Womba: A Musical Instrument for an Unborn Child

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ABSTRACT
This paper describes the motivation and process of developing a musical instrument for an unborn child. Well established research shows a fetus in the womb can respond to and benefit from stimuli from the outside world. A musical instrument designed for this unique context can leverage the power of this interaction. Two prototypes were constructed and tested during separate pregnancies and the experiences are presented, and the limitation of the sensor technology identified. We discuss our discoveries about design considerations and challenges for such an instrument, and project thought-provoking questions that arise from its potential applications.

1. INTRODUCTION
When do we first become able to play a musical instrument, and benefit from it? We challenge conventional notions of when a person can begin their journey of learning to control sound by proposing that a baby's motions in utero could be the first musical gestures of its emerging life. While this idea may seem radical and questionable in feasibility and value, well established fetal research has demonstrated a child has developing yet substantial capacities to sense, move, learn, and remember well before it is born [2, 4, 10, 11, 13]. Tapping into the budding abilities of the unborn child, nurturing their development, and exploring the complex questions that arise from designing for this context have motivated us to to undertake the work described in this paper: the Womba, a musical instrument for an unborn child.

In considering numerous studies on the fetal development and the benefits of playing a musical instrument [2, 4, 7, 10, 11, 13], we propose that sound triggered by fetal motions could potentially be enriching by informing the growing baby of its own movements, i.e. help develop body awareness, contribute to an understanding of cause and effect, and help develop a rudimentary affinity with sound and music [4, 13]. We also ponder whether giving the unborn child a "voice" outside the womb could help promote parental bonding. Formal studies on the complex outcomes that may arise from systematic use of such an instrument by an unborn child are beyond the scope of this project thus far, but these endless possibilities figure strongly in our future work. For now, our design and development process has been enlightening in terms of design considerations and constraints, and the kinds of exciting and complex questions that emerge from such an instrument. Beyond the research and fetal development possibilities, we foresee the Womba spurring thought-provoking artistic exploration through the experience of trying to incorporate sounds made by an unborn child into a musical composition and live performance.

In this paper, we will overview research surrounding fetal interaction with the outside world, identify some related projects, describe our current Womba prototype, discuss issues and questions that arose from our implementation, and present future work.

2. BACKGROUND AND RELATED WORK
2.1 Prenatal Stimuli
Where a child in utero was previously believed to be an inert being, growing in isolation from the outside world, a multitude of fetal origin studies in the 1980s-1990s have revealed that the fetus has highly developed capabilities, and the womb environment and external influences on it have a powerful formative effect on who the fetus grows to be [10]. This growing body of research continues to expand our understanding about how infants sense outside stimuli, learn, and bond with parents while in utero.

A fetus can perceive sensory input from inside and outside the womb, with hearing considered likely to be the most developed of all the senses before birth. The period from approximately 25 weeks gestation until 5-6 months of age is the most critical to the development of the neurosensory part of the auditory system, which must receive stimulation in the form of speech, music, and meaningful environmental sounds in order for the critical tuning of the hair cells in the cochlea to occur [4].

He or she can begin to move with outwardly perceivable motion as early as 20 weeks old, and this movement is a powerful mechanism for defining the fetus's body and sense of self, as well as for engaging in "dialogue" with the outside world [3]. They respond to stimuli such as their mother's voice and sounds outside the womb with movement and physiological changes such as heart rate [2], and have postnatal memory of such frequent experiences as lullabies repeatedly sung [13]. Fetuses have even been conditioned to kick for a controlled auditory and vibrotactile stimulus in experimental conditions [11]. Extrapolating from the numerous studies on fetal development could suggest that an unborn child not only has the basic potential for interaction with a specialized musical instrument, but also that its developing body and mind may thrive on such auditory and kinaesthetic interaction with the outside world [4].

2.2 Prenatal Interaction Devices

Numerous researchers and product designers have developed wearable prenatal systems for one or both of the following purposes: 1) to provide controlled sensory input to a mother's abdomen for influence of the unborn child, or 2) to monitor or sense activity within the womb for informational benefit of interested persons outside, beyond typical medical/diagnostic applications. The current existing systems for each purpose will be discussed and contrasted with the proposed instrument.

