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The Sound of Ultrasound: How Fetal Monitor Users Listen to Doppler Sounds

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ABSTRACT

The electronic fetal monitor senses the heartbeat of the fetus and the mother's contractions during labor. Monitors use Doppler ultrasound transducers, placed on the mother's belly, to emit ultrasound and translate the reflection into audible sound. The authors explore how users listen to this sonification. A literature review revealed only the basics: they listen to fetal heart rate. However, recordings also contain "swooshing" in the uterine environment, the sound of motion relative to the transducer, and other sounds. In their care for mothers and babies, users may be listening to these elements, or getting a tacit sense of the state of the pregnancy from the sound as a whole. To ensure the next generation of fetal monitors capture all that users need to hear, interviews and surveys were conducted with labor and delivery nurses, midwives, and OBGYNs in three countries. Per these engagements, insights were gained regarding: what users listen for beyond the fetal heart rate; how profession and cultural context determines what they listen for; how they were taught to listen (if at all) in their education; the importance of listening versus looking at the monitor; and user preferences for the quality of the Doppler sound – particularly what sounds "clear" versus "real" (and what "real" means for an abstract sonification of inaudible ultrasound).

Keywords: *fetal monitor, Doppler ultrasound, information sonification*

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1. INTRODUCTION

The electronic fetal monitor is a tool used by labor and delivery (L&D) nurses, midwives, and obstetrician-gynecologists (OBGYNs) to monitor the heartbeat of the fetus, as well as the mother's contractions during labor. For sensing the fetal heartbeat, the electronic fetal monitor performs the function of traditional, analog devices such as the fetoscope or Pinard horn, which are types of stethoscopes, placed between the mother's belly and the user's ear. However, instead of using audible sound, the electronic fetal monitor uses ultrasound – sound at frequencies too high for humans to hear.

The process works like this. Ultrasound transducers are placed on the mother's belly and emit ultrasound into the uterus. The ultrasound waves reflect off of the fetal heart and return to the transducer with a slightly different wavelength because of the Doppler effect: shorter as the heart expands toward the transducer, longer as it contracts away from the transducer. The electronics in the monitor translate the difference between the initial wave and the reflected wave into a signal that is sent to the device's speaker, which produces audible sound. The result is a sonification of the inaudible ultrasound signal: what is known as the "Doppler sound." In this way, everyone in the space – including the mother – can listen to the heartbeat, which was not possible with fetoscopes or Pinards [1, 2].

There are manuals for how to use the fetal monitor, and clinical guidelines for L&D nurses, midwives, and OBGYNs to assess the fetal health, however not much is written regarding how these users listen. A review of the academic literature revealed only the basics. The

Doppler sound is primarily used to listen for fetal heart rate (FHR), blood flow through the heart valves, and must have the ability to distinguish fetal heart sounds from the sounds of the mother's organs, motion of the transducer, and other "noise" [2-7]. Moreover, midwives may have unique sensitivities to the mothers they work with – as compared to medical practitioners – because of their emphasis on emotional, and social connections [8, 9].

Little is written to describe the actual sounds a user will hear from the Doppler sound of the fetal monitor, what those sounds represent physiologically, and how that might inform clinical decisions. Recordings of electronic fetal monitoring contain more than just the fetal heartbeat; they also contain "swooshing" in the uterine environment, the sound of motion relative to the transducer, and other sounds. In their care for mothers and babies, users may be listening to these elements, or getting a tacit sense of the state of the pregnancy from the sound as a whole.

The complex, intrauterine soundscape requires careful listening and interpretation by highly skilled professionals. To ensure the next generation of fetal monitors can detect and make audible all that such expert users need to hear, the authors conducted a study to better understand what they listen for. Where possible, the authors also aimed to understand the mother's (and family's) experience with the sounds of the fetal monitor and what impacts it has on them. Interviews and surveys were conducted with L&D nurses, midwives, and OBGYNs in three countries (Canada, the United States, and Germany). The insights gained from this study extend beyond what users listen for and address a holistic audio experience of fetal monitoring for the clinician as well as the mother.

