SOUND SPHERES: A DESIGN STUDY OF THE ARTICULACY OF A NON-CONTACT FINGER TRACKING VIRTUAL MUSICAL INSTRUMENT

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ABSTRACT

A key challenge in the design of Virtual Musical instruments (VMIs) is finding expressive, playable, learnable mappings from gesture to sound that progressively reward practice by performers. Designing such mappings can be particularly demanding in the case of non-contact musical instruments, where physical cues can be scarce. Unaided intuition works well for many instrument designers, but others may find design and evaluation heuristics useful when creating new VMIs. In this paper we gather existing criteria from the literature to assemble a simple set of design and evaluation heuristics that we dub *articulacy*. This paper presents a design case study in which an expressive non-contact finger-tracking VMI, Sound Spheres, is designed and evaluated with the support of the articulacy heuristics. The case study explores the extent to which articulacy usefully informs the design of a non-contact VMI, and we reflect on the usefulness or otherwise of heuristic approaches in this context.

1. INTRODUCTION

With traditional acoustic musical instruments, there is a strong coupling between the playing gestures and the mechanisms that produce the sound: these two areas of concern exert powerful constraints on each other. By contrast, in the case of Virtual Musical Instruments (VMIs) [4,6] interaction gestures and sound design are, in principle, orthogonal. Consequently, the design of VMIs generally requires careful explicit attention to the mapping from gesture to sound manipulation.

Despite the freedom thus afforded to VMI design, a review of sources such as Mulder [4] and the Taxonomy for real-time Interfaces for Electronic Music performance (TIEM) [6] suggests that the majority of VMI controllers nevertheless rely on physical interaction between player and instrument. That is to say, many if not most VMI designs involve exerting a tangible force on a musical instrument in order for it to produce a sound. This is unsurprising. Research in areas such as Physicality in Human Computer Interaction [12] and embodiment in Music Interaction Design [11] suggest various routes by which physical contact offers rich affordances for designers and performers.

However, some VMIs are controlled without physical contact interaction [4,6] and instead rely on the proximity, or movement (gestures), of parts of the body. Non-contact VMIs raise interesting challenges for designers and performers alike in creating satisfying interaction designs for music making. The present case study explores some of these challenges.

Interaction designs for VMIs are often arrived at intuitively, and in the hands of many digital luthiers this is an optimal approach. By contrast, some instrument designers may find design and evaluation heuristics [13] useful when designing and evaluating new VMIs, particularly in focusing the process of iterative design. This paper reports on a design case study in which an expressive non-contact finger tracking VMI is designed and evaluated using a candidate set of design heuristics and evaluation heuristics for VMIs. These heuristics, which we have labeled *articulacy* (defined in section 3.1 below) are derived from design considerations from the literature [1,2,5,7]. The present case study affords a first look at how design and evaluation heuristics such as articulacy can inform a non-contact VMI design, and a preliminary reflection on the usefulness of such heuristics for this purpose.

2. BACKGROUND

Until recently, hardware to support finger tracking has been expensive and confined to specialist use. However, Lee [3] showed an accessible and affordable finger tracking technique utilizing the Nintendo Wii Remote controller (Wiimote) for the Nintendo Wii game console. He cleverly exploited the Wiimote's built in infrared camera and simple Bluetooth connectivity, demonstrating how to implement a finger tracking application. More recently, Microsoft's Kinect introduced another low cost opportunity for developing body-tracking applications. More generally, Vlaming [8] identifies a wide range of motion capture techniques and systems. The present case study focuses on the design and evaluation of a new non-contact virtual musical instrument, Sound Spheres, which is aimed both at musicians and novices, and which uses Lee's finger tracking motion capture technique for its gestural interface.

3. DESIGN CRITERIA

As already noted, because interaction gesture and sound design may vary independently in Virtual Musical Instruments, the designer must generally pay explicit attention to the mapping from gesture to sound manipulation. VMIs that successfully appeal to performers involve rich and subtle constraints on the connections between gesture and sound. However it is hard to characterize explicitly the nature of these constraints. Such characterization is particularly challenging in the case of non-contact VMIs where interaction with physical objects is absent. The HCI literature suggests many candidate design considerations, some relatively simple, such as clarity of feedback [13], and others more complex, such as appropriate exploitation of physicality [12] and systematic consideration of issues of embodiment [11]. For the present purposes, simple considerations are needed, suitable for guiding the design and evaluation of non-contact VMIs.

