that the field of music has yet to witness the same degree of IoT investigation as other domains, proposing a future internet of musical things (IoMUT) [40]. We embrace this view and look towards a future of smart, interconnected augmented objects.

Embodied and Encumbered Interaction

Integrating a complex ecology of digital services and resources [20] into the use of physical tools, such as guitars, results in multitasking [34] and frequently encumbered interactions and usability issues [32]. Studies in *multi-object manual performance* [34] and encumbrance in one-handed interactions [32] have consistently shown that when users engage in secondary manual demands (e.g. operating a laptop), their performance with a particular artifact (e.g. a guitar) becomes less accurate.

This artifact ecology is further complicated when other related technologies and resources are brought into play, such as amplifiers, tuners, or sheet music. [25,28,40] consider in particular the common combination of guitar and digital signal processing (DSP) effects. For example, [25] considers the situation of DSP effects being controlled on a laptop whilst having a guitar at hand, and proposes augmenting the guitar by embedding electronics into the instrument in order to bring control of such effects within hand's reach. We are also interested in what it means to engage with a wide ecology of physical and digital resources while encumbered with the guitar (or other tools) in hand.

FIELD WORK

Approach and Methodology

We adopted an ethnomethodologically inspired approach to fieldwork, capturing observations and discussions of participants in their everyday environments [9]. This is a methodological approach employed in HCI and CSCW which involves working up thick descriptions [16] of 'taken for granted working practices' [36]. We engaged with our participants while they were actively preparing for a real-world public performance; observing their actions, rationales and tools used to get *"the job done"* at the various places they do their work [16]. To support our observations, we also conducted semi-structured interviews, both with the musicians we observed but also with a wider sample of active musicians. Interviews sought to promote discussion around the topics of instrument proficiency, experience, individual and collaborative practices, and the methods, tools and resources used throughout their preparation processes.

Participants

Overview and Recruitment

We chose to focus specifically on guitar and bass guitar players as we wanted to capture a corpus of rich observational and first-hand discussion data with a comparable group. Nonetheless, observing these participants in group rehearsals also permitted the observation of wider collaborative practice across a range of instrumentalists. We focused our engagement with working musicians [14]: those actively–and regularly–engaged in live performance. They may be professional musicians, semi-professional or proficient hobbyists. Participants were recruited through close acquaintances and via a call for participation in social networking websites. Initial participants were then used to 'snowball' further recruitment.

Summary of participants

22 participants were recruited to take part in interviews, 5 observations of individual practice and 9 bands observed in rehearsal. The ratio of female to male participants was 1 to 3, spanning an estimated age range of 19-64.

Data Capture

Observational sessions were conducted as our method describes. They took part in the individual's normal working environment (e.g. a room at home and/or the band's rehearsal studio). Audio and video of these sessions were captured and subsequently reviewed, where key interactions, emerging themes and accompanying vocalizations were subsequently notated. Semi-structured interviews took place at a number of locations, aligned with observational sessions, but sometimes as isolated activities. As with the observational sessions, audio and video of the interviews were captured and subsequently transcribed and emerging themes identified.

FINDINGS

Given the scope of this paper we present five exemplars drawn from our participant set which highlight the common practices observed. Pseudonyms have been created for each participant.

Paco

Description

Paco is a male guitar player who has played in bands in the past but currently performs solo. He frequently performs blues and rock songs at 'open mic nights' in pubs. He has been playing for 9 years, is self-taught, although he is currently taking online lessons to improve his instrumental technique. Paco was learning new songs for an upcoming performance.