Mdoe et al [1] and Skeide [2] both point out that a benefit of Doppler sound is that the midwife and mother (and other family members) share the listening experience, and thus the emotional connection with the fetus. Per Howes-Mischel [8], hearing the heartbeat together can humanize the fetus as a baby. The medical environment can seem cold and mechanical to expecting mothers and families, but the Doppler sound can help establish the natural, beautiful humanity of childbirth [10]. In designing sounds and sonifications for the fetal monitor, we wondered how we might make the experience less like surveillance and more like sharing the "symphony" of heart beats and uterine contractions.

2. METHODS

This study was conducted in two phases. In the first phase, L&D nurses based in Toronto, Canada (n=8) were interviewed in-person for 45-minutes each. The average experience as an L&D nurse was 12 years. The protocol for interviews was based on background research, including a literature review of fetal monitor use, focused discussions with clinical experts (midwives and OBGYNs) and engineers who make the fetal monitor, and a speaker hardware analysis.

In each interview, nurses were asked open-ended opinion and experience questions about their use of the fetal monitor, fetal monitor sounds, and the Doppler sound in particular. Most interview time was spent on "listen and respond" activities. Nurses listened to recordings of Doppler sounds as produced by different fetal monitors, as well as potential modifications of these sounds (chosen per the background research). Some modifications emphasized heart beats, whereas others for a wider range of phenomena to be heard. The same recording was used, varying only the method of playback. Nurses described what they heard and made comparisons.

In the second phase, midwives and OBGYNs were engaged through an online survey and in-person interviews. The survey reached 81 midwives and 38 OBGYNs (total n=119). 86 were based in Germany and 33 in the United States. 38% of all those surveyed had 20+ years of experience and 14% had 5 or fewer years of experience. The interviews were only with midwives (n=6) for 45-minutes each. All 6 were based in Stuttgart, Germany. Three were relatively new to the career, with 3-4 years of training and 1 year of post-graduate experience. The other three were more senior, with 17-40 years of experience.

Survey takers were asked about what they listen for when using the Doppler sound, any difficulties they may have had hearing it, and what their preferences were among four modifications of the sound vs the unmodified sound: making the "swoosh" louder and quieter, and shifting all frequencies higher and lower. (The exact modifications are proprietary and cannot be shared here.) Sounds were included on the survey as playable files. Survey takers were also asked about anything else they wanted to share about the sound of the fetal monitor. The questions and structure of the survey were as follows:

Experience with the Fetal Monitor

- When you are listening to the fetal Doppler sound (also called "ultrasound"), what are you listening for? [Open]
- When you are listening to the fetal Doppler sound, do you listen for anything besides fetal heart rate? If so, what do you listen for? [Open]
- Have you ever had difficulty hearing the fetal Doppler sound, even at max volume? [Open]

Listen and Respond 1

Please listen to the following 3 sounds. Each is a different version of the same recording of a Doppler sound.

[Option A was the control. B and C had modifications to emphasize or deemphasize different parts of the sound]

- Which option would most help you perform your work? [Multiple choice]
- Why did you choose that option? [Open]

Listen and Respond 2

Please listen to the following 3 sounds. Each is a different version of the same recording of a Doppler sound.

[Option D was the control. E and F had modifications to emphasize or deemphasize different parts of the sound]

- Which option would most help you perform your work? [Multiple choice]
- Why did you choose that option? [Open]

Concluding Question

- Is there anything else that you would like to share about the sound of the fetal monitor? [Open]

Interviews with the six midwives addressed these same questions as in the survey, however listening conditions were much more controlled. As with the L&D nurses, midwives listened to recordings of Doppler sounds as produced by different hardware setups, as well as potential modifications of these sounds (now adjusted per the findings of Phase 1). In this phase, we used three different recordings, chosen to provide a variety of phenomena in the uterine environment. Each midwife heard all recordings with all hardware setups and modifications during playback. They described what they heard and made comparisons.

Survey data were exported from the online platform (Qualtrics) to a spreadsheet (Microsoft Excel) for analysis and visualization of quantitative data from close-ended questions, as well as tallying and synthesis of qualitative data from open-ended questions. Interviews were recorded and transcribed, then excerpts were tagged and clustered using a qualitative data analysis platform (Notably).