The Thummer Mapping Project [5] identified four common physical instrument variables (pressure, speed, angle and position) that control instrument dynamics, pitch, vibrato and articulation. In a later study Paine [7] re-iterated these control parameters as important factors for the design of new musical interfaces. Jordà [1,2] described other factors considered important to the consideration of a good musical instrument, suggesting playability, progression (learning curve), control and predictability. He also suggested that the balance between challenge, frustration and boredom must be met. Ferguson and Wanderley [9] highlighted reproducibility as one more important factor for digital musical instruments, suggesting that musical instruments that allow a performer to be expressive must also permit a performer to imagine a musical idea and be able to reproduce it.

In order to provide a simple set of heuristics for the design and formative evaluation of a non-contact VMI, we have borrowed and adapted these various considerations. Note that the simplicity of the approach reflects our preference in the present case for a light-weight methodology. For heavier-duty methodologies, see section 10.

3.1 Articulacy heuristics

We will consider the articulacy of a non-contact VMI to refer to (a) the degree to which pressure, speed, angle and position can be used to control the instrument and (b) the degree to which the design achieves playability, progression, control, predictability, reproducibility, and balance between challenge, frustration and boredom.

This set of considerations can be applied straightforwardly to VMI design simply by using them as a checklist of desirable properties. Similarly, they can be applied to formative VMI evaluation by considering, or measuring (see section 6), the extent to which they are achieved in a given design. Despite the extreme simplicity of this method, closely related approaches have been found useful in HCI design elsewhere. Indeed, our approach broadly echoes such approaches as Molich and Nielson's [14], which has been widely applied to user interaction design in general.

The purpose of this paper is to present a design case study, which includes a simple formative evaluation using eight test subjects, to explore the extent to which the articulacy approach, or similar approaches, might usefully inform the design and evaluation of non-contact VMIs.

4. OVERVIEW OF SOUND SPHERES

The Sound Spheres VMI is controlled solely by the movement of the musician's fingers in the air. Unlike some finger tracking applications, complex finger gestures are avoided and only the finger tips are used. Highly reflective tape placed on the fingertips reflects infrared light to the Wiimote's infrared camera (figure 10). The Wiimote then passes data concerning the positioning of the fingertips to the Sound Spheres VMI software.

The position of the finger tips is represented on the user interface (figure 1) as small spheres (*tracking spheres*). Only four fingertips can be simultaneously tracked with the Wiimote's infrared camera and hence this poses a limitation of up to a maximum of four tracking spheres. The movement of the tracking spheres is used to trigger sounds through collision with a set of fixed larger spheres (the *sound spheres*), which are organized in two rows, each comprising the 12 notes of an octave (figure 1). The two rows correspond to two different octaves, one octave apart. To differentiate the natural notes from sharp notes, sound spheres of different sizes are used. This type of visual differentiation is used in many traditional musical instruments, loosely echoing for example, the layout of piano keys or glockenspiel bars.