Sourcing and Auditioning Resources

The session commenced with Paco sitting down at his laptop on his desk with his guitar held in traditional fashion (i.e., seated position, guitar against body and resting on legs). He began an online search for cover versions of a song he wanted to learn. In a browser window he navigated to YouTube (YT) and typed the title of the song into the search bar. Figure 1 [left] shows how Paco coordinated this process while holding his instrument: with both hands off the guitar, Paco is resting his right upper arm on the body of guitar to both stabilize and keep it in place, reaching over to the operate the laptop. Using the mouse he then navigated the search results and chose a full band cover version of the song, opened in a separate browser tab and started playback. After a short period of listening to the recording – during which he was also looking for lyrics and chord progression resources on the Ultimate Guitar (UG) site – Paco navigated back to the YT video and closed it, saying: *"This cover is good, but it sounds too 'full'. So, I would search something that resembles how I am going to be playing it".* He returned to his search results and selected an alternative version to assess (see Figure 1 [right]).
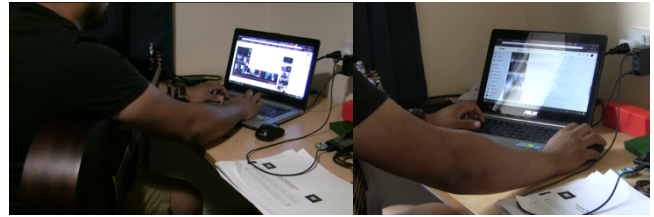

Figure 1: Paco at Work [left & right]

Throughout this observation, Paco continued to search for song videos on YT and lyrics and chord 'charts' on UG, sometimes playing along with them, moving backwards and forwards from engagement with his guitar and operating multiple resources on his laptop.

Focusing on his selection of resources in greater detail, Paco paid attention to those charts with higher ratings (as given by UG community members), opening and comparing versions, noting consistencies and inconsistencies. On one occasion he noticed that some of the chord symbols on the chart were not positioned correctly above the lyrics: *"something that happens a lot is that you see how chord changes are usually placed wrong".* Paco then compared how the music unfolded on the video in relation to the selected UG chart, identifying the points of error. Having listened to it, Paco then played the song on the guitar without the video recording, testing the adjustments he just gleaned from the YT video.

Mike

Description

Mike is a male self-taught bass guitar player who currently plays in 4 bands. He plays in a function band who regularly perform at social events; and also in a band performing original music, which has produced several albums. He has been playing electric bass for approximately 50 years and is proficient in a varied range of musical styles, including Rock, Jazz and Folk. We observed Mike on two occasions, i.e. practicing at home and during a band rehearsal.

Configuring the space

Mike undertakes his musical practice in a room in his home which is used as a general utility, study, and music room. As illustrated (see Figure 2), there is a desktop computer set on a small desk along with a printer, blank note paper, pencils and pens, and a desk chair on wheels (out of shot). To the left of the desk Mike has his bass guitar and a guitar stand which is positioned within easy reach of the desk area. The guitar is connected to a small practice amplifier, also within close reach of the desk area. The amplifier has been deliberately positioned – by leaning it back against a filing cabinet – so that the speaker and controls are in a direct line to Mike when he is sitting at the desk.

Figure 2: Mike's Home Set-up

Fine-grained preparation
At the moment of observation Mike was midway through learning a new song for an upcoming concert, of which he still needed to learn the bass solo. Similarly, to our observation of Paco, Mike works at his desk holding his bass guitar throughout and uses YT to source video resources. Mike highlights a challenge of working with the instrument in hand while operating a computer: *"The big problem with using a computer is having to manually rewind, fast forward, stop"*.

Playing along to a video of the song on his bass guitar, Mike initially recapped those sections previously learnt: *"So, I'm just making sure I've got the right chords, not the exact bass notes"*. After a few moments of playing he stopped plucking the strings with his right hand, reached out and grabbed the computer mouse to adjust computer's playback volume. Throughout this adjustment Mike continued to play the notes on his bass guitar just with his left hand, thus remaining in synchronization with the progression of the song (see **Error! Reference source not found.Error! Reference source not found.**). Once adjusted, he returned his hand to the instrument and resumed playing with both.

When the YT rendition of the song reached the bass solo section Mike wanted to learn, he stopped playing and appeared to concentrate more attentively to the video. He then transitioned into a process of breaking down the solo section into short fragments to learn in isolation. This involved a repetitive succession of quick shifting actions between computer and bass guitar: operating the transport on the YT video player with his right hand, Mike manually located the start point of the fragment he wanted to listen to and would then set it playing. After the phrase had sounded he would quickly stop the video and return his hand to the guitar and try and mimic what he had heard. This would be followed by a return to the computer where he would manually 'scrub' the play-head cursor back to the (approximate) start point of the fragment and the cycle would start once more: *"What would be really good would be some way for me just to take that little piece and just keep cycling it. And I'm sure I could probably do it on GarageBand or something like that but I've never really invested the time in*

