Embodied Cognition in Performers of Large Acoustic Instruments as a Method of Designing New Large Digital Musical Instruments

Lia Mice and Andrew P. McPherson *

Centre for Digital Music, Queen Mary University of London,
Mile End Road, United Kingdom E1 4NS
l.mice@qmul.ac.uk, a.mcpherson@qmul.ac.uk

Abstract. We present The Large Instrument Performers Study, an interview-based exploration into how large scale acoustic instrument performers navigate the instrument's size-related aesthetic features during the performance. Through the conceptual frameworks of embodied music cognition and affordance theory, we discuss how the themes that emerged in the interview data reveal the ways size-related aesthetic features of large acoustic instruments influence the instrument performer's choices; how large scale acoustic instruments feature microscopic nuanced performance options; and how despite the preconception of large scale acoustic instruments being scaled up versions of the smaller instrument with the addition of a lower fundamental tone, the instruments offer different sonic and performative features to their smaller counterparts and require precise gestural control that is certainly not scaled up. This is followed by a discussion of how the study findings could influence design features in new large scale digital musical instruments to result in more nuanced control and timbrally rich instruments, and better understanding of how interfaces and instruments influence performers' choices and as a result music repertoire and performance.

Keywords: Embodied Cognition, Digital Musical Instruments.

1 Introduction and Background

When interacting with an interface not only does the performer move their body to control the interface, the interface design and affordances control the way the performer moves their body. This paper introduces The Large Instrument Performers Study, an interview-based study with performers of various large acoustic instruments, and discusses the results, analysed through the thematic analysis methodology. The study findings are analysed in terms of embodied music cognition, affordances and idiomatic writing to show ways that size-related aesthetic features of large acoustic instruments shape the performer's choices while improvising, composing and performing repertoire.

* Research supported by EPSRC under grants EP/L01632X/1 (Centre for Doctoral Training in Media and Arts Technology) and EP/N005112/1 (Design for Virtuosity).

Through elucidating the ways in which the size of large instruments influence performance, instrument designers can learn about the ways large instruments are more than small instruments scaled up, and consider the impact of size-related affordances when designing new instruments. Now that DMIs can be any shape and dimension, and performed with virtually any gesture, exploring the impact of instrument scale on performers choices is useful for Digital Musical Instrument (DMI) designers when deciding what size to create instruments. As music production increasingly takes place in the home (due to faster consumer computers capable of running professional grade digital audio workstations), there is a trend in commercial DMI design of scaling down instruments and interface dimensions, resulting in smaller and smaller 'desktop' instruments such as the Korg Volca series of miniature synthesizers. But what is lost when an instrument is scaled down? More research is needed to understand the true impact of an instrument's scale and dimensions on music creation and performance.

Leman's embodied music cognition theory provides an interesting framework for exploring the impact of an instrument's scale and dimensions on music creation and performance, arguing that our bodily interactions shape our perception of music [1]. In the context of musical instrument performance, the body's 'vehicle' for mediation is musical gestures, which *"have an important experiential component that is related to intentions, goals, and expression."*[2] Not only are musical gestures linked to musical intentions, they are also linked to cognitive processing of the sounds they create, and in this way physical interaction with instruments involving gesture/action consequences changes our performance gestures and choices, and therefore our thinking.

Expanding or contracting the physical dimensions of an instrument results in changes to the musical gestures. In the taxonomy of affordance theory [3] [4] [6], it could be said that the size of an instrument influences its affordances, that is the possibilities, such as the gestural language for performance. Additionally, as De Souza argues, affordances offer the performer 'distributed cognition' in that an instrument may 'know' things for the performer [5]. In this way, the performer does not need to know every detail about the instrument to play it. As Magnusson [7] illustrates, the piano knows a pitch class represented by each of its keys. By only offering the tones created by pressing the piano keys, and not all the microtones in between, the embedded knowledge contained in a piano forms a 'script' that influences compositions created on the instrument. It follows that 'distributed cognition', or as Magnusson [8] calls it 'material epistemology', not only offers affordances but also constraints, and it is therefore through both that instruments elicit influence on performer's choices.

Tuuri et al. [9] argue that an interface enforces 'experiential control' on a user through 'push' effects (affordances that result in the user feeling the technology guides or constrains their embodied interaction) and 'pull' effects (affordances that result in the user feeling they are in control of the technology). Jack et al. [10] provide evidence of 'push' and 'pull' effects of a DMI's design on musical gestural interaction, showing that performers optimise their gestures to correspond with the sensing modalities of the instrument.

