Exploring the (un)ambiguous Guitar: A Qualitative Study on the use of Gesture Disambiguation in Augmented Instrument Design

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ABSTRACT

Some of the performer's gestures, despite corresponding to different physical interactions, might produce a similar sonic output. This is the case of upward and downward string bends on the guitar where stretching the string shifts the pitch upwards. Bending represents an expressive resource that extends across many different styles of guitar playing. In this study, we presented performers with an augmented electric guitar on which the gesture-to-sound relationship of downward bending gestures is changed depending on how the instrument is configured. Participants were asked to explore and perform a short improvisation under three different conditions, two augmentations that correspond to different auditory imagery and a constrained scenario. The different sessions of the experiment were recorded to conduct thematic analysis as an examination of how gestural disambiguation can be exploited in the design of augmentations that focus on reusing performer's expertise and how the gesture-to-sound entanglement of the different modalities supports or encumbers the performer's embodied relationship with the instrument.

Author Keywords

Augmented Instruments, disambiguation, auditory imagery, multimodal sensing, subtlety

CCS Concepts

•**Applied computing** → **Sound and music computing;** *Performing arts;* •**Information systems** → Music retrieval; •**Hardware** → **Sensor devices and platforms;**

1. INTRODUCTION

From its origin at the beginning of the 20th century the electric guitar has been embraced as a tool for musical experimentation by different musical traditions [3, 6, 14]. As a result, different idiomatic playing styles and expressive techniques have emerged contributing to the development of a series of gestures and interactions that convey both musical meaning and articulation and are able to produce a recognisable signature for genres and even particular personal styles and instruments [21].

Plucking, tapping, bending, fretting, sliding, etc are examples of combinations of *excitation* and *modification* gestures that performers use as expressive resources and that when honed over years of practice, contribute to the embodied relationship between musicians and their instruments. Experienced guitarists are not only able to use these gestural resources on demand to achieve a specific sonic effect but can rapidly adapt to unexpected reactions and unfamiliar sounds thanks to their ability to recreate and anticipate sounds in their minds, a phenomenon referred to as *auditory imagery* [12].

This acquired *imagery* often encompasses gestures that, despite being associated with different physical interactions might have similar, even identical, sonic results and therefore be virtually indistinguishable from this perspective, resulting in similar auditory feedback. This opens a possibility for designing augmentations based on the analysis of such actions so that their sonic effect is differentiated. We refer to this process as *disambiguation*.

Here we aim to explore how these augmentations might challenge the performer's *imagery* and whether this allows them to repurpose their existing skills by accessing their existing gestural vocabulary to control new interactions.

We presented nine experienced guitarists with an augmented guitar under different modalities of interaction designed around the disambiguation of bending gestures. Each modality alters the imagery of gesture differently, which might allow us to draw further insights into which augmentations are a better fit for this approach.

2. BACKGROUND

2.1 Disambiguation in augmented instruments

We define *ambiguous gestures* as those sound-generating gestures which produce a similar sound despite presenting different interactions to the performer.

The electric guitar is no stranger to ambiguity: for example, a *vibrato* effect can be produced by rocking the fingertip and stretching the string longitudinally (*axial vibrato*) or by bending and pulling it transversally (*radial vibrato*) and the direction in which the string is plucked does not have an immediate obvious on the sound of the instrument. Many of the existing techniques result in a sound that, although not

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always identical, can be hard to distinguish [25].

We propose that by focusing on disambiguating specific gestures from the guitarist's vocabulary we can help disentangle gesture-to-sound relationships and motivate augmentations that provide a great level of control intimacy while repurposing performer's expertise, allowing them to quickly adapt to these and engage in new forms of musical expression.

However, this is not a new paradigm within NIME. Several augmented DMIs have been designed over the years that reuse performers' skills for augmentation which have specific relationships with gestural ambiguity.

TouchKeys [17] allows performers to create new control mappings for the position on which the fingers are located on a key, creating the possibility of disambiguating key presses that occur in different locations for a single key. The Svampolin [19] detects stick and slip states of bowing gestures and bowing direction, using this data to create a simplified representation of bow-string interaction. Actions are then projected through a velocity model to obtain sound features related to gestures which are unambiguous from each other. Morreale et al. [18] present an augmented guitar pick that extracts signals related to the movement of the device relative to the magnetic pickups of the guitar. Although Magpick can capture plucking and strumming direction, the designers decided to not create disambiguated augmentations, but instead use the integrated signal in one-dimensional mappings that control effect parameters.