trying to find out how to do that". After several repetitions of this cycle, Mike accidentally clicked the mouse on a link to a different video whilst trying to operate the playback controls. This meant Mike had to pause his process, reselect the correct YouTube video and find his way back to the right location within the song. After further cycles, Mike drew this process to a halt, stating that online instructional videos can be quite useful in these situations, upon which he turned to YT once more. His search resulted in sourcing and viewing a tutorial video that displayed a close up view of a bass player performing the song alongside a synchronized music notation visualization underneath: *"Here's a really good one which actually has the music [i.e. notation]. These are very helpful"*. Mike set about working along with this video. His gaze frequently swapped between the computer screen and his left hand, to monitor his hand placement on the guitar's fretboard.

Figure 3: Mike playing along while operating his computer

The matter of accuracy or authenticity of reproduction was discussed during this session. Mike stated that those parts of a song that had prominent musical material – such as this bass solo – an audience would expect to hear it played as the original, so ought to be reproduced with a finer degree of accuracy: *"Yeah, so, some parts of a song will be very broadly brushed. But there might be one little piece which is very well-known. So, it's worthwhile spending a little time to get that bit as people expect to hear it"*.

Collective decision making
Mike's band would plan their individual preparatory work within group rehearsals and would share related resources with one another in-between: *"When we rehearse as a band we may come up with some ideas: 'Oh shall we try this song'. Instead of doing it there and then we'll go home, maybe record those songs, send out an mp3 or a YouTube link for other people to listen to and feedback"*. Mike demonstrated how this worked in practice, navigating to his email inbox: *"So this is an MP3 that the guitarist sent me this morning with some ideas [for a new song]. So, I have heard this before, but I've never tried to play along to it"*. After downloading the attached audio file Mike set the file playing and attempted to play along: *"so I'll find the key first. I don't have the chords written out for this"*.

When the recording finished playing, he stated, *"so what I would do with this one now is I would take it back to the very start and try just to write the chords"*. Demonstrating this process, Mike, still holding his guitar, reached for a sheet of note paper and moved his computer keyboard and mouse aside to make space to set the paper down on the desk. What followed was a similar cyclic process witnessed in the previous example, i.e., playing short fragments of the recording, however on this occasion Mike used a slightly different technique. Specifically, he maintained his right hand on the media player transport controls (see Figure 4 [left]) while simultaneously playing his bass guitar one-handed by fretting the notes with his left hand. After a few repetitions, he exchanged the mouse for the pen and started writing down chord changes on the paper, while continuing to play his instrument with just his left hand (see Figure 4 [right]). Once the written chord sequence was complete, both hands returned to play the instrument and Mike continued to listen to the song and follow his notated chord chart. This process continued on, which also observed Mike testing the accuracy of his written notation against the recording, adjusting his chart accordingly: *"So, then the next thing with this will be to actually rehearse together and make sure whatever I've thought in my head works with what the songwriter was thinking"*.

Figure 4: [left] Scrubbing a video and playing one handed; [right] writing notation and playing one handed.

Archiving resources
Mike explained how this 'chart' would be used to scaffold his initial learning of a new song, but they would often be retained them after the learning process is complete: *"I have files of tons of stuff going back years. I've got chord charts, words, lyrics; all from different bands I've played with.* Mike only archives consolidated material, i.e. when all details are clarified a new version is created for archiving. The purpose of Mikes' archiving is two-fold: resources are used as a personal reference when the band convenes to work on the song collaboratively in rehearsal; and second, they are referred back to if returning to a song after an extended period of time.

Cindy

Description
Cindy has been playing the electric bass guitar for around 13 years and is self-taught. She currently plays in 5 bands, each different in style, which requires an extensive repertoire of songs. We interviewed Cindy on one occasion.

Creation and updating of resources
Cindy supports her learning process through a series of word-processed and printed 'charts', which contain differing degrees of information granularity. These sequences of charts speak to her changing needs as she learns new songs. When approaching a new song for the first time, Cindy typically creates a chart which details in-depth information to scaffold initial orientation and learning. First stage charts may contain sectional descriptions of the song's arrangement, the lyrics and chord progressions for each section, along with diagonal lines that represent how many times the note is played in each measure. A second stage chart is created as Cindy's familiarity with a song develops when she requires less supporting information. At this stage she may compile multiple songs onto one sheet of paper, detailing the song titles alongside the sectional arrangement and their corresponding repetitions (e.g. 'Verse Chorus x2'), but discarding details such as the lyrics and the chords. When Cindy has committed the songs to memory a final version of the chart is created displaying only the song titles.

