Sound -> Object -> Gesture: Physical Affordances of Virtual Materials

Jon Pigrem
j.m.pigrem@qmul.ac.uk
Queen Mary University of London
London, UK

Nick Bryan-Kinns
n.bryan-kinns@qmul.ac.uk
Queen Mary University of London
London, UK

Andrew P. McPherson
a.mcpherson@qmul.ac.uk
Queen Mary University of London
London, UK

Robert H. Jack
robert@bela.io
Bela
London, UK

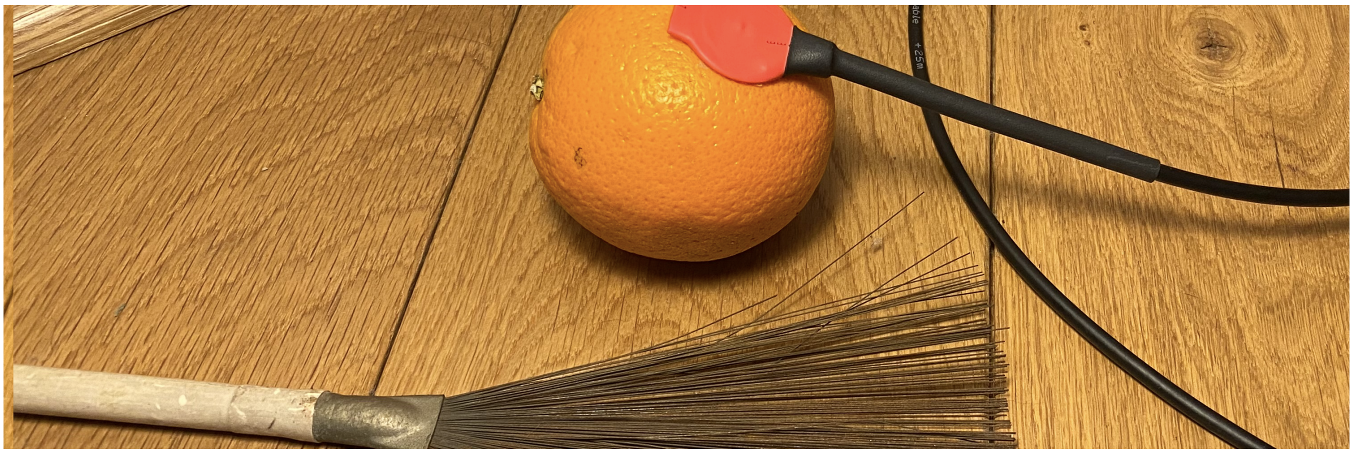

Figure 1: A Digital Musical Instrument as a Design Probe

ABSTRACT

This paper explores the influence of materials communicated through the sound of digital musical instruments. We are particularly interested in how musicians approach the design of new instruments when the sounds they make are constrained to recognisable material timbres and behaviours. We present a digital musical instrument (DMI) design study in which 20 participants design 80 new DMIs using an instrument kit. We use enactive approaches to design to enable the participants to borrow from everyday understandings of interaction in the real world, revealing aspects of their environment mediated purely through sound during the study tasks. We demonstrate that the influence of virtual material is strong, with participants not only taking material cues from the sound, but in places interaction strategies and performance approaches. We suggest that in addition to commonly referenced modalities of sight and touch, sound can be both precursor and mediator to our selection of, and gestural interaction with, materials at the design stage. We present two specific approaches to instrument design (Sound, Object Gesture – SOG, and Sound Gesture Object - SGO) which we found to underpin participant's approaches to the design task and have wider effects on the instruments they designed, and the model of creativity employed in their use.

CCS CONCEPTS

• **Human-centered computing → Sound-based input / output**; **Empirical studies in interaction design**; **Empirical studies in HCI**; **Interface design prototyping**;

KEYWORDS

DMI design, material afforance, enactive design, design probes, research through design

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1 INTRODUCTION

How do we build digital musical instruments (DMIs), and what can we learn about ourselves in the process? Tahiroğlu et al. [44] state: "To design a DMI is to probe musical history and to ask what musical ideas and ideologies we subscribe to".