It can therefore be argued that the gestural language for performing an instrument is governed by the 'push' and 'pull' effects of the instrument's affordances and constraints. De Souza explores the link between affordances and distributed cognition, proposing 'idiomatic music' as those compositions which feature *"characteristic patterns that cannot be predicted by grammatical rules alone"*, arguing these characteristic patterns are the result of players interacting with the affordances of the instrument, composing not on a note-by-note basis but also through selection of 'ready-made sequences' on offer [5, page 77]. This music that is *"suited, adapted, and optimised for an instrument"* is what Tanaka [11] refers to as 'idiomatic writing', and is therefore the result of the physical affordances of the instrument. Huron and Berec [12] show idiomatic writing for an instrument can become less idiomatic if the circumstances change, observing that trumpet players find it more difficult to perform trumpet repertoire that is shifted in key or tempo so as to alter key fingerings and duration of breath.

The size of the instrument changes its relationship to the body and therefore its affordances, and in turn influences the idiomatic music of the instrument. However, more research is required to fully understand the extent of this influence as well as other factors that may be at play. In particular, the preceding reference raise the questions of what circumstances DMI designers can control and change, and the resulting impact on DMI repertoire and performance.

2 The Study

The Large Instrument Performers Study was designed to explore the possible impact musical instrument scale and dimensions may have on the performance of composed and improvised repertoire on the instrument by identifying affordances specific to large acoustic instruments, and how these affordances impact the performer's choices. The study consisted of one-on-one interviews with seven instrument performers who are trained on physically large instruments (see Figure 1). Some participants were trained on more than one instrument of an instrument family in which one instrument is larger than the other, for example baritone saxophone and tenor saxophone. The interviews lasted up to one hour. During the interviews, questions about performance technique and repertoire were asked and participants were encouraged to perform their instrument(s) as examples arose. The interviews were videoed and took place either in a professional music studio, on campus at Queen Mary University, or over Skype.

The participants were asked questions designed to reveal how the performers respond to effects introduced by the large scale of the instrument, such as physical navigation challenges, the additional physical effort required to perform larger instruments, and the relative changes in tone, timbre, volume and intensity encountered when performing repertoire on a large instrument versus a smaller similar instrument.

Specific questions asked included: Which techniques/patterns require you to move the most? Which techniques/patterns require you to move the least, or require microscopic precision? How long can you perform the instrument before

you are too tired to continue? What causes the fatigue? How do you think the instrument influences the music you make when improvising? Would you improvise in the same way on a different instrument? What is an example of well written music for your instrument? How would it change if you performed it an octave higher or on another instrument?

The performers were also shown repertoire composed for cello, "Cello Suite no. 1 in G Major" (all movements) by J. S. Bach, and asked what issues they would encounter if they attempted to perform it on their instrument. The videos were manually transcribed and the transcription data analyzed following a thematic analysis methodology [13]. Codes emerged through an iterative process that took a theory-driven approach [14], in that the raw interview data was examined for trends and correlations that relate to the theories of embodied music cognition, affordances and idiomatic writing. Four iterations of coding were performed resulting in a codebook that was updated and refined at each coding iteration.

3 Results

3.1 Thematic Analysis Codebook and Overarching Themes

The codes that emerged from the thematic analysis methodology were organised by the grouping of codes that shared a theme. Figure 2 presents an overview of the codebook structure and which participants commented on each code.

At a high level, we noticed a differentiation in the themes between those that describe instrument characteristics, and those that illustrate performer reactions to those characteristics.

In the context of how size-related affordances impact performer choices, the codes reveal both trends and individual insights that illustrate how large acoustic instruments impose fatigue issues on the performer influencing their decision of how long or whether to perform the instrument at all; how timbral variations across registers influence choices performers make when improvising on the in-

Participant Number	Primary Large Instrument Played	Other Instruments Played	Primary Style
P1	Contrabassoon	Bassoon, double bass, electronics	Contemporary, ambient
P2	Contrabass clarinet	Clarinets (soprano, bass, alto), flute, guitar, piano, saxophones (soprano, alto, tenor, baritone)	Contemporary classical, experimental
P3	Organ	Piano, soprano clarinet, voice	Classical, renaissance
P4	Contrabass flute	Flutes (bass, alto, concert, piccolo), recorder, piano	Contemporary
P5	Gyil	Percussion, drum kit, piano, guitar	World jazz
P6	Tuba	Guitar, gong, self-designed mechanical instruments	Metal
P7	Baritone saxophone	Saxophones (alto, tenor, soprano)	Jazz

Fig. 1. Study Participants

strument; how micro-level control and design of large instruments can result in substantial changes to the sound, influencing new performance techniques.