Kit's Band

Description
Kit's band is a covers band that predominately play classic rock and punk music with occasional original songs, typically written by Kit. The band has 4 members, consisting of 2 guitarists (Marvin and Stuart), a drummer (John), and a bassist and singer (Kit). For the most part the band perform at festivals and charity gigs. The band were rehearsing a series of songs for an upcoming festival.

Pre-rehearsal preparation
Pre-rehearsal preparation is often undertaken via a designated Facebook group used by the band members to discuss the objectives of their upcoming rehearsals: *"We'll very often have an exchange with each other. We have our own Facebook group. We'll say stuff like: 'tonight we're gonna learn this song and we need to do this or let's look at this again'… there's a certain amount of objective setting"*.

Configuring the space for rehearsal
We join the band as they set up for rehearsal in hired rehearsal room which provides public-address (PA) system with a mixer, as well as microphones and stands for use. The band members bring their own instrumental equipment (i.e., drum kit, two electric guitars with effect pedal boards and amplifiers, a bass guitar and bass amplifier, and an electronic keyboard connected). They position themselves and their equipment in an (approximate) circle formation where they and their equipment face into the middle of the room, enabling for shared view of each other and a shared exposure to the audio from their instruments and amplifiers. Each band member took control of the set-up process for their own equipment, which took differing amounts of time to position, configure and power on. This meant that some of the band member started engaging in other pre-rehearsal activities. For instance, Marvin (guitarist) began tuning his guitar and testing out some of his effect pedals, whilst John was still assembling his drum kit, and Kit was 'sound checking' the PA system, adjusting the levels of the keyboard and vocal

microphone, there appeared to be an established routine and roles within their set-up.

Paper resources in use

Once the equipment was set, Kit produced a folder containing printed copies of the 'set-list' of songs which he had pre-prepared. He handed a copy of the set-list to Marvin first who had brought his own resources. Kit went on to distribute copies to the other band members, while Marvin was observed comparing his own set-list to the one supplied by Kit, which he subsequently discarded, placing it on the floor. Marvin then grabbed a small table, moved it over next to his guitar set-up, and proceeded to use it as a make-shift music stand, placing his paper resources along with a pen on it (see Figure 5 [left]). These word-processed sheets contained song lyrics and a bigger sheet listing the set-list with abbreviated chord changes next to the song titles (**Error! Reference source not found.**).

Figure 5: Marvin using a table as a music stand [left]; Stuart using his guitar pedal board as a music stand [right]

John also re-appropriated furniture–a stool–as a stand for his set-list. Other band members took different approaches to the management of supporting resources. Stuart, for example did not set out and organize his charts at the beginning of the rehearsal, as was the case with Marvin and John, rather he reached for a chart half-way through the rehearsal for one particular song; placing it on the floor directly below his microphone stand, partly covering his guitar effect pedals (see Figure 5 [right]).

Directing

The band began to rehearse songs, often stopping at various points within them when significant mistakes occurred. In these breaks they would then discuss what happened and seek to clarify errors and misunderstandings. For the most part Kit took the role of directing the band. As songs were being played he would signal upcoming sectional transitions by calling out instructions into the microphone (e.g. *"Just bass and drums"*) or he would direct activities during those breaks in-between to move the momentum of the rehearsal forward (e.g. *"let's go from the top"*) (see Figure 6 [left]). Kit would also impart musical detail regards the song's structure and harmonic content and even teaching the other band members how parts ought to be played. One example

of this latter point occurred as they rehearsed *Dear Prudence*, by the Beatles.