Our proposal differs from these approaches in that we conceptualise disambiguation as a design paradigm rather than an implicit result in the scope of interaction. We suggest that a *bottom-up* approach, where designers analyse specifically-ambiguous gestures and how they relate to performers' auditory imagery, and design interactions over their differentiating features could provide a rich experience while providing minimal disruption.

2.2 Motivation: a subtle sabotage

The following question remains unanswered: how do we design interactions that are minimally intrusive if these directly challenge the performer's auditory imagery?

Guidi and McPherson [11] present a study where expert guitar players were able to accurately control a sound effect with the use of Magpick [18] while at the same time subconsciously adapting their playing to compensate for behaviours that were designed to disrupt their interaction by changing the sensitivity of the augmented plectrum over time. This supports the idea that experimented performers might be able to repurpose sensorimotor skills when presented with augmented instruments that challenge their expected gesture-sound relationships.

Moreover, Guidi et. al [12] showcase how auditory imagery can support skill transfer in the adoption and embodiment of modified instruments by putting a violin with transposed notation in the hands of professional performers. The results suggest that when musicians struggle to identify a specific sound event as part of their auditory imagery, the motor program to control this is unavailable and the performance disrupted. However, musicians can still perform fluently when the auditory feedback is unfamiliar but they can access their auditory imagery and anticipate the related motor program.

2.3 Case study: electric guitar string bending

String bending is a *modification* gesture and a common idiomatic resource guitar players employ on demand to exert precise, continuous control over pitch. It can be used to create melodic ideas, accentuate specific notes and even access microtonality (as in the case of the *blue* notes).

The physics behind string stretching [10], makes bending ambiguous: the pitch of the played note will always be raised regardless of the bending direction. This offers an opportunity for designing augmentations where auditory feedback changes with respect to bend quantity and bend direction.

3. THE (UN)AMBIGUOUS GUITAR

An Augmented guitar for bending disambiguation.

We developed an augmented electric guitar - the *(Un)ambiguous guitar* - which allows us to extract information on string displacement for all six strings aligned to hexaphonic audio, and a *processing unit* that analyses both data streams simultaneously to infer gestural information and create mappings to process the hexaphonic output in real-time. The hardware and software components of the instrument are open-source and available on the supporting website [1]

3.1 Technical details

3.1.1 Guitar and sensors

The guitar was hand-built from individual parts to resemble a familiar Stratocaster but showcases a fixed bridge and lacks any controls on its surface (see Figure 1). Instead of the traditional electromagnetic pickups found in most electric guitars, the instrument is equipped with an active hexaphonic pickup[2] which can be connected through a Roland GK-compatible 13-pin DIN connector [1] and a multichannel bend-sensor adapted from the work presented in [?] to sense direction and quantity of bending. This version was developed as a drop-in replacement for humbucker pickups and breaks out six channels of horizontal string displacement data to another 13-pin DIN connector.

The apparatus presented in [?] senses variations in magnetic flux produced by the horizontal displacement of the string and was employed to showcase how such measurements can capture gestures associated with left- and right-hand techniques in real-time, and to characterise them in terms of pitch-contour to accurately estimate pitch-shifting produced by bending.

3.1.2 Processing unit

A *processing unit* was developed to take the signals from the hexaphonic pickup and the multichannel bend-sensor. Three Bela units [16] are employed to process these signals such that each receives two adjacent string outputs from the hexaphonic pickup and the corresponding analog signals from the bend-sensing apparatus synchronously. The line output of each unit is then summed with an analog mixer to present a single line output to the user.

A Pure Data patch was developed to exchange MIDI messages through USB with the unit in order to change the parameters of the algorithms running on it (see Figure 2).

[1]https://instrumentslab.org/research/exploring-the-unambiguous-guitar.html
[2]https://www.cycfi.com/product/nu-multi-6/