The interview content relating to techniques and repertoire performed on large instruments was categorised under three themes: idiomatic, easy and natural; unidiomatic, difficult and unnatural; and virtuosic or impressive composition. Comparing the insights that fell into one or more of these themes resulted in interesting insights into the differentiation between what is easy, natural, idiomatic and/or virtuosic in the context of idiomatic writing for large instruments.

3.2 Influence of Size and Weight on Performance Fatigue

Six out of the seven interviewees identified the cause of performance fatigue to be uniquely related to the instrument size. Causes included the instrument weight, the posture required to play the instrument due to its size, and extreme use of diaphragm/core muscles to support the air column and air pressure required to perform large scale woodwind instruments. As a result, five out of seven of the participants use a device or performance method designed to minimise performance fatigue caused by the instrument's weight.

In some cases the instrument's size and/or weight influences whether the performer chooses to perform the instrument at all. P4 commented she often opts not to perform with the contrabass flute at improvisational concerts because carrying the contrabass flute limits her ability to travel with more than one flute, whereas if she selects a smaller flute such as alto flute she has the option to also carry another flute such as concert flute or piccolo, offering her greater options at the concert. P6 said he seldom performs tuba in concert due to environmental concerns related to need to transport such a large instrument by car.

3.3 Timbral Variation Across Registers in Large Wind Instruments

Beyond identifying the aforementioned obvious size-related affordances of large instruments, the study identified a less obvious influence of the size of large wind instruments on composed and improvised repertoire. Large acoustic wind instruments are often designed to have a rich tone in the lower register. This feature is a result of the instrument having a very large pipe/sound chamber. Activating the entire chamber will result in the lowest, most resonant tone. Playing in higher registers uses smaller sections of the chamber, resulting in more airy, frail tones in the higher registers. These unusual upper tones are more difficult to perform in tune because more air pressure is required (due to the instrument's size). Maintaining a steady pressure at the intensity required is a difficult task for even the most advanced players.

Although a byproduct of the instrument's design, the unusual tones in the upper registers can become an interesting aesthetic resource to draw on when composing and improvising on the instrument. The study results indicate that the unique tones of both the upper and lower registers influences performer choices through embodied cognition and 'push' effects.

Code	Mentioned By Participants						
	P1	P2	P3	P4	P5	P6	P7
Impact of Size, Weight or Fatigue of Large Instruments on Performers							
Which technique/passage makes the performer move the most	x	x	x		x	x	x
Fatigue	x	x	x	x	x		x
Weight		x		x		x	x
Strength required to perform instrument	x	x	x		x	x	
Size		x					
Timbral Variation Across Registers In Large Instruments							
Choosing difficult techniques for sonic gratification	x						
Effects of variation across register on repertoire arrangements			x	x		x	x
Effect of playing in different registers on idiomaticity	x	x		x		x	
Influence of timbral variation on repertoire	x	x	x	x			x
Instrument is designed to have a strong bottom register	x		x	x			
Micro Scale Within Macro Scale of Large Instruments							
Microscopic design that has a large effect	x						
Microscopic gestures that have a large effect	x			x		x	
Improvising or Composing on Large Instruments							
The feel of the instrument changes how I improvise		x					
What performer doesn't play when improvising		x		x			
What performer plays when improvising		x		x			
Idiomatic, Easy or Natural to Perform on Large Instruments							
Idiomatic techniques		x	x	x			
Peformance of idiomatic music	x	x			x	x	x
Composition relating to idiomaticity	x	x	x	x	x	x	x
What is easy to play on the instrument	x	x		x	x		
What makes music idiomatic for this instrument	x			x		x	x
Unidiomatic, Difficult or Unnatural to Perform on Large Instruments							
What is difficult to play	x					x	
What makes a composition unidiomatic	x	x		x		x	x
Examples of unidiomatic compositions		x	x	x		x	x
Performances of unidiomatic compositions		x		x		x	x
What is more difficult to play than it seems		x		x			
Virtuosic or Impressive Composions for Large Instruments							
Video of virtuosic composition	x					x	
Exampes of virtuosic or impressive writing	x	x	x	x			
What makes a composition virtuosic for this large instrument		x	x	x			
Performing a Different Instrument's Repertoire on Large Instrument							
Performing repertoire intended for a different instrument is possible		x	x	x	x		
Performing repertoire intended for a different instrument is not possible	x	x	x	x	x	x	

Fig. 2. Thematic Analysis Codebook

All performers interviewed improvise on their instrument. When asked what they often play when improvising, four out of seven interviewees mentioned drawing inspiration from the timbral variation across registers. Composing and performing improvisations that are influenced by this aesthetic is an example of embodied cognition, as the performers are making specific choices based on the instrument's affordance of different tone colours at each register.