Figure 6: Kit directing proceedings in general [left]; giving verbal direction to Marvin [right]

It seemed that Marvin was playing the chord sequence incorrectly, which Kit noted. In reply, Kit moved closer to Marvin and vocalized the correct sequence of chords (Figure 6 [right]), which he followed up by demonstrating the chord progression on his bass guitar as Marvin played along. However, Marvin was still uncertain. Kit responded by asking Stuart (the second guitarist) if he could borrow his guitar to demonstrate. Kit then played the chord progression while simultaneously singing the vocal line to Marvin, who watched and listened. Following Kit's initial demonstration, Marvin then started playing along with Kit. The final stage in this sequence of interactions witnessed Marvin asking Kit to dictate the chord names to him so he could amend the mistakes in his chord chart (see hand written annotations in **Error! Reference source not found.**).
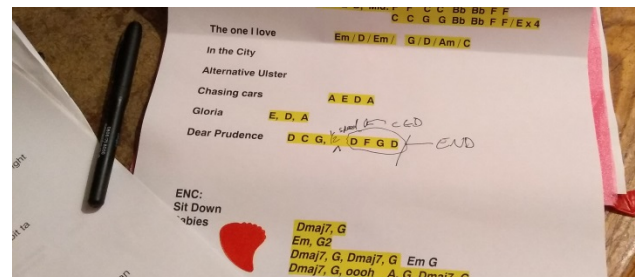

Figure 7: Marvin's annotated setlist

Digital resources in use

On several occasions there was a collective confusion regards the song's structure. In one instance the band were struggling to agree upon the structure of the introduction for a cover version they were working on. To clarify this uncertainty Marvin, with his guitar still in position, reached for his mobile phone from the table and searched online for the original song recording. Once the song was found and selected, he played the song on his mobile phone holding it up to his vocal microphone so the sound was amplified for the other band members through the PA system.

After a short break from working on and rehearsing specific songs, the band then played through a set of 20 songs in

succession. Although they occasionally took very brief breaks between songs, they did not stop within the songs themselves or discuss any 'fine-tuning' of songs, as was observed previously. Their process here seemed to be more about rehearsing the performance as a whole, as opposed to specific songs or specific facets within a song.

Janice's Band

Description
Janice plays in a David Bowie tribute band. The band has 5 members, consisting of 2 guitarists (Molly and Anthony), a drummer (Peter), a bass player (Arthur) and Janice, the singer. The band perform at various venues, including festivals and pubs.

Pre-rehearsal preparation
Janice described her band's use of Google Drive to share and discuss resources before rehearsals: *"We have a google drive, so we basically sometimes upload music to that. Occasionally is has been used in the past to drop chord sheets and they've been corrected because someone has said 'this isn't the right chord'"*. Moreover, she went on to detail the band's use of WhatsApp group chat to communicate: *"There's a chat that we talk about [things about rehearsals]; find videos of David Bowie doing it live on the web, and then say 'this is a good ending to the song' so everybody will go on and practice that particular ending. We use WhatsApp basically"*.

Digital resources in use
Janice's band employ digital resources within the rehearsal setting. For example, at one juncture Anthony asked, *"What's next then [i.e. song], what else are we doing?"* In response, Janice took to her mobile phone, which she used to call up a set-list she had previously prepared. No other band members had a copy of the set-list to hand, paper or digital. As she recalled the set list out loud looking at her mobile phone display while speaking into the microphone, they collectively discussed which songs they wanted to rehearse. Subsequently, when working on one of the chosen songs, Anthony turned to Arthur and asked if he had the chords for this song available on his tablet, which he had brought along and placed on a music stand. Up until this point Arthur had not used the tablet himself, but had it sat there as an available resource. Arthur had the 'Ultimate Guitar: Chords and Tabs' app [45] installed on his iPad which he then used to search for the song in question, which when sourced, he showed to Anthony. Anthony asked Arthur to lend him the tablet and the stand so he could use it while they rehearsed that particular song. Similarly, Janice employed her mobile phone during this song to read the lyrics as she sang along.

DISCUSSION

Understanding the Current State
Looking across our findings, what have we observed about playing and rehearsing with guitars that helps us to understand the challenges of interaction present in these situations that speak to the design possibilities for augmenting the guitar?

First, it is both fundamental and self-evident that the guitar is a **physical tool** whose primary purpose is to make music; at least that is the case for working musicians, although not, for example, for collectors. And unsurprisingly, making music is the primary goal of all of our participants. We see in all of the observations that the guitar is almost always not only present at hand but also ready to be played. When Paco or Mike transfer their focus to their computer, for example to find and play a video, their guitar remains in what is its usual playing position – in front of their body. Although this makes interacting with the keyboard or mouse/touchpad more awkward this allows them to start playing again much more quickly that if they had set the guitar aside. Similarly, in Kit's and Janice's bands it is rare for the guitar to be put down once the rehearsal has started, even when other resources or devices are brought into use.