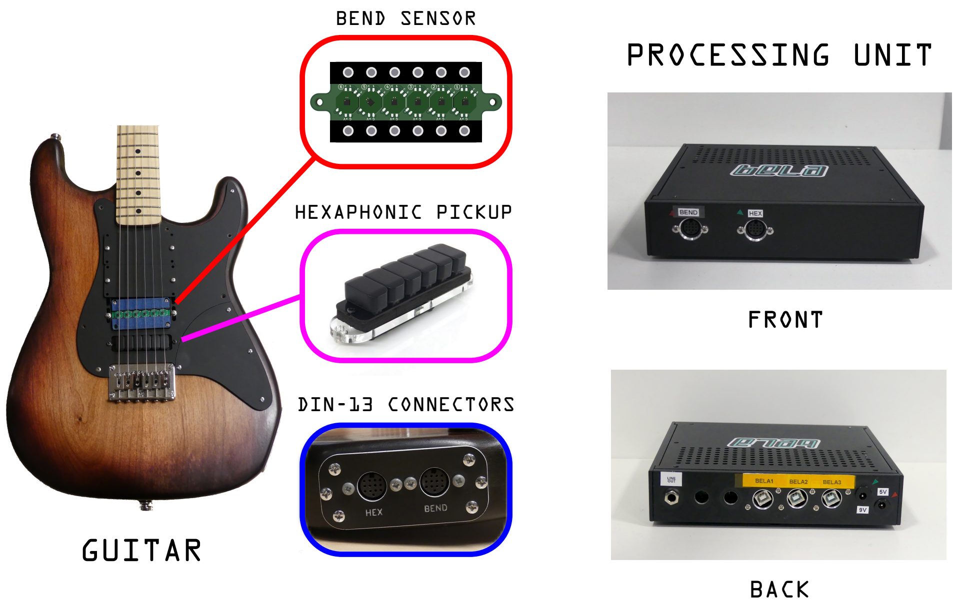

Figure 1: Picture of the augmented guitar used for the study (on the left) and the processing unit containing 3 Bela minis and analog conditioning circuitry (on the right).

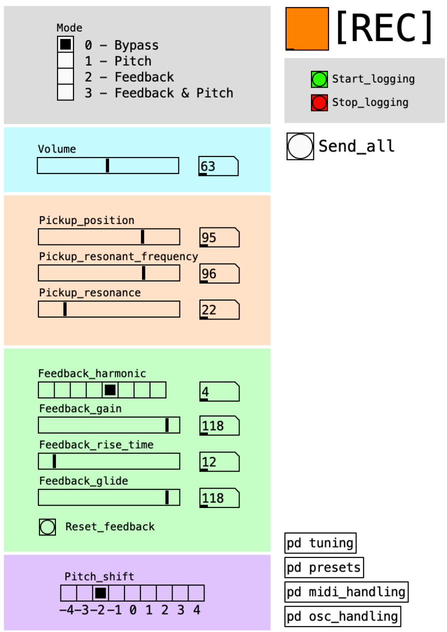

Figure 2: Capture of the Pure Data interface that controls the behaviour of the instrument

3.1.3 *The B- and G-bender parallelism*

The B and G strings are mostly associated with bending gestures during solo performance, but they also relate to a well-known mechanical augmentation designed to continuously manipulate the pitch of a string through external action: the Stringbender [20] (widely identified as G- and B-bender). Therefore, we only employ the bend-sensing setup corresponding to these strings to restrict the focus of the experiment while offering a familiar metaphor.

3.2 Isolating bending gestures

Since we want to focus on disambiguation bending gestures, it is important that these are isolated from other excitation and modification gestures.

The bending sensor employed for tracking the movement of the string (Section 3.1.1) does not provide a direct mechanism for separating plucking and bending gestures so a multimodal approach was followed for further disambiguation. Sensor data is employed together with a transient envelope and pitch estimates from a YIN detector [7] to extract different states of the bending gesture in real-time (see section 3.2.2).

3.2.1 *Calibration*

Since the mapping between displacement from the bend sensor and the pitch-shift produced by a bend gesture changes from fret to fret, we followed the procedure suggested in [2] for calibration. Several downward bends were captured for each fret and least-squares linear regression was used to obtain an approximate characterisation for latter mappings. Boundaries of the steady string for upward and downward bends were also captured for each fret. This neglects hysteresis in the sensing setup but provides a sufficient approximation for mapping as shown in [2].

3.2.2 Disentangling plucking and bending

To facilitate separation between plucking and bending gestures we conceptualised a simple model of the interaction of the string that divided a note into 5 different possible states: *note transient*, *note on*, *note off*, *bend on* and *bend off* which worked in parallel with an ASR (Attack Sustain Release) model for bending gestures. A transient envelope consisting of the difference between two envelope detectors with the same release time but different attack times was used to filter the transient produced from plucking the string. Three different thresholds were adjusted to determine the beginning of the transient, its end (and the start of the note) and the release of the note.