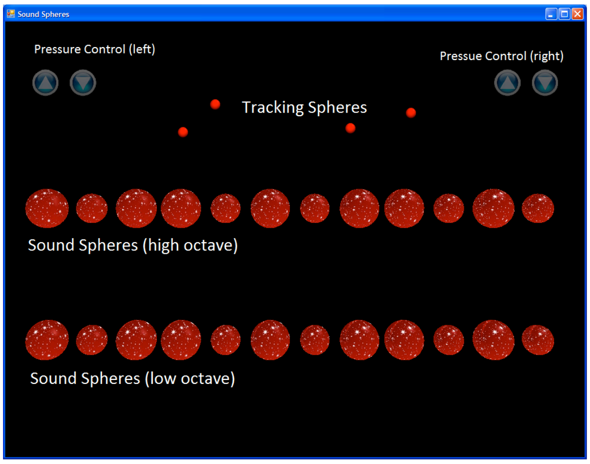

Figure 1. Sound Spheres User Interface

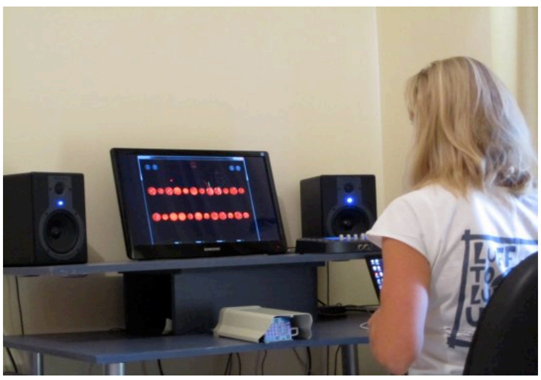

Figure 2. Playing the Sound Spheres

5. DESIGN OF SOUND SPHERES

To support the design of the Sound Spheres VMI we used the articulacy design heuristics outlined above to guide a rapid prototyping approach. Some limited pilot testing was carried out with users during parts of this process (see section 5.4). However, the design heuristics were used to guide design decisions when user testing was impractical, in ways discussed below.

Given the starting point – fingers in free air directing the collision of spheres to produce sounds – there are, broadly speaking, three principal categories of design decision to be made, which are summarized in table 1. The first is the design of specific gestures, or aspects of gesture, for each of the four *instrument control parameters* identified by articulacy, i.e. position, angle speed and pressure. In practical terms, this decision particularly concerns how the values of the various control parameters are to be derived from the finger tracking data. The second category of design decision is to map each control parameter to an appropriate sound shaping operation. The third is to design visual feedback as needed.

Generally, design decisions for the first two control parameters, position (fig. 3) and speed (fig. 4) were relatively non-problematic, whereas decisions for the angle and pressure control parameters were more challenging, especially pressure, in the absence of tactile feedback.

In the remainder of this section, we outline the principal design decisions associated with each of the four control parameters in turn (sections 5.1 - 5.4) and then consider visual feedback for the VMI as a whole (section 5.5).

Instrument control parameters	*Effect on sound*	*Visual feedback*
Position Position of a tracking sphere at point of collision (figure 3).	*Stereo Panning* The sound is increasingly panned to the left or right speaker dependent on the position of collision.	*Flying Sparks* The direction of sparks is dependent of the position of tracking sphere collision (figure 6).
Speed Speed of a tracking sphere's movement at point of collision (figure 4).	*Volume* A greater speed results in a higher volume.	*Spin* The greater the speed of the tracking sphere the faster the sound spheres spin on collision.
Pressure Based on momentum of tracking sphere at point of collision. Tracking sphere size is changed to increase or decrease momentum.	*Parametric EQ* A greater pressure results in a tone where the higher frequencies are boosted.	*Size* The greater the pressure the larger the tracking sphere.
Angle Angle generated by a tracking sphere's start position and collision point (figure 5).	*Chorus* An acute angle results in a chorus effect with a greater degree of modulation than a less acute angle.	*None*

Table 1. Outline of principal design decisions

5.1 Key design decisions for Position

When a tracking sphere collides with a sound sphere the value of the *position* control parameter is taken to be the horizontal distance from the point of collision and the central line of the sound sphere. This position is used to modify the sound generated at the point of collision by stereo panning to the left or right according to the distance from the sound sphere's central line (see figure 3 and table 1).

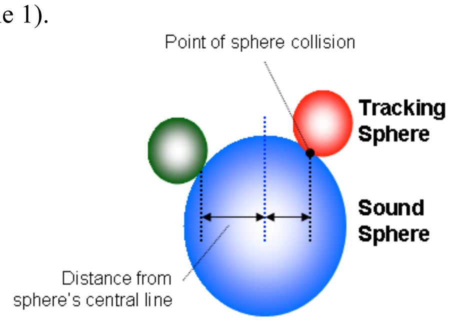

Figure 3. Position articulation

5.2 Key design decisions for Speed

When a tracking sphere collides with a sound sphere the average *speed* of the tracking sphere is taken to be the distance between the start and collision positions divided by the time difference between the start and collision positions, as illustrated in figure 4. The speed is used to adjust the sound generated at the point of collision simply by adjusting the volume, with a greater speed resulting in a higher volume.