These systems range in interactivity, but the vast majority are devices for transmitting sound of the mother's or designer's choosing to the fetus. The sounds may be music, speech, or sound effects, with typical intentions being towards education, soothing, or parental bonding. In all existing devices, the sonic material is pre-recorded or pre-generated, and the control element lies in how the sonic material is selected and triggered on or off. An example is described by a prenatal speaker system described by [5].

In terms of utilizing the movement of the fetus as input to external systems, [12] presents a patent for a baby-controlled interactive "toolbox" designed for fetal movements to trigger playback of music or sounds such as simulated crying, laughing, animal vocalizations, and human vocalizations. The Kickbee is a device that is designed to send a generic "I kicked Mommy" 'tweet' to a Twitter feed when the baby kicks in the womb [9].

2.3 A Pre-natal NIME

Considering the potential for the fetus to trigger and respond to external stimuli described by existing literature and building upon existing devices that attempt to provide sensory input, we introduce the concept of a pre-natal musical instrument.

In contrast to devices that simply generate stimuli, a musical instrument allows direct and active manipulation of the output sound, which provides more changes in neuroplasticity compared to the transient "Mozart Effect" from merely listening to recordings that became popular in the mid-1990's [7]. We go beyond the triggering of playback as described by [12] and [5]. By leveraging the detected fetal movements used as input of the 3-layer NIME model described by [6], we can explore the possibility of creating rich musical interactions initiated by a child still in the womb.

3. WOMBA PROTOTYPE

We present the Womba, the first musical instrument designed for an unborn child. In this section we first describe some design considerations for the instrument, and then we present the two prototypes that were constructed to explore this possibility.

3.1 Design Considerations

3.1.1 General Parameters

Designing an instrument for the otherworldly environment of the womb and primordiality of its fragile player presents some unique challenges and design considerations, particularly pertaining to the optimum sound parameters of the instrument. Foremost consideration should be paid to the safety, comfort, and potential influence on the fetus. Secondly, the sounds and the usage period of the musical instrument needs to have effective parameters for being perceived by the fetus, considering their stages of development and what stimuli most likely produces a fetal response. Below are some considerations in designing the sound with the fetus in mind.

- Feasibility: Contrary to previous belief, studies have shown that womb is no louder than a typical environment in which most of us live [4] and thus quiet enough for external instrument sounds to carry through.
- Window: The fetus can start hearing, responding to sound, and making externally-sensed movements at 20-24 weeks gestation. [4].
- Fundamental Frequency: the uterine walls attenuates sound at 5 dB per octave between 315 and 2500 Hz, while lower frequencies around 261 Hz (Middle C) propagate quite well [4].
- Timbre: The fetus responds the most to a female voice, especially its mother's, and will even show preference for music with more frequencies similar to that of the female voice [13]
- Volume: The loudness should be limited to 70 dB to protect the fetus's hearing. The fetus is particularly vulnerable to high volume levels at lower frequencies. Directionality and number of transducers may also be important due to propagation characteristics [4].
- Harmonic Content: [14] suggests infants have a preference of consonance over dissonance that is independent on prenatal or early postnatal experience. This may be a consideration for the pitch choices of the instrument.
- Timing: The protection of sleep and sleep cycles is important for healthy auditory development. For in utero learning, a preterm infant must hear the voice or music when awake or in quiet sleep, followed by a period of REM sleep for the formation of auditory memories [4].

Once meeting these basic sound parameter considerations and others yet to be determined, we envision that the sounds most appropriate for a particular child would be chosen by its parents. If a process of bonding will take place between the child and its instrument sound, and between the parents and their child's instrumental "voice", then this choice is a very personal one. The Womba may ultimately need to offer a range of timbre and pitch options or incorporate parental input. It remains to be studied how much this factor could shape the unborn child.

3.1.2 Sensor Requirements

While there are various biomedical sensing techniques available for the detection of fetal movement used for medical purposes, most of them are not readily feasible especially considering the initial stage of our development and resources. Therefore, for the purpose of this project we decided to employ passive sensing techniques on externally observable movements of the fetus using sensors readily available to the DIY community. We also limit the movements of interest to those that will create externally visible deformations on the mother's belly. For our first implementations, we attempted to simply detect the presence and location of movement.