Bending direction (upwards or downwards) was inferred by thresholding a hysteresis model of displacement with respect to the values corresponding to the steady string (no bend). Attack and release states of the bending gestures were then extracted by measuring peaks and their direction over bend velocity which was computed via decimation and differentiation of the displacement variable.

3.2.3 Pitch correction and fret estimation

Since YIN and other pitch detectors are prone to errors [15], we leveraged our simple string state model and the data from bend calibration to regulate its predictions. Since we are only interested in estimating pitch during bend gestures, we accumulated predictions during the transient state of our model to obtain the best estimate candidates (based on YIN's confidence) during the initial attack of the note. Once a good estimate (or the end of the transient) was reached, we computed all the possible frets that could lead to each candidate (without bending and assuming a bend of up to 5 semitones) and, for each of these, obtained the estimated pitch corresponding to the string displacement following our calibration polynomials. The predicted frequency was matched against all fret candidates and estimated fret (and corresponding pitch estimate) was chosen by measuring the shortest distance between YIN's estimation and the prediction based on string displacement.

3.3 Modalities

Having developed a control mechanism to extract string-bend direction and quantity and the general mappings of pitch-bends across the fretboard, we designed two new mapping strategies for downward bends as a way to challenge the existing ambiguous sound-to-gesture relationship.

3.3.1 Disambiguated Pitch Control

In this scenario, the pitchbend quantity parameter is employed to control a realtime monophonic pitchshifter as proposed in [?], where a scalar sets the amount of pitch-shift produced by a downward bend. A scaling factor of $-1x$ compensates for the natural pitch shift, effectively cancelling the effect of the bend - configuration to which we refer as ***reduced (or constrained) bend control*** - whereas an augmented behaviour can be achieved by using a factor with an absolute value greater than 1. The ***augmented bend control*** modality uses a factor of $-2x$ on the downward bends to invert the pitch-shifting rule so that they produce a downward pitch shift of the same quantity as an upward pitch but in an opposite direction.

This modality is however still conceptually tied to the original gesture-to-sound relationship of bending as both manipulate the pitch of the instrument (effectively 're-tuning' the downward bending gesture to a different range) and therefore remains linked to the original imagery of the bending gesture.

3.3.2 Feedback Control

We introduce a new mapping modality where the interaction of bending is disentangled from the guitarist's imagery. Here the bending amount is mapped to an effect that, while still using pitch information, does not manipulate pitch directly but adds a new sonic interaction on top of the sound of the bent string.

We built this interaction on a real-time *virtual acoustic feedback (VAF)* generator adapted from [9] that simulates the idiosyncratic 'howling' sound produced when an electric guitar is close to the speaker through which the instrument is being amplified at high-gain settings. This sound, widely associated with the rock genre and derived playing styles, has been appropriated by players outside of this area [22], [8]. We employ the same frequency estimation as the previous modality to set the frequency of the nonlinear oscillator and create feedback that follows pitch changes. The pitch-bend quantity parameter related to downward string bends is re-mapped to a value in decibels to control the gain of the oscillator so that the amount of feedback raises with the amount of pitch-bending produced by a downward bend.

We expect that using the same features to create the mappings for both modalities will allow us to analyse the effects of sound manipulation and not the differences in mapping related to the analysis of bending

4. QUALITATIVE STUDY

4.1 Motivations

A qualitative study was designed around *the (un)ambiguous guitar* to analyse how guitarists react to the disambiguation of bending gestures and how different augmentations affect their performance.

We pose the following questions related to how the modalities affect the mental imagery of the performer:

- Is one augmented modality generally preferred to the other two? And if so, why? Are any of them easier to adapt to and incorporate into the performer's gestural repertoire?

- What do participants focus on when trying to perform on the augmented version of the instrument?

- Are guitar players able to anticipate the sonic results produced by the different modalities after having familiarised themselves with the instrument?

- Are there particular patterns of interaction that recur across different musicians for a certain modality, or across modalities?

We hypothesise that physically bending the string downward or upward are mostly equivalent in the performer's imagery, since they both raise the pitch of the string, and thus the choice of one gesture over the others is not linked to specific auditory feedback but to ergonomics. We also speculate that modalities not linked to the existing imagery of bending (i.e. *feedback control*) are easier to adopt by performers and that the *constrained* behaviour will be less preferred to the other two.

4.2 Methodology

We invited 9 experienced guitar players with different levels of expertise and backgrounds to explore the possibilities of the *(un)ambiguous guitar* through the execution of a series of exercises and improvisation.