In this paper we explore the notion of the Digital Musical Instrument as a research probe to investigate the influence of material factors on their designers. We present a study in which 20 musicians each design 4 new instruments using a contact microphone-based design kit and physically modeled sounds which suggested a range of real materials (wood, rubber, metal, ceramic). We explore the influence of these suggested material factors in relation to the physical objects selected to complete the instruments by their designers and the subsequent set of gestures used in their performance.

2 RELATED WORK

2.1 Enaction, Embodied Cognition and Creativity

Essl & O'Modhrain [6] propose an enactive approach to the design of new tangible music instruments, stating the design intention to "retain the familiar tactile aspect of the interaction so that the performer can take advantage of tacit knowledge gained through experience with such phenomena in the real world". They define *enaction* as "the necessary and close link between action and perception", linking their concept of enaction to tacit knowledge, stating it to be "inevitably dependent upon embodied knowledge, the kind of knowledge that is derived from being and acting in the world".

The concept of enaction comes from Varela's [48] notions of embodied cognition. Varela focused on our lived experience, and the mind's ability to enact meaning from interaction with its environment through sensorimotor exploration. Varela states the enactive approach consists of two key points: *(1) perception consists in perceptually guided action and (2) cognitive structures emerge from the recurrent sensorimotor patterns that enable action to be perceptually guided.* Noe [36] continues the theme of action guiding perception, however breaking away from Varela and Gibson's [9] dependence on the visual and replacing it with notions of 'touch', claiming perception not to be a process in the brain, but instead an activity of the body. We enact our perceptual experience.

O'Modhrain [38] states: "Enactive interfaces are desirable because they allow the user to utilise their preconceived knowledge of interacting with the world when using the interface". Hayes incorporates enactive processes in the creation of live electronic music and sonic art [13], as well as using them as a lens with which to investigate areas of musical interaction such as creativity [12], attention [15] and interaction [14].

Wessel's [49] review of the enactive approaches reviews the work of Varela and Noe, highlighting their dependence on the visual and questioning theories of auditory perception. Deeper within DMI literature, the importance of materials and our lived experience with them is highlighted earlier still by Cadoz [4] in his discussion of instrumental gesture.

2.2 Research through a Material Lens

Tangible interaction pioneer Ishii states that we are "at another seashore between the land of atoms and the sea of bits, we are now facing the challenge of reconciling our dual citizenships in the physical and digital worlds" [17]. Moving ever closer to the overlap between the virtual and the physical, Robles et al. [41] advocate the term *texture* to articulate material relations between the physical and digital, hailing the *material turn* in interaction design and calling for greater "computing through a material lens".

Karana at al. [23] demonstrate the influence materials can have on their users, stating "The 'material' should also elicit meaningful user experiences in and beyond its utilitarian assessment. This requires qualifying the material not only for what it is, but also for what it does, what it expresses to us, what it elicits from us, and what it makes us do". Writing from a human-computer interaction (HCI) perspective, Karana et al. [24] reflect on the processes taken to develop new materials for acoustic guitars, appealing to the "multiple sensory modalities" that can be "simultaneously active during an aesthetic experience".

We suggest as designers and makers of digital instrument in an increasingly virtual world, the meaningful user experiences reflected on by Karana et al. [23] can also be evoked sonically through the manipulation of virtual materials, harnessing a more ecological approach to auditory perception.

2.3 Design Probes as Research Tools

To explore and understand the nature and meaning of materials in design often relies on the notion of a *probe* which has become a common feature in a range of design based studies [10]. Gaver [7, 8] developed the idea of the *cultural probe* to explore experimental design in a responsive way. The probes were collections of evocative tasks aimed to elicit inspirational responses from participants in a familiar setting. Hutchinson et al. [16] present the *technology probe* for working within families in the home. Like the cultural probes, the goal of the technology probes is to inspire people to reflect on themselves and their ways. The researchers add the use of a specific technology to Gaver's probe concept to collect a technical detail as well as social commentary.

Challenged with the complex composition of physical and digital qualities in computation materials, Junge & Stolterman [22] present the *material probe* as an approach to explore the materiality of digital artifacts. Influenced by Gaver's probes, they seek to understand how people perceive material quality of artifacts when interviewed through a process of imagining, interacting with, and contrasting the physical and the digital.