In terms of sensor choice, we initially experimented with fabric stretch sensors, force sensitive resistors (FSRs), piezo transducers and contact microphones. Out of these, the piezo and FSRs were employed in our prototypes due to how

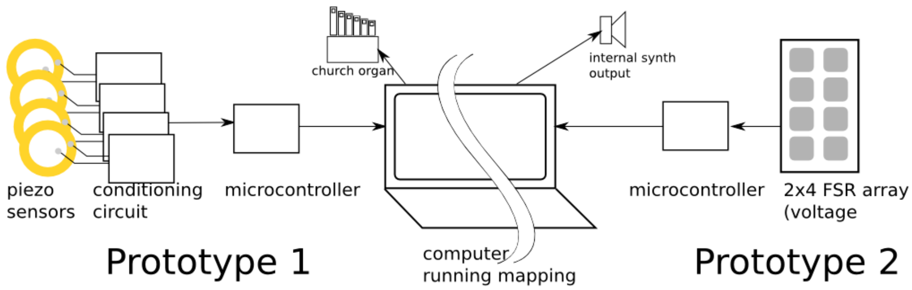

Figure 1: Block Diagrams of the Womba Prototypes

quickly we were able to integrate them and obtain usable output signals. While the list of sensors is not exhaustive, and the use of more elaborate signal conditioning circuitry and processing may yield better results [8], it is left as future exploration at this point. In the process, we discovered that the selection, integration and mounting of sensors for this particular application is no trivial task, and some comments are made in the discussion section.

3.2 Implementation

Two prototypes were constructed and used over the period spanning March 2013 and January 2015, which coincided with two women's pregnancies. Following is a more detailed description of each prototype.

3.2.1 *Aura-Solan*

The first prototype was built and tested in the 30th week of the pregnancy. At this point, there was still ample room in the womb for the fetus to move, and most of the visible movements were sharp, jabbing motions. As such, piezo sensors were used. Four sensors were placed at discrete locations where the baby's movements were frequently observed. A block diagram of the prototype is shown on the left side of Figure 1. The sensors were simply taped to the belly using surgical tape.

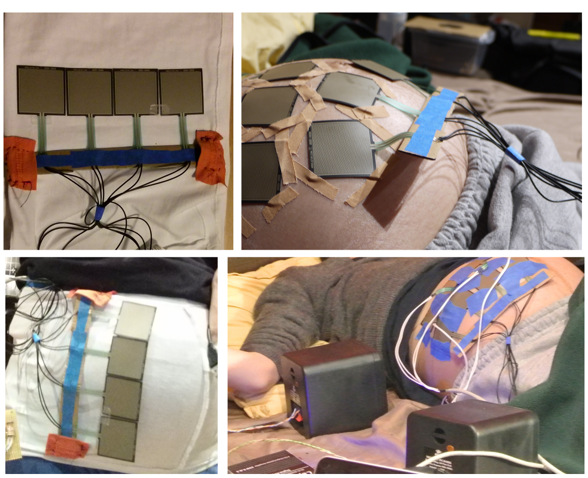

Figure 2: The Second Prototype

3.2.2 *Vivian-Johanne*

The second prototype was built and tested in the 37th week of the pregnancy. At this point, the growth of the fetus restricts the movement, and most of the observed movements created larger, rolling deformations of the belly as the fetus shifts within the womb. Piezo sensors were no longer suitable. Here we employed the Interlink 406 "square" FSRs. An array of 8 sensors were spread out across the belly, as shown in Figure 2. We attempted at better sensor packaging through the use of sewn pouches on stretchy "pregnancy waistbands", but obtained better results in the end with taping the sensors directly, as the first prototype. A block diagram of the second prototype is shown on the right side of Figure 1.

3.2.3 *Mapping and Synthesis*

In both prototypes, we employed simple threshold mapping for the triggering of notes. For the first prototype, we were provided with an unique opportunity to connect the system to a MIDI-enabled church organ, thereby creating the link between possibly the newest form of gestural musical input to the oldest musical "synthesizer". The sensors were mapped simply to the notes of an open position C-major chord, spread in ascending frequency from low to high on the belly. The second prototype, with its 8 sensor inputs, triggered chime-like samples of ascending frequency along an anhemitonic pentatonic scale (these sounds can be heard as they were generated by a baby in real-time in the Womba demonstration video). Considering that continuous force values were available, more interesting mapping schemes are definitely possible, and we note it as an area for future exploration.