4.2.1 Participants

All participants have more than 14 years of experience playing electric guitar and five of these consider themselves active performers. With the exception of P7, participants are affiliated with a research group in music and audio technology and four are NIME practitioners. As such, their expectations of music technology might be different from that of players with no contact with music technology research. Participants play in a wide range of styles ranging from experimental music to metal, progressive rock, funk, folk, blues, jazz, bossa-nova, synth-pop and post-punk.

4.2.2 Protocol

Participants were invited to take part in an experiment that spans two sessions of 30-60 minutes held in a controlled studio environment. Voice recordings were taken using a microphone for annotation and analysis, and the guitar's processing unit gathered synchronous data corresponding to the bend-sensor and the raw and processed recordings of the hexaphonic pickup.

During the sessions, a think-aloud [13] protocol was followed in which participants were asked to verbalise anything they found interesting, surprising or encumbering during their interaction with the instrument.

4.2.3 First session

In the first session, participants were presented with the *(un)ambiguous guitar* connected to an effect processor and amp-simulator unit which could be adjusted by the player to their liking. The guitar's processing unit acted as a black box that was configured by the researcher for the different augmented modalities.

The session started with the instrument configured on its *original behaviour* with no specific interaction programmed so that participants could familiarise themselves with the guitar itself.

Following this, the guitar was reconfigured by the researcher to the first augmented modality described in Section 3.3 (*augmented bend control (ABC)*) and, after a phase of free exploration, participants were asked to perform three exercises to further familiarise themselves with the new behaviour including upwards and downward bends across the fretboard, vibrato and pre-bends (where the string is bent before being excited). This procedure was then repeated for the second modality (*feedback control (FBC)*).

4.2.4 Second session

The second session puts modalities into the context of a simple improvisation over a minor blues backing track. A blues style was chosen due to the bending gesture being widely associate with it and because it tends to belong to the repertoire of many electric guitar players, regardless of their background.

The session began with a refamiliarisation with the instrument in the original modality followed by an improvisation over the backing track. Three more improvisations were recorded afterwards, two using the augmented behaviours and one with a modality which has not yet been introduced to the performer, the *constrained bend control (CBC)* where downward bends are effectively cancelled. This modality was added in order to analyse whether players were consciously disrupted by their use of downward bending or were able to ignore its effect.

4.2.5 Interview and MPX-Q questionnaire

At the end of the second session, participants were asked to complete a questionnaire (see Appendix A) reflecting on specific aspects of their experience with each modality, which served to structure a short interview lead by the researcher (guitar player and designer of the augmentation).

The questionnaire in Appendix A is a slightly more condensed version of the *Musician's Perception of the Experiential Quality of Musical Instruments Questionnaire* (MPX-Q) [24, 23] in which a bottom-up process was taken over the course of three iterative studies to generate a series of criteria for assessing the quality of musical instruments based on psychometric analysis. Our adaptation of MPX-Q reduces the number of items to 27, eliminating many associated with materiality, ergonomics, playing comfort and visual aesthetics, since these are shared across modalities.

Participants rated each of the 3 disambiguated modalities from 1 to 3 in ascending order depending on how well they perceived each of them to satisfy the items in the questionnaire (1 corresponding to the modality that better adjusts to a specific statement, and 3 to the one that fits it the least). Ratings were used to instigate a discussion on the inter-related aspects which might have influenced participants' experiences and preferences. The interview concluded with an open prompt for any further comments or suggestions regarding the instrument.

4.2.6 Analysis

We analysed the transcriptions of the recordings following a reflexive thematic analysis (TA) approach [4, 5]. The raw recordings were divided into excerpts of interests and a series of preliminary codes drawn from common threads and relationships on these. A second researcher was then invited to review and refine these codes over different rounds of TA and to help conceptualise the final theme structure that we believe describes the patterns of interaction with the instrument. We consider our approach deductive despite not using an initial codebook since part of the material from the interviews was framed by the reflection on the MPX-Q questionnaire.

5. FINDINGS

We identified a layered theme structure that shows different threads amongst participants. Themes are organised under *topics* that link them together. These relate to ideas around the following concepts:

- *Auditory Imagery* – how the augmentation changes the relationship between sound and sensorimotor programs[26].
- *Embodiment* – whether the augmentation elicits conscious patterns of interaction or disrupts existing patterns.
- *Engagement* – participant's willingness to explore the augmentation.
- *Appropriation* – performer's interest in developing a further relationship with the augmentation,

Moreover, we recognise three main themes and five further subthemes that complement them.