Actually, playing the guitar is a **skillful physical activity** which normally occupies both hands to the exclusion of other activities. Mike was able to manage some one-handed interaction with his computer while tapping notes on the fretboard with the other hand, but this only allowed him to check principle notes and limited aspects of rhythm. More often, like Paco, periods of playing must be interleaved with periods of device interaction. Similarly, in the band rehearsals, introducing content from a phone or tablet fully occupied that person's hands for that period of time.

Second, a guitar is seldom used in isolation; rather it is used together with **diverse supporting resources**. Naturally these include other related pieces of musical equipment, such as amplifiers and effects pedals. But they also include a broad range of digital and paper-based (informational) resources, including video recordings of complete performances (Paco, Mike, Kit's band), descriptions of songs such as lyrics (Paco) and chord progressions (Paco, Mike, Cindy), audio recordings (Mike), demonstration videos (Mike), set lists (Cindy, Kit's and Janice's bands). Digital resources have diverse origins, including "official" or published versions (Paco), unofficial covers (Mike, Paco), community-contributed lyrics (Paco) and works in progress (Mike). As a result, nominally equivalent resources (e.g. versions of the "same" song) can vary in their accuracy or suitability. Paper-based resources also featured frequently, reflecting some of the well-rehearsed merits of paper-based records [7], including convenience (Mike), support for annotation (Mike, Kit's band), reliability and portability (Kit's band) and archiving (Mike). However, some of the musician's had made the transition to digital (e.g. in Janice's band for chords and lyrics).

Each of the practice sessions that we observed was part of a longer **process of preparation** to perform. Often the earlier stages of this process were individual (Paco, Mike) and the later stages were co-present (the band rehearsals). The emphasis of activities also shifts through the process, typically from initial familiarization with a song (Paco, Mike), through detailed learning of individual parts (Mike) to coordination of complete songs (Kit's band) and performances (Janice's band). Different resources were

typically implicated at different stages of the process, although "reference" versions of songs featured throughout. In some cases, resources were created, used and discarded within one particular phase of activity, for example Mike's notations of song chords and structures during his initial learning of a song. In other cases, resources were incrementally refined within the process of rehearsal, as in Cindy's annotated set-lists.

Finally, we note that practicing is a highly **social activity**. Most obviously, musicians performing in a band also spend key parts of their practice times rehearsing together in the same room with other members of the band. In a rehearsal everyone hears what everyone else plays, and this enforces a high level of coordination on who plays what, when (with marked frustration when this coordination breaks down or is not observed by individual musicians). In addition, before meeting face to face the members of the band coordinate via a range of social online tools, e.g. through email (Mike), Facebook (Kit's band), Google Drive and WhatsApp (Janice's band), in order to agree set lists, versions of songs to use, new songs to learn and so on. However, beyond the band members we see frequent use of material coming from other – often not personally known – musicians, e.g. via YouTube (Paco, Mike, Kit's band), or from community sites for sharing lyrics and chords (e.g. Ultimate Guitar).

Opportunities for Guitars and Other Tools
Considering all of these characteristics and observations, we believe that the most promising opportunities for technical intervention in terms of augmenting the guitar lie in improving the relationship between the musician with guitar in hand and the various resources that support them through the rehearsal process. Specifically, how can we enhance access to the use of supporting resources (from videos to 'charts') when musicians are playing and about to play; and how can we enhance the creation of these kinds of resources, again during the nitty-gritty of hands-on rehearsal.

But is this only relevant to guitars? As we have observed, they are physical tools, skillfully used, in concert with diverse supporting resources, many of them digital. And it is difficult to effectively engage with these resources while playing. Of course, the same could be said of almost any musical instrument. But consider other physical tools, for example a power tool such as a woodworking router being used in DIY project. It requires careful two-handed use, and there are a plethora of instructions, tutorials and other resources online that are directly relevant when in use, but hard to access and coordinate in the moment of use. The same holds for hand tools used in arts and crafts, electronics and making. So, in considering the specific case of augmenting the guitar, we can also shed light on challenges and strategies for augmenting many other physical tools employed in everyday situations.