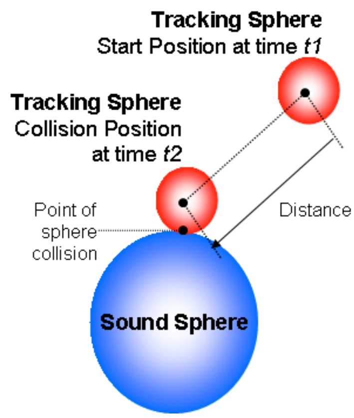

Figure 4. Speed articulation

Prompting design decisions associated with instrument control parameters is helpful, but the articulacy heuristics also prompt a consideration of the degree to which any design decisions impact on playability, progression, control, predictability, reproducibility, and balance between challenge, frustration and boredom.

In the case of the above-mentioned design decisions for speed, articulacy's playability design heuristic prompts the question of how it might be possible for a player to execute low speed gestures when there is a need to strike sound spheres rapidly in succession. However, reflection reminds us that an analogous problem exists in many traditional instruments without playability being impaired. For example, the volume of a xylophone is dependent on the speed on which the player strikes the bars, despite the fact that the mallets may have to be moved quickly to keep time. Playability is not thereby destroyed. Of course, playability depends on skill, but the present design appears to offer a broadly welcome design trade-off between playability, progression and challenge.

Continuing the prompted reflection on playability and challenge, an analogy with piano fingering suggests that the Sound Spheres player has a choice of playing a forthcoming note with any of the four *tracking spheres* and hence finger distance could be minimized with practice. Finally, a small movement of the fingers can affect a big movement in the tracking spheres (sensitivity) allowing individual adjustment of the "action" of sound spheres to assist playability.

5.3 Key design decisions for Angle

Compared with the design decisions associated with position and speed, the design decisions for *angle* are necessarily a little more oblique. The key facilitating step turned out to be to consider the *starting* position for a finger trajectory, as well as the collision point.

Thus, when a tracking sphere collides with a sound sphere the *angle* is taken to be the acute angle between three points, as illustrated in figure 5: point 1 is the center of the tracking sphere at the start of its movement towards the sound sphere, point 2 is the center of the tracking sphere at the point of collision with the sound sphere, and point 3 is any point horizontally displaced from the point of collision. The sound generated at the point of collision is adjusted dependent on the acute angle between these points. The echo, distortion and chorus effects provided by Microsoft's DirectSound were tried and the latter was judged the most suitable for the collision sound. In particular, a more acute angle results in a chorus effect with a greater degree of modulation than a less acute angle.

Thus, the collision of a tracking sphere with a sound sphere at an identical position can sound different depending on the starting position of the tracking sphere. This enables musical expression by swiping fingers in different ways. The articulacy heuristics again direct us to consider the degree to which this design decision may impact on such factors as playability, progression, control, predictability, reproducibility, and the balance between challenge, frustration and boredom.

This leads to a reflection on analogous situations, such as when a drummer strikes a cymbal. A change in the angle at which a drummer strikes a cymbal will produce a different sound. Sometimes a player will use a shallow angle and appear to brush the drumstick over the surface of the cymbal, and sometimes a more direct hit is executed, with widely different sounds being generated. Returning to the design decision in Sound Spheres, little can be concluded about playability, but these considerations do suggest challenge and possible progression.

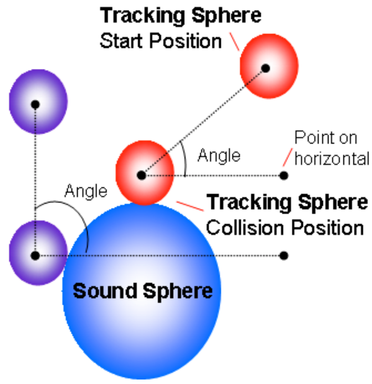

Figure 5. Articulation of Angle: two different collisions are illustrated, each with their own angle.