Influenced by Gaver's cultural probes [7, 8], Tahiroğlu et al. [44] present the phenomenological probe, exemplified by Ulfarsson's halldorophone [47] and tasked with probing experience and interaction with a DMI. Jack et al. [18] review the role of DMI as *research product* [37], extending and exemplifying the notion of the probe as a way to learn more about ourselves and our interactions.

In contrast to previous research on the role of material affordances in the design process [24, 40], and to address some of the questions that arise from these studies, our work starts with sound and material affordances that are conveyed sonically. As we will describe in more detail, a physical modelling environment enables the synthesis and real-time control of a set of accurate models, generated from the material properties of real objects. This control provides more than just the playback of a routine or audio file, its material behaviour codified into tactile malleable timbres. The system enables a close constraint on the output of the DMIs created by our participants and a focus on the role of sound as a guiding factor in material-based interaction.

3 STUDY

The focus of this study is to investigate the influence of sonic properties on material selection, and subsequently the influence of both those factors on performance.

We wanted a better understanding of how people make DMIs when the sound they produce is constrained to that of specific materials (for the purpose of this study - wood, rubber, metal and ceramic). We are interested in how the sound will (or not) guide and inform the design process and subsequent performance with the new instruments.

The research question we seek to explore is:

- How do musicians approach the design of a new musical instrument when its sound is constrained to a recognisable material timbre?

In order to explore this question we produced an instrument design kit. The kit uses a single piezo contact mic as input modality, promoting direct tactile interaction with objects attached to it [6]. Enactive approaches [12–15, 38] to design fostered through the study tasks (discussed below) lead to to very natural links between participant's action and their perception of object and material.

Our goal was creating a platform with which our participants could develop research products [18]. The study was conducted 'in the wild' [2, 42], more specifically in the homes of the study participants. Unlike previous design studies [1, 27, 28, 50] which provide a set range of materials for the design process, our participants were free to pick from anything they could find. We are particularly interested in the tangible objects used by participants to complete the instrument design process and the relationship of these objects to the four provided sound models.

3.1 Instrument Design Probes

Inspired by approaches to design probes as research tools discussed in section 2.3 [7, 8, 16, 18, 22, 44], seven instrument design probe kits were produced.. One is shown in Figure 2. Each kit comprised of a Bela Mini [29] running the Faust physical modeling library [33], a contact microphone, a chargeable speaker, reusable tape to connect the sensor, and the study guide. The study guide is available in the digital appendix.[1]/

3.1.1 Hardware. The Bela platform [29] was selected due to its low latency performance and ease of interface with a range of sensors. In order to capture rich gestures and key acoustic features of physical interaction for use by the synthesis engine, a piezo transducer [21, 35, 50] was selected as the main input modality for the deign probe kit. This approach to input modality also follows notions of enactive design discussed in [5, 6, 39].

The Bela samples the audio signal received from the contact microphone at audio rate (44.1kHz 16 bit), feeding it directly into the Faust model as a continuous excitation signal, where modal resonances are added in real-time.

[1]http://jonpigrem.com/assets/files/STUDY-GUIDE.pdf

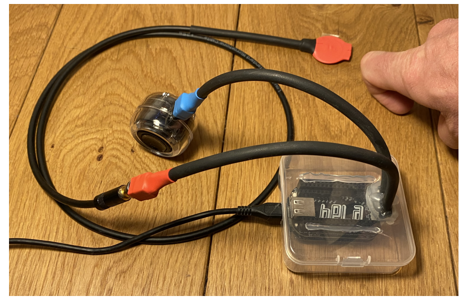

Figure 2: Instrument Design Probe

3.1.2 The Physical Models. It was important to constrain the sound of the instruments enough to present a recognisable material timbre, while still enabling the participant autonomy in the design process. Using the Faust physical modeling environment [31] and following the process outlined by Michon [32, 33], a range of realistic material timbres were developed for the study.