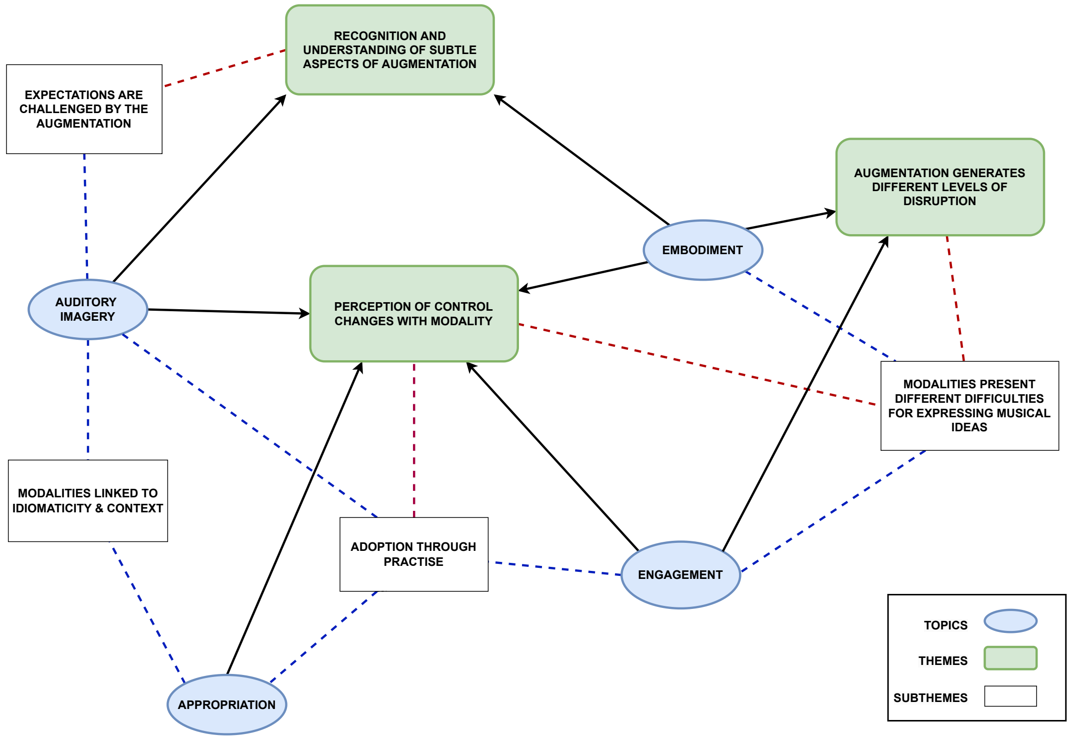

Figure 3: Theme map result of the Thematic Analysis described in section 4.2.6. Dotted lines represent connections between themes and subthemes (red) or topics and subthemes (blue).

5.1 Understanding subtlety of interaction

Being able to understand the mechanism of the augmentation and its subtleties and adapting to this is critical for the embodiment of the interaction [18].

During the first part of the study, participants were able to quickly recognise the sonic effect of the two augmented modalities and their possibilities. At least 7 participants (**P1-6**, **P8**) recognised the augmented disambiguation within the first 2 minutes of interaction, whereas for the constrained behaviour at least two participants (**P3**, **P6**) could still not figure out what the modification was after exploring and improvising, but felt that their performance was hindered by it.

Participants were able to identify many of the limitations of the bend-sensing mechanisms without these being disclosed to them and, in most cases, to quickly elaborate mechanisms to navigate them.

P1, **P3** and **P8** identified differences in pitch-shifing range for the first modality and found whereas **P2-4**, **P8** and **P9** noticed that changing the speed of the bend would affect the response of the augmentation, while another five (**P3-6**, **P8**) noticed that control was reduced for the lower frets and quickly moved to explore the response of the guitar on the higher frets. More interestingly, 8 out of 9 participants highlighted a discontinuity in the interaction with the downward bend before the effect of any of the augmented modalities was noticeable.