4. RESULTS AND DISCUSSION

A number of challenges and potential research questions arose from our experimentation with the two prototypes employed during two separate pregnancies, and are presented here for discussion.

4.1 Technical and Logistical Considerations

From our exploration of off-the-shelf sensors commonly used within the NIME community, we quickly realized the limitations of using existing sensors for our application. While we do not rule out the usage of better techniques that make existing sensors more suitable, the physical packaging and mounting of the sensors remains a challenge. Other complications we noticed were the distinction between the physical movements of the mother (such as breathing) and the preloading or false triggering of the sensors. Another interesting consequence of fetal development is that as the pregnancy progresses, the kinds of movements will change and either the sensing system must be able to either be able to detect the full range of potential motions, or be changed at different points of the pregnancy. It also may be worthwhile investigating the construction of custom sensors, or up and coming solutions for the wearable computing market such as [1].

Timing project work periods to coincide with fetal activity deserves an honourable mention here. In both implementations it was challenging to work around the baby's irregular and unpredictable wakeful period. It is worth considering more comfortably wearable prototypes that can be easily activated at the opportune time. Project work also had to be completed before birthdates, of course.

In terms of mapping and synthesis, at this point we are excited about the vast amount of yet to be explored possibilities that may offer new depth as we move towards more meaningful conclusions on the matter.

4.2 Further Research Questions

Beyond the technical implementation issues, our research ultimately brings us a step closer to asking the more interesting questions, such as:

- Would the baby eventually associate its movements with the sound, and come to deliberately control it?
- Would the baby develop an affinity with the sound, and would the sound have a unique effect on the baby once born?
- How would the instrument affect the baby's learning and development?
- How would the instrument affect parental-child bonding?
- How would the baby be shaped by the sound and mapping, in terms of its character, associations with sound and motion, embodied cognition about sound, etc.?
- How do we best map movement, space and sound in the womb context, with the knowledge that the chosen mapping would perhaps shape the child's embodied notions of sound?
- Are there cautions to be considered in having a baby control this instrument, such as causing stress, disrupting sleep patterns, etc?

It would require further exploration involving more participants, working alongside experts in prenatal and early childhood research fields to attempt at answering any of these questions. In addition, we anticipate that the technical requirements would also change as we iterate through this process. We hope that this presentation of our work thus far is a step towards such interdisciplinary collaborations.

5. FUTURE WORK

So far, we reported on our design considerations, challenges, and preliminary implementation efforts, but we acknowledge the requirement of further prototype development, exploration, and systematic studies before the Womba can offer artistic value or address deeper questions like those posed in 5.2. Going forward, we will continue developing the system from a technical perspective. As mentioned in the discussion, there are various limitations in the sensing techniques employed. Considering that a continuous range of sensor values are available, the mapping implemented is also but a preliminary step towards more interesting strategies for generating sound. Another potential avenue for exploration is the visualization of the movements as feedback for the a.)mother, b.)audience and c.)fetus itself [2].

In terms of prenatal and early childhood research, we hope to engage with experts in the field to further investigate some of the questions raised, as well as potential new ones as they will undoubtedly arise with access to further knowledge and expertise on the subject.

From an artistic point of view, we hope to explore the creation of compositions utilizing this novel form of interaction. In addition to gestures from the fetus, there are additional sources of input from the mother, father or other third party that may create interesting interactions.

Finally, we also acknowledge the potential for commercialization of such a product. The existence of various solutions attempting to facilitate fetal interaction indicates a market demand for such a product, and we will be attempting to pursue potential opportunities alongside the scientific research and artistic exploration.

6. CONCLUSION

In this paper, we presented the conception (pun intended), and first examples of implementing a new musical instrument for an unborn child. We discuss some of the technical challenges encountered in the process of building and testing two prototypes during two separate pregnancies, and discuss potential for future work from the perspective of scientific and artistic considerations. We hope the Womba project empowers us to explore and celebrate the notion that human beings are musical beings, from the very start.

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