The method outlined above for determining the angle of a collision assumes that the starting position of each finger-driven tracking-sphere trajectory is well defined. In practice, the transition of a tracking sphere from playing one note to the next will frequently involve continuous motion, and hence the point at which a movement corresponds to the start of playing a new note can be difficult to ascertain. The engineering decision as to how the starting point is to be identified will have implications for articulacy factors such as playability, so reflection on playability is prompted. When playing a traditional percussive instrument such as a xylophone or steel drums, or even a stringed instrument like the piano, the movement of the striking object (be it a mallet, stick or fingers) from one note to the next is rarely linear. A player generally lifts the object from one striking position before they start the movement to make another strike. With this in mind, the decision was taken for the tracking sphere's starting position to be determined by the point at which the movement changes from a positive direction in the y-plane to a negative one, i.e. the point at which a downward movement begins, after an upward movement. Sound is also generated if a tracking sphere hits a sound sphere from below (i.e. with an upward movement not followed by a downward movement), but the angle and speed controls are not applied in that case, in order to nudge players towards the xylophone-like playing of Sound Spheres to reinforce the articulation of playability and predictability, while not restricting the free movement afforded by a non-contact VMI.

5.4 Key design decisions for Pressure

In a non-contact environment, finding an appropriate gesture, or aspect of gesture, to map onto a *pressure* control parameter presents a design challenge.

To help guide design, pressure was deemed to be closely related conceptually to momentum. Momentum is defined as the product of an object's mass and its velocity.

Consider two objects with different masses travelling at the same velocity, and consequently different momenta. If they were both to collide against the same surface then the one with the larger mass would exert more pressure. If we assume the virtual mass of tracking spheres to be proportional to their size, we can conclude that a larger tracking sphere would exert a greater pressure on a sound sphere than a smaller tracking sphere travelling at the same velocity. In other words, by varying the size of a tracking sphere we can vary the pressure being applied to a sound sphere during collision.

To implement the ability to dynamically and rapidly change the size of the tracking spheres, the user interface displays a visual component called a *pressure control* (Figure 1). A pressure control has been placed on either side of the user interface so that it can be quickly accessed by tracking spheres controlled by either the player's right or left hand. The pressure control has two circular surfaces, one containing an upwards facing arrow representing increasing pressure and one a downward facing arrow representing decreasing pressure. This control will gradually increase or decrease the size (and hence the implied pressure) of *all* tracking spheres when the center point of *one* of the tracking spheres is positioned over one of the pressure control's surfaces.

The design of the pressure control was motivated by the need to provide an interface that is intuitive to non-musicians while providing the degree of control expected in music technology. As such, while the upward and downward arrows are familiar from home electronics (e.g. to modify sound volume in discrete steps), they provide the same continuous control as e.g. modulation wheels. Without any additional movement, just by hovering a tracking sphere over an arrow, the size of all tracking spheres is changed in a continuous way.

Reflecting once more on playability, progression and challenge, it is clear that by using one hand to vary pressure while the other hand triggers sounds, it should be possible to change pressure relatively rapidly.

Pressure is used to modify the sound generated at the point of collision in the following way: a greater pressure results in a tone where the higher frequencies are boosted using parametric EQ.

5.5 Visual feedback

The articulacy heuristics encourage the use of visual feedback to assist with the communication of position angle and speed, moderated by considerations such as playability, progression, control, predictability, reproducibility, challenge, frustration and boredom. The Sound Spheres VMI provides visual feedback to the player when the tracking spheres collide with sound spheres in several ways, as follows.

Firstly, graphics are displayed at the point of each collision (figure 6). A graphics particle engine was implemented to display a set of flying sparks at the point of collision. The direction and dispersal of the sparks is dependent on the *position* of the collision in the sense defined in section 5.1. This is illustrated in Figure 6.

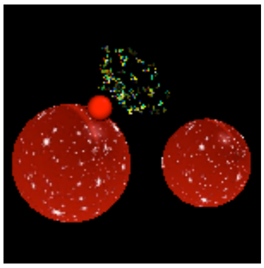

Figure 6. Sphere Collision Sparks

Secondly, when a tracking sphere collides with a sound sphere, the sound sphere vibrates as if it were on a spring. The vibration diminishes over time and then stops. The direction of the vibration is always up and down. Consideration was given as to whether the direction of vibration should also be dependent on *angle*, however reflection on articulacy issues prompted this idea to be dropped. As the sound spheres are placed close together, any sideways vibration could result in their collision, with likely negative consequences for playability, control and frustration. Hence, the vibration of the tracking spheres is not related to any specific control parameter and indicates sphere collision only.