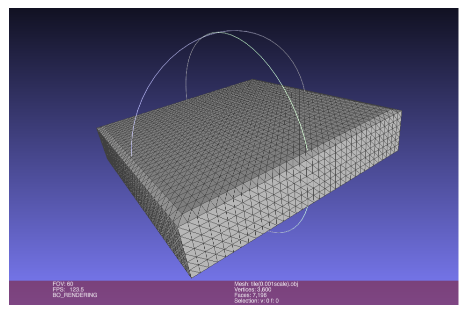

Figure 3: 3D Volumetric Meshed Model

We initially created 20 models, all based on the non-functional prototype instruments used in [40]. These 20 models were reduced to the final 4 through an informal listening sessions with 10 colleague researchers. Audio demonstrations of each sound can be found in the digital appendix.[2]

- Model One was a model of a 150x150x20mm block of wood. The model sounded somewhere between a woodblock, a Cajón, and the body of an acoustic guitar.
- Model Two was a model of a 150x150x20mm block of rubber. The model was hard to excite due the natural damping of the virtual-material, however once excited it would ring out with similar resonant properties to that of a stretched skin or membrane of a drum.
- Model Three was a model of a 150x150x20mm block of aluminum. The model was very resonant and had longer decay than the other models. It took very little energy to excite and could ring until damped.
- Model Four was a model of a 150x150x20mm Ceramic Tile. The model, although easy to excite, was very thin and lacked the resonance of the previous models leading to a short sharp response.

[2]http://jonpigrem.com/page26.html

3.2 Study Design

3.2.1 Participants. Twenty participants (15 male, 4 female, 1 genderqueer), with a mean age of 32 (sd 5.14), were recruited for the study via on open call on the Queen Mary residents list. All participants were asked to self identify as 'musicians' as we felt prior musical training would aid the themes and language used at interview. Participants musical background and experience with conventional and digital musical instruments and general digital technologies was assessed using a questionnaire [27, 28], and their general musical sophistication [19] established using using the Goldsmiths Musical Sophistication Index questionnaire [34]

3.2.2 Method. A study kit was delivered to each participant, and the 'Study Guide' walked them though the completion of the study.

To start the design process and inspire some initial interaction, the study guide states: *"Experiment by attaching the contact microphone to objects in your home. Select a sound model, turn on the speaker and explore the outcome. Please do think of the 'instrument' as a whole, a combination of the object you interact with and the sound that comes from the speaker".*

"Explore interaction: how are sounds made, how are sounds controlled, what is the range of potential, what sounds / feels good to you? Feel free to be as conventional or unconventional as you wish. Experiment, there are no right or wrong choices."

Participants were asked to spend no more than 30 minutes on each instrument design. On completion of each instrument, participants were asked to document their design with a few photos and then record a short performance to a provided backing track (discussed below).

3.2.3 Musical Task. Following the completion of each DMI prototype participants were asked to self record a short video of themselves performing with it to a backing track using their laptop or phone camera. As the quality of the overall recording process was unknown due to the 'in the wild' nature of the study, we didn't consider musical analysis, instead opting for a visual inspection of gestures used. The backing track can be auditioned in the digital appendix.[3]

3.2.4 Data Collection and Interviews. Following the creation of each DMI, participants completed a questionnaire probing their actions and the connection they felt to their instruments. A 5-point Likert scale (strongly disagree to strongly agree) was used to rate the statements in Table 1.

At the end of the study a summative ranking task was completed, in which each participant ranked their instruments in preferential order against the metrics - favourite, most playable, most controllable, most musical and most natural. Influence for these metrics was taken from Jack [20] and Saitis [43].

In the weeks following the design task we conducted structured interviews (Table 2) with all participants remotely over the Zoom platform. The interviews were audio and video recorded, transcribed and then thematically analysed [3, 25] using a predominantly inductive approach.