P1 described that when performing tones in higher registers of the contrabassoon *"the notes begin to get weaker"*, creating a unstable timbral quality that he makes use of when composing. *"In an orchestral setting, unless you want to specifically exploit this change in timbre in taking the instrument up an octave it might be better to write (the same part) for a bassoon instead... In my own music however I swap octaves a lot specifically to introduce this slightly more frail sound."* By extending his compositions into the higher register for the purpose of utilising this 'frail' tone (rather than other compositional choices such wanting an ascending melody), P1 is revealing the 'push' effects of the timbral aesthetic of the high register. This is an example of embodied cognition in that P1's compositional choices are changed by interacting with the instrument.

P2 is also drawn to the timbral variation across registers on the largest version of the instrument he performs. He mentioned that the E-flat clarinet is designed to have a uniform tone across all registers. By contrast the contrabass clarinet is not, hence it affords more tonal options to the performer. He said the contrabass clarinet *"has a lot richer sounds and things that I can really do with it, whereas the clarinet has more of a certain kind of sound and it doesn't have the same richness and variation."* When asked to name a composition that feels natural to play on the contrabass clarinet, P2 nominated 'Dark Light' by Thanos Chrysakis [15] because it *"highlights the capabilities of the instrument."* Composed for contrabass clarinet, 'Dark Light' features long tones in both the low and high registers. P2 later mentioned that performing contrabass clarinet in the higher registers is more difficult and less precise than performing in the lower registers. *"The higher you go the more notes I have on a single fingering... so I can't move between them as quickly as I have to do it with my mouth rather than with my fingers, so the precision isn't the same."* We find it interesting that even though performance of contrabass clarinet is more difficult for tones in the higher register, P2 indicated the most natural composition to perform on the instrument (in Tanaka's terminology, an example of 'idiomatic writing' for contrabass clarinet) features many complicated tones in the higher registers.

Similarly, P4 said that performing the same part in different registers on the contrabass flute *"would probably make it more difficult. If it was going higher it would make it harder to play in tune."* P4 said this difficulty in performing the higher register in tune is a byproduct of the contrabass flute design, which was designed to optimise the lower register tone at the expense of the higher register tone. *"The smaller (flutes) are deliberately made to make them as even as possible. Whereas the bigger ones are deliberately made not to do that. Because for example if you're playing a bass flute and you're playing in a flute choir, what you want is a really strong bottom octave... (On the contrabass flute) you*

get much better resonance in the low register, but it's possibly a bit weaker and a bit out of tune in the higher register where you're not going to use it very much."

Additionally, P4 indicated that performing the same passage in different registers of the contrabass flute would result in changing the character of the music. P4 said *"the character between the octaves changes quite dramatically. They each have a very different tone colour... I think if you put it in a different octave it would definitely change the character of the music."* When asked what types of sounds and passages she performs when improvising on contrabass flute, her responses included *"slow melodic material, possibly in the different octaves."*

Notably, it is not only the weaker, higher register that influences the performer's choice to perform a tone despite its difficulty. P1 said *"What I love on the instrument (contrabassoon) is holding the low notes for a long time. But that is very difficult."* He explained that unlike performing a long bass tone on another instrument such as the piano which would require the relatively easy gesture of pressing a key with one finger, performing a long bass tone on the contrabassoon requires precise core control. *"The lower you get, the more control you need over a consistent flow of air."* Despite the effort, what P1 enjoys performing the most on the instrument is long sustained bass tones. He regularly features them in compositions, commenting *"if you're using that with something on top that is such a brilliant foundation."* When asked why he prefers to use the contrabassoon rather than for example an electronic instrument for sustaining long bass tones, P1 said *"The performative and aesthetic element is important to me. I like using big effort instruments to make relatively reduced music. I have been using smaller instruments for ease of travel and using pitch shifting pedals to take them down an octave and although the end result is almost the same sonically as playing on a bigger instrument, it changes the essence of the music."* That P1 prefers to perform such a difficult technique on the contrabassoon instead of an easier technique on a different instrument is another example of embodied music cognition as he believes that creating the (almost) identical tone on a different instrument *"changes the essence of the music"*, implying that the instrument, not the tone, is changing his perception of the music.