Thirdly, when a tracking sphere collides with a sound sphere, the sound sphere spins around its horizontal axis. The initial speed of spin is dependent on the *speed* of the colliding tracking sphere, and the speed of rotation diminishes over time until the spinning stops. In order to ensure that the speed of spin is readily apparent to the user, we use spheres instead of circles, in an otherwise 2D layout (Figure 1), and then map graphical textures onto the sound spheres.

Visual feedback for *pressure* has already been described in the previous section.

To sum up, there are three elements of visual feedback for the collision of spheres (sparks, spin, vibration) in order to provide a better sense of collision and better compensate for the lack of tactile feedback.

6. EVALUATION

Heuristic evaluation is often used in HCI when user testing is impractical. However, it can also be used to help structure tests with users. The latter approach was used in the evaluation of the Sound Spheres VMI. In the formative user testing, eight participants took part in individual sessions to play the Sound Spheres. Five of the participants were musicians. Participants without prior music knowledge or instrument playing experience were included to check whether they were disadvantaged in using finger tracking for playing music. Three participants (including one musician and two non-musicians) had previously participated in design prototyping. The sessions were split into a number of stages that required the participants to try out different elements of the instrument (Figure 7).

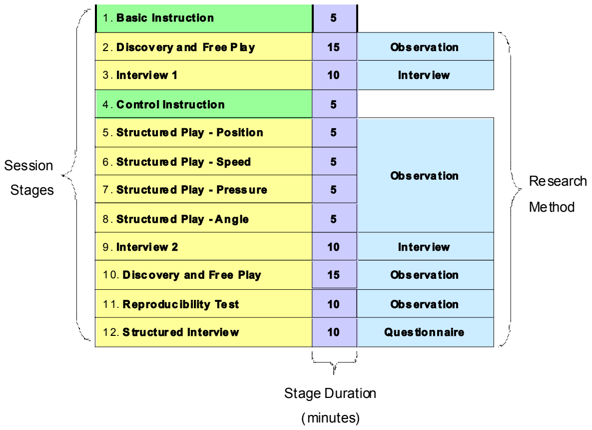

Figure 7. User study stages

Parts of the evaluation were suggested by the articulacy heuristics, while others were intended to explore wider issues. Both qualitative and quantitative data were collected. Observation notes were taken during the user study sessions to provide data for a comparative study to determine patterns of use and behaviour (feelings), body movement and posture, ease of use of the interface, ability to understand and use the control parameters, progression of learning, likes and dislikes, etc. Video recordings were also taken to support, validate and clarify observation notes. Interviews were conducted with each participant after each stage, and the responses were also used for a comparative study.

At the end of each user study session the participant was asked to complete a questionnaire with 49 questions. The initial 5 questions served to identify the participant and their ability to play and read music. Two questions asked the participant to rank the control parameters in terms of ease of use and importance to musical outcomes. The last 3 questions asked for general comments about what participants liked most and least about Sound Spheres. The remaining 39 questions covered the various design factors (playability, progression, control, predictability, reproducibility, and balance between challenge, frustration and boredom), asking participants to respond using a 5-point Likert rating scale (strongly disagree, disagree, neither agree or disagree, agree, and strongly agree) thus providing quantitative data to which statistical analysis could be applied.

Spearman's rank correlation method was used to determine the relationship between 57 pairs of questionnaire responses, e.g. if the ease of use of the speed control parameter correlated with the preference for its applied visual feedback. Furthermore, due to the small sample size, the non-parametric Mann-Whitney U Test was systematically applied to each of the 41 questions to test the hypotheses that questions may be answered differently between musicians and non-musicians, and between those who did and did not participate in the prototype reviews.