[3]http://jonpigrem.com/assets/files/Study_Task_Two_Backing_Track.wav

Table 1: Questionnaire Questions

Q1	*The sound informed my selection of material/object during the design stage.*
Q2	*There is strong connection between the sound of the instrument and the material / object chosen.*
Q3	*I felt connected to the instrument.*
Q4	*I felt able to communicate musically through the instrument.*
Q5	*I felt in control of the instrument.*
Q6	*The instrument felt unnatural to play.*
Q7	*The instrument felt like a part of me, an extension of my body.*
Q8	*I found the instrument unresponsive and hard to control.*

Table 2: Interview Questions

Q1	*How would you describe each of your instruments?*
Q2	*How would you describe the sound of each instrument?*
Q3	*Please outline your design process for each instrument?*
Q4	*Please tell me why you chose to use the material / objects that you have to complete the instrument?*
Q5	*Please tell me about the links (if any) between the sound of the instrument and the material / object chosen for the interface?*
Q6	*Please tell me about how you played the instruments during the musical performance task?*
Q7	*What do you like the most about each instrument and why?*
Q8	*What do you like the least about each instrument and why?*
Q9	*Please tell me what factors (if any) you think influenced the design process the most and why?*
Q10	*What elements of each instrument do you feel influenced your performance the most and why?*
Q11	*What was the biggest challenge during the design process?*
Q12	*What were the best and worst things about the toolkit?*
Q13	*Please talk me through your rankings in the summative ranking exercise*

4 RESULTS

Each participant made 4 new DMIs. The complete data set of 80 instruments can be found in the digital appendix[4] and selected artifacts will be reviewed below.

4.1 The Instruments

The following rich descriptions of artifacts developed by participants using the instrument design probes are the production of an analysis of photographs and video recorded performance with each instrument, followed by a thematic analysis of detailed description and explanation of action given by the participant at interview.

4.1.1 Model One - Wood. Instruments made with Model One tended to become wooden percussion instruments. The terms *wood, percussion, Cajon* and *drum* were prevalent in the thematic analysis. Ten participants selected wooden objects (two wooden boxes, a

[4]http://jonpigrem.com/page29.html

wooden table top, a wooden chair, three wooden toys, 2 wooden pots and the body of a guitar) and made percussion instruments, with a further five making percussion instruments from a range of other hard objects (cardboard backed notebook, metal lampshade, a tin lid, a can, and a plastic keyboard). The gestural language displayed by these 15 was a similar combination of finger taps and scrapes in proximity to the sensor.

Four participants made predominantly 'pluck-based' instruments using strings metaphors (elastic bands, metal ruler & guitar strings) that were capable of pitched performance, with a fifth incorporating using sporadic pluck gestures on elastic within an otherwise percussive performance. The use of strings and plucking metaphors were only found in instruments made with Model One.

Two participants approached the task differently to the rest: one creating a performance environment for the instrument from the mechanics of a bicycle and the other creating a drone instrument using a desk fan.

Figure 4: Participant 2 - Instrument 1

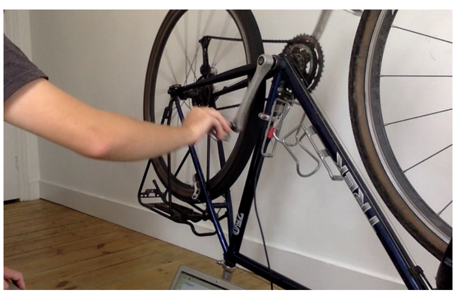

Figure 5: Participant 9 - Instrument 1

4.1.2 Model Two - Rubber. Instruments made with Model Two tended to become drums and were played with sticks or beaters. The terms *drum, skin, membrane, bongo*, and *conga* were prevalent in the thematic analysis. Fourteen participants made drum-type instruments comprising of a resonant bodied strike-able surfaces such as tins, pots, pans and tubs. Two further participants made striking type instruments (ruler and rubber shoe), which achieved a similar resonance as heard in the model's sound.

Twelve participants chose to play instruments made with this model using sticks or beaters, with a further six using their fingers or hand as beaters. Beaters were only used on three other occasions outside their use in instruments made with this model.

Two participants approached the task differently to the rest. One using an electric razor to provide a constant excitation to the sensor which was then modulated, and other using two metal pots in a cymbal type metaphor.