Challenges and responses
Drawing on the findings and the literature we identify three specific challenges that have to be met to unlock these opportunities: [1] support for encumbered interaction, i.e., with the guitar in hand; [2] support for contextual interaction, i.e., which are sensitive to specific situation; and [3] support for connected interaction, i.e., that spans multiple devices and contexts. We consider each challenge in turn, together with potential responses to that challenge.

Challenge 1: Support encumbered interaction
The musician's focus is on making music, specifically playing the guitar; their interaction with digital technologies and other resources is secondary and supportive. Note that this is unlike most uses of augmented musical instruments, where the interaction is a new facet of music making or sound shaping [7]. We have seen that use of keyboard, mouse or touchscreen all seriously disrupt the ability to play, normally forcing the musician to shift physically between playing and interacting. Mike managed to adapt to use a one-handed technique in order to operate his computer with the other, but the result was awkward, error prone and only usable for some aspects of his practicing. So how can we respond to this challenge?

The first possible solution is to **reduce the overhead** of transitioning between playing and interaction. For example, the Sensus guitar [40,44] situates touch sensors around the body of the guitar. In general, some movement of the hands will still be required, but it can be much faster than reaching across to another device, sometimes as fast as a single note. But the speed of interaction also depends on the speed of the touch actions, which in general depends on how specific they are. For example, contrast pressing a "play" button with navigating a menu. So even a proximate touch interface will either need time to use or need to be carefully (re)configured for specific activities. And it will still inevitable disrupt playing which fully employs both hands.

The second possible solution is to use **another modality** to interact, leaving the hands free to play. For example, gesturing with the instrument [40], gesturing with the arms, head of body [24,31], or explicit direction of gaze [41]. Alternatively the musician could use their voice to interact, e.g. with spoken commands [19], or even harness the notes and phrases that they are playing [18]. However, we note that all of these forms of expression are already used at least some of the time in musical performance. Physical gestures help maintain tempo, coordinate with other musicians and convey emotion or effort, or form part of choreographic performance routines to an audience. The kinds of interactions needed for supporting material are also often quite discrete, e.g., switching or moving through material. In contrast many gestural controls are based on continuous variables (e.g. orientation), which can be effective, for example to control audio effects [25], but recognizable gestures take time and are perhaps more likely to disrupt normal playing (e.g. if they depend on hand or finger pose) [15]. Many musicians sing, and any other voice interaction will compete with the sound of the music. Playing specific notes implies either that the system is specifically primed to expect them, or that the musician will have to diverge from the current song for a bar or two to play some other key phrase (although at least they don't need to stop playing).

The third possible solution is to **make the system "smart"**, i.e., for the system to work out what the musician wants to do in terms of supporting resources and do it automatically for them. It might do this by learning, provided that there is sufficient consistency between sessions and activities, although we have seen that activities and resource can be quite different at different stages in the rehearsal process. For more specific activities (such as playing along with a recording) something comparable to a score-following system [21] could potentially keep the playback in sync with the musician, perhaps including repeating sections and so on. A third approach to "smartness" is to exploit information about the context in which the interaction is happening, and we deal with this next as a distinct challenge.

Challenge 2: support contextual interaction
The idea of context-aware computing [12] draws attention to the fact that the "environment" in which interaction takes place can also be directly relevant to and useful in responding to a user activity or request. In particular, [12] argues that the **people** and **things** around an interaction and the **place** where it occurs are particularly significant. In relation to our observations we can see particular instantiations of these categories in relation to music-making. Significant people include: the musician themselves; and the other members of the band (in group rehearsals). Significant (physical) things include: the specific guitar being played; the musician's other instruments that may be nearby; other musician's instruments; other musical equipment such as effects pedals and amplifiers; computing devices including phones, tablets and desktop computers; and various paper resources such as set lists. Significant places include: the musician's personal practice space; and the group rehearsal space. Other researchers have challenged the simplicity of this type of categorization [13], pointing out that "relevance" to an interaction is itself constituted within the situation under consideration, rather than being a universal absolute.