3. RESULTS AND INSIGHTS

3.1 Sound is important for fetal monitoring

In the words of one L&D nurse, "we know more from things we don't see." About ⅔ of midwives interviewed thought that sound was more important than visuals because the sound made it easier for midwives with experience to intuitively interpret what was happening. For experienced and highly trained users, sound can possibly reveal a lot more nuanced information about the wellbeing of the fetus, which could have been missed by visual traces. A nurse we interviewed described an example of the importance of sound for fetal monitoring: "by the sound I know how the baby is… Sometimes we have a horrible heartbeat and we have a healthy baby."

3.2 L&D nurses listen for FHR, midwives listen for more

In Phase 1, we found that L&D nurses in Canada are primarily listening for the "tempo" of FHR, including baseline, decelerations, and accelerations. This aligns with the findings of the literature review. Their process for listening to the Doppler sound is depicted in Figure 1. L&D nurses said that they heard other sounds, but did not actively listen for them.

Per the survey in Phase 2, midwives and OBGYNs in Germany and the United States are primarily listening for the FHR, i.e., its tempo, as well as its rhythm ("lub-dub"). This confirms what was found in phase I from interviews with L&D nurses in Canada. Survey-takers prioritized FHR clarity and absence of background noise in most situations (see Figure 2). Yet 60% of midwives and 70% of OBGYNs listen for more than FHR . Midwives surveyed listen for fetal movement, background noise, volume, and maternal heart rate, and they tend to pay more attention to these than OBGYNs surveyed (see Figure 3). Interviews with midwives also revealed that they listen for child movement, umbilical cord, placenta, and maternal heart rate, but stated that these were not as important as the FHR (see Figure 4).

In general, both the L&D nurses and midwives interviewed preferred sonification options that sounded (in their words)

more "clear." These were options which emphasized the fetal heartbeat by favoring relatively high-end frequencies. However, neither groups preferred options that did this to an extreme. Nuance is required for balancing clarity with reality.

3.3 Context determines what is listened for

What users listen for is defined by socio-institutional contexts, most notably by the type of their profession, and the clinical privileges that profession has within different cultures. As one Canadian L&D nurse put it, when asked if she listens for arrhythmia in the fetal heartbeat, said that this is beyond her professional responsibilities/clinical privilege, so she learned not to listen for it. This is not the case with midwives in Germany, who have responsibilities and status on par with doctors. People limit their attention to things about which their opinions are valued.

Different units can also have different cultures. Some are more rigidly hierarchical (nurses' input is discouraged beyond their professional scope) and some are more team oriented (nurses' input is more encouraged). An example from our interviews was that "the moment the woman comes into the delivery room, a midwife cares for her. So there's no other nurse or someone to help. And for both most of the time you call the doctor as someone who assists you." Physical/spatial contexts matter, too. Fetal monitoring is used in a wide variety of sound environments. Some are in quiet rooms to help mothers rest; some are in busy ER triage areas with the sound of other fetal monitors and beeps; some are in the cabinet that affects the characteristics of sound.

3.4 Different contexts may require different audio profiles

Users' professions shape what they listen for. L&D Nurses say they want to hear just FHR more clearly, but they also prefer when things sound "real." Midwives sometimes preferred Doppler profiles with low-end frequencies, while L&D nurses did not. In addition to the clinical value of the Doppler sound, there is social value from the communal listening experience among the care team, mother, and family. If it sounds less "real," will that experience be the same? By emphasizing some elements artificially, we can clarify information, but sacrifice "realism" (i.e., what we are used to perceiving) and emotional connection.

As such, a single intervention may not meet the needs of all users; a future capability to consider is adjustable audio profiles or settings on the device which can be easily toggled per the individual users and specific contexts. Sonification of Doppler ultrasound can be made to seem more abstract or be given more fidelity. It can be such that the user only hears a "toc toc" of the fetal heartbeat as with a scalp electrode, or offer a more complete, yet "noisier" experience of the uterine environment. Emphasizing some elements artificially can clarify information, but sacrifices "realism" (i.e., what we are used to perceiving) and emotional connection (see Figure 5).