Figure 6: Participant 1 - Instrument 2

Figure 7: Participant 16 - Instrument 2

4.1.3 Model Three - Metal. Instruments built from Model Three were a departure from what we had already observed, where participants seemed to borrow from prior experience with instruments. Only one instrumental reference was coded in the thematic analysis of interview data for this sound model (*Glass Harmonica* - P9). The material references however were strong, and prevalent terms used to describe the sound of instruments made with this model were: *glassy, metallic, bell like, resonant*, and some onomatopoetic references such as *"it rings"* (P11).

Nine participants matched the model with an object made of metal and a further six with objects made of glass. There were similarities in gestures used across these fifteen participants, with the envelope of the sound being matched with more elongated scraping and rubbing type gestures. The fragility of the materials used was noticeable and gestures became lighter and more delicate.

Two participants made instruments in which they brushed a textured resonant box.

Two participants incorporated water into the instruments they designed with this model. The level of the fluid in a glass was used as both a way of modulating pitch and as a performance feature. Several other cup, bowl and pan type objects were used throughout the study, but no other brought with it the association of water.

Two other participants embarked on different approaches using this model, with one using an electric shaver and the other gaffer tape.

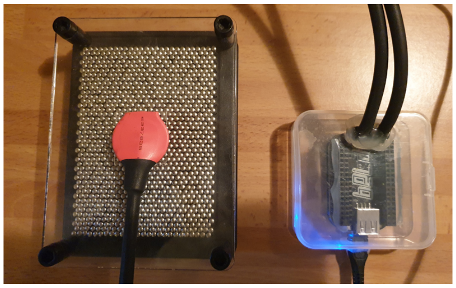

Figure 8: Participant 3 - Instrument 3

Figure 9: Participant 4 - Instrument 3

4.1.4 Model Four - Ceramic. As with Model Three, very few direct instrument analogies were provided in participants descriptions at interview, with only two participants referencing actual instruments (*cabasa* (P4) and *guiro* (P1)). Unlike Model Three however, participants were also unsure about the material represented in the sound, with terms used at interview moving towards smaller scale descriptors of sonic elements like amplitude and timbre - *'The small sound', 'the scratchy sound', 'the annoying sound', 'THAT sound'*.

Although most participants didn't provide verbal descriptions which focused on either material or instrumental analogy, eight still matched the sound with glass or ceramic objects, and a further nine participants matched it with acoustically similar objects made of metal or hard plastic (metal saw, metal bowl, metal pot, metal bottle, metal table, plastic cards, plastic pot, ping-pong ball). Unlike the metal and glass used with Model Three, the objects used for these instruments tended to be closer to the sound of the model.

Figure 10: Participant 1 - Instrument 4

Ten participants turned this short element into a 'grain' or 'bead' of a shaker or another granular analogy - two participants made

Figure 11: Participant 16 - Instrument 4

shakers, two used bristled brushes to excite the sensor, one used the leaves and branches of a plant, one rubbed pebbles around the sensor, one blew across tinfoil attached to the sensor, one rolled marbles in jar around the sensor, another used drum sticks on a bobbled glass surface attached to the sensor, and one scraped metal objects along the edge of a saw.

One participant wrapped the sensor in knitted fabric, needing and stretching the material across the sensor to create interaction.

5 DISCUSSION

5.1 Cultural Choreographies

The 'material-centred' approach to interaction observed in [40] is also evident in our data, this time conveyed by sound. In the absence of visual cues, participants seem to first seek an instrumental analogy with which to imagine the instruments they design. We were surprised by how far this analogy went and intrigued by the incorporation of strings by 5 participants using the Wooden Model and the use of beaters by 12 participants using the Rubber Model.

In the absence of direct instrumental analogies, participants appeared to identify material affordances in the sound and use these to guide interaction. Even when unable to verbally describe the material they were listening to (commonly the case with Model Four), participants still matched it effectively with interface objects.

It is interesting to see the range of approaches taken with Sound Model Four. We were surprised by how many adopted a granular analogy, creating an environment in which the sound would be more suited to a musical function (i.e. as a grain in a wider system such as a shaker).