3.4 Microscopic Performance Techniques on Large Instruments

Three out of five of the performers of large scale brass and woodwind instruments commented that microscopic changes in the embouchure and air pressure can result in huge changes in the sound and tone quality.

On the contrabass flute, a millimetre change in air angle can result in large changes and even the sound being lost altogether. P4 said *"because the instrument is so big, the air has to travel, so even something very simple like changing octaves needs very precise control of the air stream. And the distance between the octaves feels much bigger than it would do on a smaller instrument. So if you're playing a normal flute it takes a lot less air, and also the notes feel much closer together because the tube length is so much smaller. So because of that, all of those intervals, everything gets expanded. So I think from that point of view*

you're using a lot of precision of the airflow all of the time... Literally, if the air goes one millimetre in one way you'll lose the sound or change the sound."

Similarly, changes to the contrabassoon reed can cause a large changes to the instrument's tone. P1 said *"If we want a soft reed we can sandpaper that down for ten seconds, that's going to get the instrument to behave in a completely different way from not really very much of a change. So yes even though it's very big, some of the small changes can have a profound effect on the instrument."*

As a contrabassoon part maker, P1 has discovered ways certain microscopic design changes can influence the overall character of the instrument. When creating his own crooks (also known as bocals, the thin s-shaped tapered tube that the reed connects to), P1 discovered microscopic changes to the angle of the taper result in each crook having a unique sound. When comparing one self-designed crook to another, P1 said that in one *"the inside gets bigger quicker than the other one. So this has the capability to play higher notes more reliably."* While the other crook may be less reliable in the upper tones, P1 added its own characteristic that can be desirable for certain repertoire. *"The trade off is this one has more fundamental in the low notes."* By refining his crook-making process he can now design characteristics into the tone of the instrument. *"If I know I want a darker sound I know what to change to make that."*

P6 described a microscopic tuba technique he uses when playing in unison with others to create a beating sound. *"Other players will play a solid note and then I'll slightly bend the pitch of my note to create beats and that's done by a minor change in the lipping. It's really subtle. It's probably a bit to do with the air pressure as well but it's mostly a small deviation in the lip."* The result is a perceived effect of the tone rhythmically starting and stopping even though each performer is playing one long tone.

3.5 Influence of Difficulty and Virtuosity on Idiomatic Writing

Interview data relating to improvisation, repertoire, gestural performance techniques and performing repertoire intended for different instruments revealed interesting insights into what makes a technique, pattern or composition more or less difficult, idiomatic, virtuosic or impressive to perform on large instruments. In many cases the results offered insights that contradict common preconceptions of idiomatic writing, such as the assumptions that idiomaticity is synonymous with ease of performance, and virtuosity is synonymous with difficulty of performance. The compositions P2 and P5 regard as the most idiomatic and/or natural to perform on their instruments also contain performance techniques they consider the most difficult. P5 said the most idiomatic music for the Gyil is the polymetric Degaari traditional music, elaborating *"holding both metres and being able to play between them - that's hard for me and I don't think that's virtuosic... And if people thought that it was hard when they're listening to me then I'm not doing it right."* We find it interesting that the factors that impress audiences about this music, such as its speed and use of the full range of the instrument, are not what make it difficult to perform, and the mental challenge posed by the polymetric groove is not necessarily a factor that makes it virtuosic.