3.5 Listening is not part of education, but could be

Most participants – both L&D nurses and midwives – learned how to listen through experience after they have completed their education. They learn on the job to think intuitively about the sounds; it is not taught in school. One midwife stated this type of training "is not so easy to train the people because you have to do a lot of the work beside the patient's beds." Another stated, "we didn't have any training on how to listen to the Doppler sound… I wish we had that because sometimes you just hear and you need to know what to do when you're just hearing and not looking." Interviews with L&D nurses revealed that those who trained in an earlier era tend to rely more on what they hear; current training does not seem to emphasize learning how to listen.

Better Doppler listening skills will improve how care teams work together, communicate with each other, and the outcome of patients. For experienced and highly trained users, sound can possibly reveal a lot more nuanced information about the wellbeing of the fetus, which could have been missed by visual traces. One OBGYN, who was engaged in an expert discussion prior to interviews, believes that there should be training that immerses users in the sounds for embodied learning and before providers are already working.

4. FINAL THOUGHTS

The sound of devices is often understood purely in physical terms, e.g., is it loud enough? Yet listening to device sounds must be understood in social terms. Midwives play a different role in the childbirth process than L&D nurses – especially across countries – and so they listen for different things. Moreover, listening does not only serve a clinical function when it is done together with mothers and families, it also serves to establish a relationship with the baby soon to be born.

As such, it is surprising that there is a lack of research concerning how users of the fetal monitor listen to the sonification of Doppler ultrasound to perform their work, even though many of those we engaged (including most midwives) thought that sound was more important than visuals when using the fetal monitor. It is similarly surprising that how to listen to the Doppler sound is not part of the formal education of L&D nurses, midwives, or OBGYNs. Growing this understanding, and incorporating it into clinical education and fetal monitor sound design, could lead to improved outcomes for mother and baby.

5. LIMITATIONS

Sound files in the online survey were played via each participant's device, so reproduction quality could not be controlled. As such, these sound files were chosen as examples of different directions for modification on the actual monitor. Results were interpreted as relative preferences among approaches to modification and not as participants' assessment of sounds to be played from the monitor itself.

Concerning listening conditions in interviews, testing was not conducted with the level of background noise that users can experience in actual use cases, or any background noise at all. Nor did testing reflect the competing demands for attention that users often experience. Finally, concerning hardware, device/speaker placement was not in the cabinet as is often the case; cabinets can alter perceived acoustics of the speaker, especially the low frequency.