7. RESULTS

Statistical analysis of the questionnaire responses showed strongly positive feedback to many factors relating to the Sound Spheres VMI. For example, 87.5% of participants thought that the Sound Spheres VMI facilitated the creation of music well and that their playing improved over time. 75% of participants thought that it was easy to move the tracking spheres using the finger tracking method. Responses to questions about factors such as general playability, the progression of the musician's ability, control, and balance between challenge, frustration and boredom suggested that the Sound Spheres VMI was generally judged positively in these respects. Responses to questions on the factors of predictability and reproducibility generally showed negative judgments in these areas. In fact, as observed during the reproducibility test, all participants were able to repeatedly play a simple tune but only two of them performed it with good timing. However, observation and the results of the Mann-Whitney U Tests suggested less negative judgments where more playing time (i.e. practice) was given to the participants, which indicates that Sound Spheres allows progression towards more accurate reproduction.

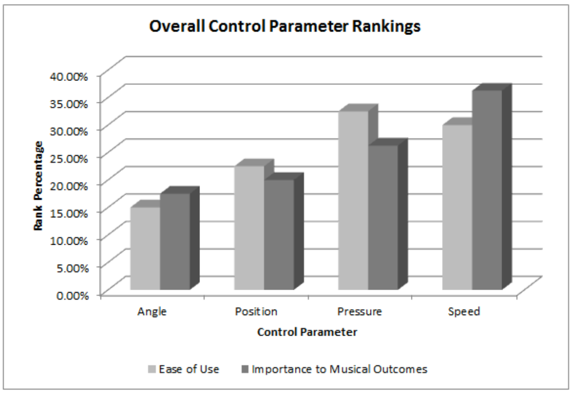

Figure 8. Control parameter rankings

The control parameters of *pressure*, *speed*, *angle* and *position* were ranked from 1 to 4 based upon their ease of control (1 being the easiest and 4 being the hardest) and also for their importance to musical outcomes, i.e. which control could be used best for affecting the musical outcome (1 being the most important and 4 being the least). A scoring system was applied to the rankings received by each of the participants (4 points were given to a rank of 1, 3 to a rank of 2, etc.) and a ranked scoring was calculated for each control parameter. The percentage of the sum of all the control parameters scorings was calculated for each. These percentages are shown in Figure 8. In general the control of *pressure*, *speed*, and *position* was considered easy, and the sounds generated for each of these controls were considered apparent, consistent and appropriate. *Angle* was the control parameter that received the most negative feedback in terms of its ease of control and associated audio result.

There appear to be several reasons for this, which we will briefly review. Firstly, the positioning of the sharp note sound spheres (which were placed lower than the natural notes) made them difficult to hit at an angle. Secondly, participants found that they often played more than one intended note when using the *angle* control due to the close proximity of sound spheres. Thirdly, visual feedback was not implemented for the *angle* control parameter. This suggests the combination of both audio and visual feedback (synchresis) may play an important role in non-contact VMIs.

Only 8 of the 57 Spearman's rank correlation results showed statistical significance and through further analysis 5 of these results were considered unreliable. For example, one negative correlation coefficient value suggests that the Sound Spheres VMI facilitates the creation of music better as the control of the tracking spheres gets harder. This is the reverse of what would be expected, especially considering that 87.5% of participants thought that the Sound Spheres VMI facilitated the creation of music well and 75% thought that the movement of the tracking spheres was easy. However a strong correlation exists between the improvement of ability to play the Sound Spheres VMI over time and the ability to distinguish the application of more than one control parameter at a time. This suggests that progression of ability or skill in playing the Sound Spheres VMI can be achieved. Correlation also suggests that accuracy in positioning the tracking spheres increases as the consistency in control of tracking sphere movement increases.

The Mann-Whitney U Test results indicated that there was no significant difference between musicians and non-musicians in the way questions were answered. However, there were five questions that identified significant (i.e. $p < 0.05$) differences between the responses of those who participated in the prototype review sessions and first time users of the Sound Spheres VMI. These results indicate that participants of the prototype review sessions were more able to consistently control the movement and position of the tracking spheres. They also used the control parameters to add expression during play more than first time participants. Participants of the prototype review sessions more strongly agreed with the change in sound being *apparent* and *consistent* when using the pressure control.