Study Results	DMI Design Choices Influenced by Study Results
Impact of Size, Weight or Fatigue on Performers	
Weight	Consider ways DMI design may decouple size from weight, such as light-weight materials, a design that packs down into travel cases
Strength required to perform instrument	Consider how a DMI that requires physical strength to perform influences the material epistemological scripts of the instrument, and what is idiomatic to perform on it, for example resulting in slower tempos, recurring clusters of tones located near one another
Size	Consider ways to avoid size-related constraints of large DMIs such as open spaces/layouts performer can see past, translucent materials
Timbral Variation Across Registers	
Choosing difficult techniques for sonic gratification	Consider designing in 'easter egg' tones accessible via most difficult to perform gestures at the very limit of what is performable.
Effects of variation across register on repertoire or arrangements	Consider assigning one register as the most resonant and weaker tones in other registers; Offer access to many registers at once via many tones or choice of a scale with fewer tones per octave
Effect of playing in different registers on idiomaticity	Consider the ways that implementing sound design that varies across results in creating scripts of idiomatic music for the instrument.
Instrument is designed with a strong bottom register	Consider whether the DMI is intended for performance as a solo instrument or in ensembles
Micro Scale Within Macro Scale	
Microscopic gestures that have a large effect	Consider DMI designs that allow for microscopic gestures to result in a large sonic effect on the overall tone/performance of the DMI.
Improvising/Composing on Large DMIs	
Feel of the DMI changes improvisations	Consider how the strength and effort required to perform the DMI may influence the performances/compositions created on the DMI.
What is Idiomatic, Easy or Natural to Perform on Large Instruments	
Idiomatic techniques	Consider the impact of the 'push' and 'pull' effects of what tones or passages are created by the easiest to perform techniques.

Fig. 3. Suggested Guidelines for Implementing Findings into DMI Design

4 Discussion

Current ongoing trends in DMI performance research include effortfulness [16], physicality and whether controllerism/laptop music engages audiences [17]. We argue that while large DMIs engage more with the body and are more physical and visible than their smaller counterparts, more research is required to fully understand ways in which their size influences DMI music and performance.

Keeping in mind Magnusson's [7] notion of 'scripts' and 'material epistemologies', the hidden knowledge embedded in instruments that shape idiomatic writing, DMI designers can draw inspiration from the detail and variation of sonic features of acoustic instruments when creating sound design that inspires virtuosic composition on DMIs. The interviews with contrabass flute and contrabass clarinet performers show that the varying timbral qualities afforded by large wind instruments influence performers' choices when improvising on the instrument, as well as their decision of whether to perform the instrument at all

(in place of performing the smaller version with a more uniform tone across all registers). This indicates that non-uniformity of tone across registers is a strong aesthetic resource for compositional inspiration. DMI designers could consider implementing this characteristic not only large DMIs but DMIs of all sizes.

The observations from the Large Instrument Performers Study show that the 'push' effects of timbrally varied tones across registers influenced performers to make use of multiple registers while improvising and composing. That the participants chose to perform within the more difficult registers, even at the risk of discomfort or error, shows the extent to which performers value these tones. We argue these findings should encourage designers of DMIs of all sizes to consider the value of offering simultaneous access to multiple registers and varied sound design across registers, as well as microscopically precise gestural controls - even those initially unnatural or difficult to perform.

In light of the study findings that reveal large wind instruments respond to microscopic changes in gestural control and micro-scale design details, we argue that to reach new frontiers of virtuosic digital instrument performance and repertoire, large DMI designers should take into account the microscale within the macroscale. Scaling up the DMI to be larger is only the first step. Until large scaled DMIs match or exceed the nuanced precision of large acoustic instruments, large DMIs we will not reach their musical and performative potential.

Exploring human interaction with an instrument too large and complex to master was an approach taken by the group Sensorband (Atau Tanaka, Zbigniew Karkowski and Edwin van der Heide) with their architectural scale instrument SoundNet [11]. In the context of researching embodied cognition and idiomaticity, we argue there is more to be discovered from musical interactions with instruments designed to overwhelm the performer with its physicality. One physically overwhelming instrument discussed in The Large Instrument Performers Study was the contrabass flute, which requires so much breath support the performer can become dizzy. P4's expert insight into performing such a physically overwhelming instrument illuminated our discussion by providing a perspective from the extreme end of acoustic instrument performance.

4.1 Guidelines for Implementing Findings into DMI Design

Drawing on the findings on the study, Figure 3 outlines a series of design features that DMI designers could consider.

5 Conclusion and Future Work

We presented a study to examine the affordances of large acoustic instruments and their effect on performers choices. This study has shown us that large scale instruments are more than just small instruments scaled up; rather they are highly detailed, precise instruments that in many cases offer different sonic affordances than their smaller counterpart of the same instrument family. The findings revealed a series of interesting aesthetic design features of large acoustic

instruments, such as the timbral variation across registers and the microscopic precision of control, that have a strong influence on performers choices through embodied music cognition and 'push' effects. More research is required to understand the full impact of instrument size and scale on musical performance and composition, however this research offers initial insights to consider when designing new DMIs of all sizes.

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