This lack of continuity was signalled as one of the primary sources of disruption, even when compared to range inconsistency or the inversion of pitch direction. **P9** mentions the following for the ***ABC*** modality *"Okay, so I need to stop doing vibrato, where I would normally do it, because... Yeah, it's not predictable, because sometimes it feels like there's a step."* whereas **P7** said (regarding the ***FBC*** modality): *"I feel like you're bending up into this high note and then just transforms it. It's almost like a wah, it's like we need to cross the threshold"*. This suggests that participants are able to draw quick expectations of the sonic results of the augmentation and react to this, which links to topics of embodiment and auditory imagery. However several participants (**P2**, **P4-6**, **P8**) suggested that their expectations would need to be re-evaluated in order to embody this new interaction. **P6** mentions (regarding the ***ABC*** modality): *"So, instantly, I've worked out what's going on (...) There's like a new technique to practice, I'm trying to sort of construct something that I can hear in advance in my head, and what I think it's gonna sound like (...) I was trying to adjust my playing in order to incorporate this way of doing something"*.

5.2 Different participants, different modalities, different levels of disruption

We identified that the levels of disruption would change across participants and modalities which would suggest different kinds of engagement with the augmentations. We identified four levels of disruption from this perspective:

1. ***Unable to play (highest disruption)***

   P6 mentions regarding ***FBC*** modality: *"(...) I'm sort of missing the boat each time (...) I'm struck, yeah, (...) I'm feeling like I can't really play the song now"*. Similarly, for the ***ABC*** modality, **P1** says *"I can't really do much with this apart from doing some unrequested sitari-thing. I can't really use it much on the first two strings."*

2. ***Turn off on demand (medium-high disruption)***

   Talking about the ***FBC*** modality, **P4** mentions *"(...) although it's very interesting, and I feel it's fun to play, I wouldn't have it on all the time"*. Which might suggest a certain level of engagement but a desire to be able to recall the interaction on demand.

3. ***Downward bends can be avoided (medium-low disruption)***

   Four participants (**P1-3**, **P5**) mention that they could easily avoid undesired effects by playing the guitar without bending downwards unless they want to recall the specific interaction. **P1**: *"I think as long as you avoid the downward stuff, it seems to behave okay"*.

   P6 suggests something similar for the ***ABC*** modality where the participant mentioned that when playing jazz, they can just avoid bending down to have control over which notes are hit (and then proceed to demonstrate): *"(...) if we were doing a jazz standard or something, I could probably just play, and it wouldn't have got in the way (...)."*.

4. ***I can play as I normally do (low disruption)***

   Participant **P7**, on the other hand, when talking about the ***FBC*** modality mentions: *"I'm exploring my element, I could just play the guitar without getting that effect until I want to do it. (...) I don't really mind having to just pull it all the way down."* which suggests low disruption and level of engagement and embodiment of the augmentation on that modality higher than other peers. On the other hand, **P7** comes from a more experimental background where the sonic effects might be more relevant than a specific control of pitch, in contraposition with the expectations of **P6**, rooted in jazz, where phrasing and melody are of most importance. This relationship, among others, might support the idea that context and idiomaticity play an important role in the auditory imagery of different performers and therefore in their embodiment of specific interactions.

5.3 Modalities and control

One recurrent theme across participants relates to their ability to control the effect of the different modalities and the different mechanisms that emerge from this interaction.

At least five participants (**P1-P4**, **P8**) agreed that modality ***CBC*** offered the least options for enacting any kind of meaningful musical action. However, there was no obvious division between the controllability offered by the two augmented modalities. Performers **P1**, **P3** and **P5** seemed to indicate that they preferred the mapping of the ***FBC*** and that it was easier to express musical ideas with it, however, participants **P4**, **P6** and **P7** saw in the augmented bend modality an opportunity to explore melodic ideas. It was generally agreed however that the feedback modality, despite being easier to control, had fewer options. **P5** for example mentions *"I think because of the qualities of feedback like you can do feedback in different places, but it's always going to sound kind of similar"* whereas **P3** said: *"(...) the pitch one has more options that I can use rather than the feedback one that one is kind of just, like, a sound (...) whereas, the pitch one, I feel like it kind of made me think about new licks, and new melodic ideas."*.

Another appreciation with respect to the control offered by modalities was that, during the exercises, at least 3 participants (**P3**, **P6** and **P8**) commented that the augmented behaviours were forcing them to put more sensitivity on the bending gesture and to try to control it more precisely, especially with the ***ABC*** modality. **P7** on the other hand, embraced the "glitches" caused by the limitations of the heuristic mapping process for the ***ABC*** modality and preferred that as a nuanced expressive resource to the idea of control and precision in the execution of bends.