8. IMPLEMENTATION

The Sound Spheres software was developed using Microsoft's Visual Basic programming language and DirectX graphics libraries. The .NET managed library WiimoteLib [10] is used for handling and interpreting Wiimote data. The VMI's components are:

- The Sound Spheres software.
- Laptop computer and 24-bit sound card, external speakers and wide-screen monitor.
- Bluetooth adapter and supporting driver.
- Wiimote controller.
- Infrared LED array with cover.
- Four reflective markers.

The components are setup on a two-tiered desk with the top tier used as a surface on which to stand the speakers and computer monitor and the lower tier used as a surface for placement of the Wiimote and LED arrays. Separate tiers enable the Wiimote and LED arrays to be positioned horizontally central to the monitor and speakers without obstructing the player's view of the monitor. The Wiimote and LED array can be adjusted up or down to suit desired playing positions. An adjustable chair also allows players to raise or lower their playing position. The reference speakers are positioned either side of the monitor so that stereo effects are maximized. The system's setup can be seen in Figures 9 and 10.

Figure 9. Sound Spheres Implementation

Figure 10. LED Array, Wiimote and Cover

9. LIMITATIONS

There are many other criteria which could be used to support VMI design. Articulacy simply offers one example of design and evaluation heuristics.

The evaluation used subjective measures for the various articulacy characteristics. However, this reflects accepted approaches to heuristic evaluation.

We have reported on a single case study. Further work would be required to more deeply understand the possible value of articulacy, or related heuristics.

Articulacy might be argued to have a potentially 'reactionary' influence on VMIs. It may perhaps focus attention on relatively well-explored conceptual metaphors [11] such as position and speed. However, where other metaphors might be more appropriate, the present study offers a good starting point for constructing alternative sets of heuristics with contrasting characteristics.

10. RELATED WORK

The HCI literature on design and evaluation in Music Interaction is relatively sparse, though now growing. Wanderley and Orio [15] carried out a systematic review of existing mainstream HCI techniques for evaluating input devices and considered how these might be applied to music interaction. They also explored the notion of benchmarks (i.e. common musical tasks) that might potentially form part of a task-centric evaluation methodology. Kiefer et al. [16] reviewed some newer developments, and reported on a case study which stressed the value of interview data for identifying unexpected usability issues. Seago [17] critiqued existing user interfaces for timbre design from an HCI point of view. Wilkie et al. [11] introduced a novel approach to evaluating user interfaces for music, based on embodied cognition, image schemas and conceptual metaphor. Holland et al. [18] outlined how this approach might be applied to whole body and other non-contact interfaces for music. Modhrain [19] offers a valuable reflection on the role of evaluation in Digital instrument design. Interestingly, phenomenological approaches appear little used in this area; the Second Person technique [20] seems particularly suited to exploring the experience of musicians playing such instruments, to assist designers and evaluators.

11. CONCLUSIONS

Design for non-contact VMIs is challenging. By borrowing and adapting VMI design criteria from the literature we have assembled a simple set of design and evaluation heuristics dubbed *articulacy* for supporting VMI design. We have presented a case study demonstrating how articulacy has been used to design and formatively evaluate a novel non-contact VMI called Sound Spheres. Articulacy has been shown to help structure or guide varied design decisions, including aspects of: the design and refinement of various finger tracking measures for controlling instrument control parameters; the mapping of control parameters to sound shaping operations; and the design of visual feedback (which appears to be particularly important in non-contact VMIs). In some cases the heuristics directed the search for non obvious features of a design, e.g. prompting a controlling role for pressure in the absence of contact, and motivating various kinds of visual feedback. In other cases the heuristics motivated reflection on possible design decisions using various design criteria, e.g. considering how a mapping for speed might affect playability and progression.

After the design phase, articulacy has also been demonstrated to be useful in helping to structure the formative *evaluation* of a non-contact VMI. For example, the participants' answers to interviews and the questionnaire were designed to cast light on how well the factors of playability, progression, control, and balance between challenge, frustration and boredom were achieved in the context of various control parameters. Not all designers find design and evaluation heuristics useful, but some do. In the present case study we have demonstrated some of the ways in which a heuristic design approach might support some VMI designers in gaining experience as a step to acquiring more intuitive mastery.

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