So, the first possible solution is to **associate particular resources with particular contexts**, so that they can be automatically, or at least more readily, recalled in similar contexts in the future. Even using a simple model of context, we can see potential utility. For example, in terms of place, a musician practicing in their home rehearsal spaces may well be continuing to rehearse the songs and sections that they were last time. And they are likely to use similar types of resources presented in similar ways. Whereas the resources they use and ways they use them may be quite different in the rehearsal room. In terms of people, if some or all of the members of Kit's band are together in one room then there is a good chance that they are going to rehearse the material from Kit's band, even if each individual musician also belongs to other bands. In terms of things, picking up the acoustic guitar makes it likely that a song using that kind of guitar is going to come next. And the proximity of other specific instruments (either in their own right, or as proxies for the musicians playing them) will suggest particular songs or repertoire.

A specific instance of this is to **associate resources with the guitar** itself. The instrument can be thought of as–or actually made into–a physical anchor for digital hyperlinks [3], and the presence of the instrument then facilitates their recall (and creation). Of course, some caution is needed, both in linking to particular instruments and in interpreting context more generally. While certain aspects of context may commonly be associated with particular resources or activities, "stuff happens" and people discard their plans to suit the current situation [37]. For example, the guitar that is "normally" used might have a broken string, or have been lent to someone else, or be too heavy to bring today, and therefore another guitar is used in its place. So it is important to provide other routes to resources or ways to "correct" the system's interpretation of context, e.g. the coded guitar picks that provided another route to some of the Carolan guitar's resources [3].

As well choosing the right resources, there may also be benefit in **adapting interaction to the context**, i.e., aspects of context may predict the best way to present or interact with resources. For example work on walking user interfaces has demonstrated significant benefits when a simplified interface is presented to a walking as opposed to a stationary user [22]. In our case, the kinds of interactions observed varied markedly between individual and group rehearsal settings, and also of course between setting up, being ready to play and actually playing. So, the most limiting contexts (such as actually playing while with others) may demand the simplest interfaces and interactions. But as soon as the musician stops playing they may be happy with significantly more options.

Challenge 3: Supporting connected interaction
Up to now we have focused on the guitar itself and considered the setting and things around it as "context". But of course, they can be more than that: they can also be part of the solution. Briefly, the perspectives of ubiquitous computing and the Internet of Things (IoT) invite us to consider how instruments, devices and other parts of the built environment can communicate and coordinate directly together, potentially with no human intervention. The idea of a specifically musical IoT has been proposed by [39].

So firstly, guitar(s) and other proximate equipment and devices may **share resources and context information**. Simply communicating the proximity of a particular instrument or piece of equipment may give useful context information as discussed above. But there also opportunities to share other resources, especially in the group rehearsal setting, such as set lists, reference versions of songs and descriptions of songs including structure, chord progressions, lyrics and performance directions, as seen in our observations.

Second, the guitar and proximate devices may **form an extended user interface**. In our observations, guitars and other music equipment were used alongside phones, tablets and desktop computers, but there was no link between them. But many current IoT products – including the Sensus guitar – are adopting a UI strategy of using a paired mobile phone to support user interaction with an otherwise 'interfaceless'

device. More generally, a long history of work in ubiquitous computing has demonstrated various technical and interactional strategies for distributing interfaces and interaction across networked devices that might also be applied here (e.g. [30]).

Finally, we need to support **connectivity beyond the room**: we saw that most of the digital resources used were obtained over the Internet, whether from the WWW, email or file sharing services. In many countries it is now tempting to take Internet access for granted. But we only need one situation in which it fails, for example a rehearsal in a basement, to remind us quite how critical reliable access to remote resources can be.

CONCLUSIONS

A guitar is a physical tool for making music. Like other tools, including drills, paint brushes and soldering irons, its use is a skillful physical activity that often fully occupies both hands. But its use – in our case, in the preparation for performance – is replete with supporting resources, from YouTube videos and online tutorials, to digital and paper-based instructions (e.g., lyrics and chord sheets) and working notes. At present, bringing these resources to bear while the tool is in use is problematic. But there are opportunities to augment the tool to facilitate this use (and generation) of supporting resources if we can successfully address the challenges of: supporting encumbered interaction; supporting contextual interaction; and supporting connected interaction. While we have set out a number of key strategies for addressing each of these challenges that have broader applicability, we also note that there is enormous tacit complexity in every practice. Therefore, careful research will be required to make these strategies fit in each unique situation.

ACKNOWLLDGEMENTS

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