Moreover, participants **P2-6** and **P8** mentioned that they would like to spend more time with the ***ABC*** modality to be able to learn how to control it to develop new ideas. **P6** mentions *"I can see myself you know, in the fullness of time, spending more time playing like this"*, and **P3** said *"I feel like maybe if I practised a bit more with the first and second one I could start to really more precisely control the actual notes. They would get a lot easier to express, like, express, like, music using that"*.

Yet another aspect related to control was the desire that several participants (**P3**, **P5** and **P8**) showed for being able to adjust the mapping of the disambiguation to control different effects and parameters to the ones presented in the study or to be able to adjust aspects of the augmentation. In particular **P3** said *" I can imagine using that to control all kinds of stuff to be really cool (...). It's a new dimension of control over the guitar, so you could in theory, I guess, use that to control anything, not just like guitar-specific stuff, but even stuff outside of that"*. These appreciations align with the idea of appropriation of the disambiguated gesture and how performers embrace this new mode of interaction.

6. CONCLUSIONS

In this paper, we propose using a disambiguation paradigm as a technique to frame new augmentations in terms of performers' auditory imagery for repurposing expertise and creating rich interactions.

To test this hypothesis, we designed an augmented guitar on which we created different mappings tied and disentangled from performers' original imagery of bending gestures and analysed participants' reactions to these during a study of recognition and improvisation.

Among the themes that were conceptualised during our analysis, we see some salient ideas. Firstly, it was confirmed how expert players can easily adapt to disruptions created by disambiguation and that this can help raise awareness of the subtleties of interaction, especially when the existing imagery is challenged, but that special attention should be put to continuity of gesture-to-sound mappings.

We observed how augmentations that do not disrupt the existing imagery might be quicker to adapt to and, in general, easier to control, but that they offer limited interaction when compared to those that do provoke it. Moreover, attention was drawn to how different participants might engage with modalities that contradict their auditory imagery and to how disruption varies across both modalities and participants and is linked to idiomaticity.

Lastly, we saw how several participants engaged with the concept of gestural disambiguation and started appropriating the augmentation during the session.

We acknowledge the limitations of the study regarding the number of participants, duration and the qualitative aspects of our analysis and suggest further investigation through a longitudinal exploration and the development of continuous mappings that do not bound gesture to discrete events.

7. ACKNOWLEDGEMENTS

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8. ETHICAL STANDARDS

Participants were given an information sheet explaining the nature and demands of the research and signed a consent form to take part in the study so that data from their performances could be collected and used for research purposes. The study presented in this publication has been reviewed and approved by the first author's university's ethics board. We observe no potential conflicts of interest.

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APPENDIX

A. MODIFIED MPX-Q QUESTIONNAIRE

Our adaptation of the MPX-Q Questionnaire as it was handed to the participants before the interview.

Participant: ____________

Modality A	**Pitch bend control**
Modality B	**Feedback control**
Modality C	**Reduced bend control**

	A	**B**	**C**
[*Sample answer*]	2	1	3
The instrument allows me to learn new things.			
The instrument offers me new possibilities of things to do			
The instruments expands my experience of musical interaction			
The instrument offers me new facets of playing			
I perceive the instrument as offering a lot of variety			
The instrument feels like I can go beyond myself			
The instrument offers me interesting possibilities to manipulate sound			
The instrument offers me a good variety of sounds to evoke			
I can continually discover new things by using the instrument			
The instrument fosters my creativity			
The instruments supports me in creating new music in any style			
The instrument offers new possibilities to express myself musically			
I perceive the instrument as challenging in a positive way			
Playing the instrument allows me to further develop my musical skills			
The instrument keeps me interested			
The instrument allows me to be engaged when I am playing it			
The instrument allows me to focus on sound generation			
It is easy for me to get into a flow of playing with the instrument			

Participant: ____________

Modality A	**Pitch bend control**
Modality B	**Feedback control**
Modality C	**Reduced bend control**

	Modality		
	A	**B**	**C**
[*Sample answer*]	2	1	3
I feel in control of the instrument			
I can play precisely on the instrument			
I can control the sound appropriately			
The instrument does what I want it to do			
I can use the instrument intuitively			
The instrument responds well to my actions			
I feel like I am initiating, executing and controlling the behaviour of the instrument			
The instrument works the way I expect it to			
I perceive the instrument as allowing small and efficient movements			
The instrument feels like an extension to my body			