There is support for the influence of cultural background and instrumental training on the design process as suggested by Lepri [28]. All five builders of the stringed instruments have some experience playing stringed instruments, however this approach was not exclusively for all string players. None of our participants stated playing drums, yet their influence on the approach used in instruments built with Model Two seemed to cross both musical backgrounds and cultures. On the note of musical culture, two participants (P4 & P20) with similar local backgrounds seemed to borrow from a shared understanding of a Spanish skinned drum, however a very similar approach was taken by P8, of a different background who referred to the Bodhrain (an Irish skinned drum played in a similar way) in relation to their design.

Overall, it seems the sound brings with it interaction possibilities and instrumental understandings that form the vocabulary the designer builds around the instrument. For most it becomes very hard to unlearn or rewrite a vocabulary built over a lifetime of lived experience.

5.2 Approaches to Design

The following sections outline two key approaches to design that were observed during the study. The approaches were discovered while conducting the the post study interviews, specifically from answers given to questions 3, 4 and 5. The Sound-Gesture-Object (SGO) or Sound-Object-Gesture (SOG) approaches were observed within all participants’ actions with several participants demonstrating both approaches.

5.2.1 Sound-Gesture-Object. The Sound-Gesture-Object (SGO) approach was observed across all participants, and was more commonly associated with instruments made with Model One and Two. This approach starts with the sound produced by the model. Participants reported the sound reminded them of a gesture and they went in search of an object capable of facilitating it. When this relationship was probed at interview, participants described properties of instrumental interaction more than material factors. It seemed these gestures would then become the source of inspiration in completing the instrument.

Interestingly there was often some physical relationship between the object chosen for the interface and the sound model, however the way this was explored by the participants was quite different. The creative process appears convergent [11] with less exploration of the interface object and more development and refinement of a functional vocabulary commonly tied to an instrumental analogy.

We suggest the recognisable material factors in the sound models lead designers on a process of convergent optimisation [45] in which the interface chosen performs a very narrow but very functional set of parameters in response to prior experience with existing instruments. In these cases satisfaction is found in the outcomes, however there is very little discovery of new interaction inspired by the object itself.

5.2.2 Sound-Object-Gesture. The Sound-Object-Gesture approach (SOG) was found across all participants, and was more commonly associated with instruments made with Model Three and Four. This approach started with the sound produced by the model. Participants reported the sound led them to an object. When this relationship was probed at interviews participants used physical descriptors to rationalise their actions, “it sounds like wood", “the resonance matched’. Once this object was retrieved and incorporated into the instrumental paradigm it became the main source of gestural inspiration and the design process appeared more divergent [11]. Participants reported exploring the object as it revealed interaction possibilities in an active and creative way.

We suggest the lack of direct instrumental analogy leaves the vocabulary of the instrument open, leading designers on a process of divergent exploration [45], in which the interface opens up a range of new interaction strategies based on its physicality. The notion of divergent exploration has also been observed by McPherson et al. [30] when presenting participants with an unfamiliar DMI. We question if with greater exposure participants using a SOG approach will eventually move toward a more convergent and optimal mode.

6 CONCLUSION

We have presented an experiment investigating the role of sound as mediator in the design and use of digital musical instruments. We believe in addition to notions of visual [9, 48] and haptic [36] sensations, the auditory modality forms an important and still widely misunderstood role in the complicated relationship that informs human experience. Tuuri et al. [46] question this space, focusing on the “ongoing choreography” between human and non-human agents. Referencing Latour [26] they state: “technological objects can be conceived as so-called actants that influence human actions (see Latour, 1996), thus co-constituting choreographies through embodied practices and affordances being attributed to their design (as pre-choreographic elements)".

We evidence strong *push* effects [46] from the sound on participants’ overall perception of the musical instrument being designed, including the suggestion of gestures, performance approaches and interaction strategies. In many cases participants seemed unaware of these influences, although the frustration of the *pull* effects were also noted.

The growing overlap between the physical and the virtual leads to new possibilities for our environments, and new ways to understand a more *whole body* [36] approach to the process of perception. Our instruments are capable of suggesting virtual parameters that influence our perception of and interaction with the physical world around us. As we further explore the modalities of sound, gesture and material in combination we open up new spaces for musical and instrumental interactions.

ACKNOWLEDGMENTS

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