6. ACKNOWLEDGMENTS

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8. FIGURES

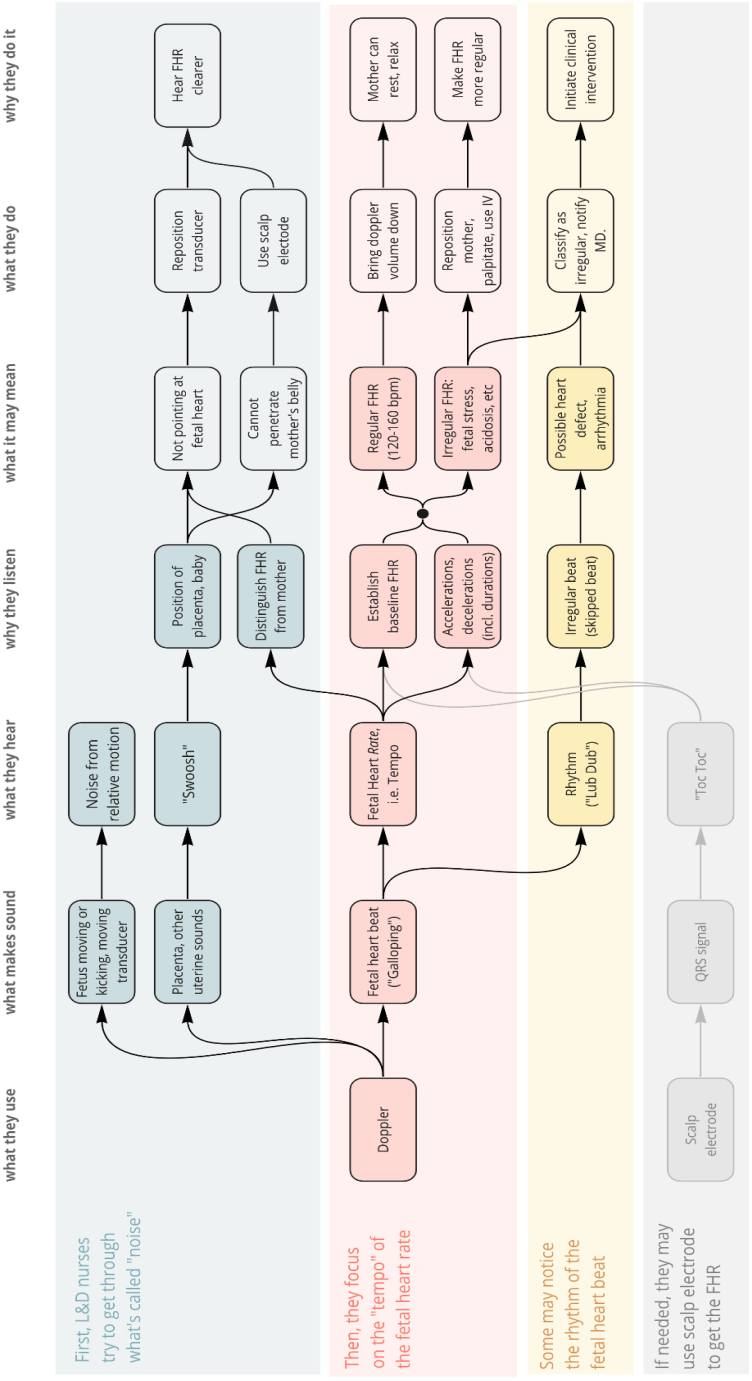

Figure 1: How L&D Nurses Listen to the Doppler Sound

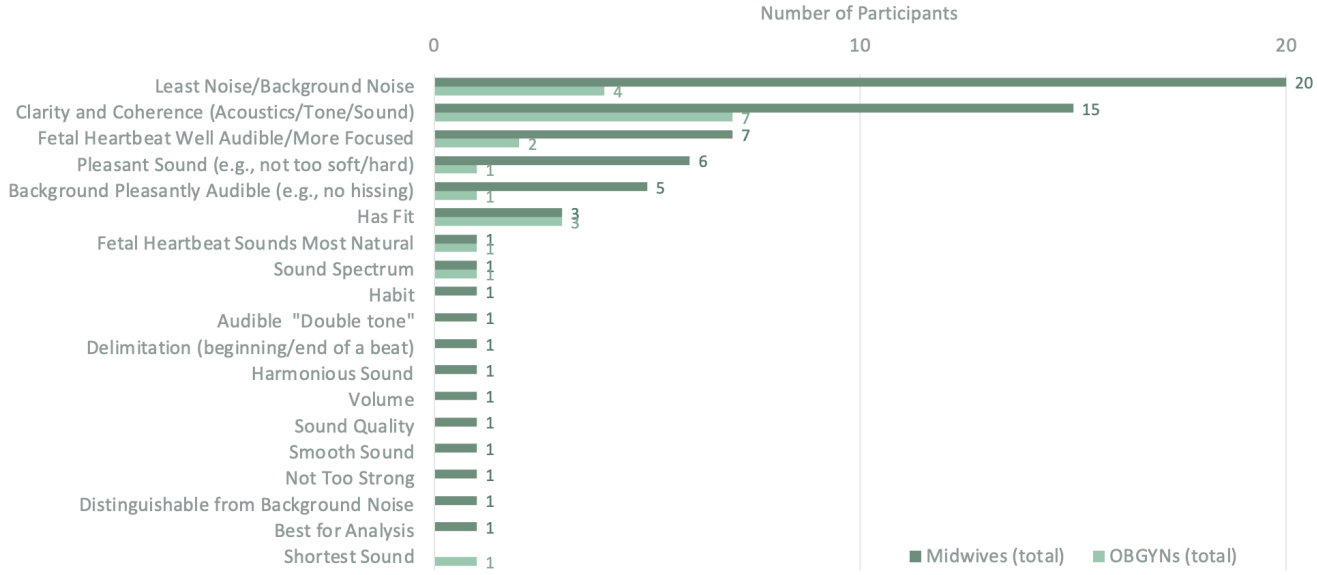

Figure 2: Survey responses to "Why did you choose that option? Can you tell us in terms of things you are listening for?" in Listen and Respond section 1.

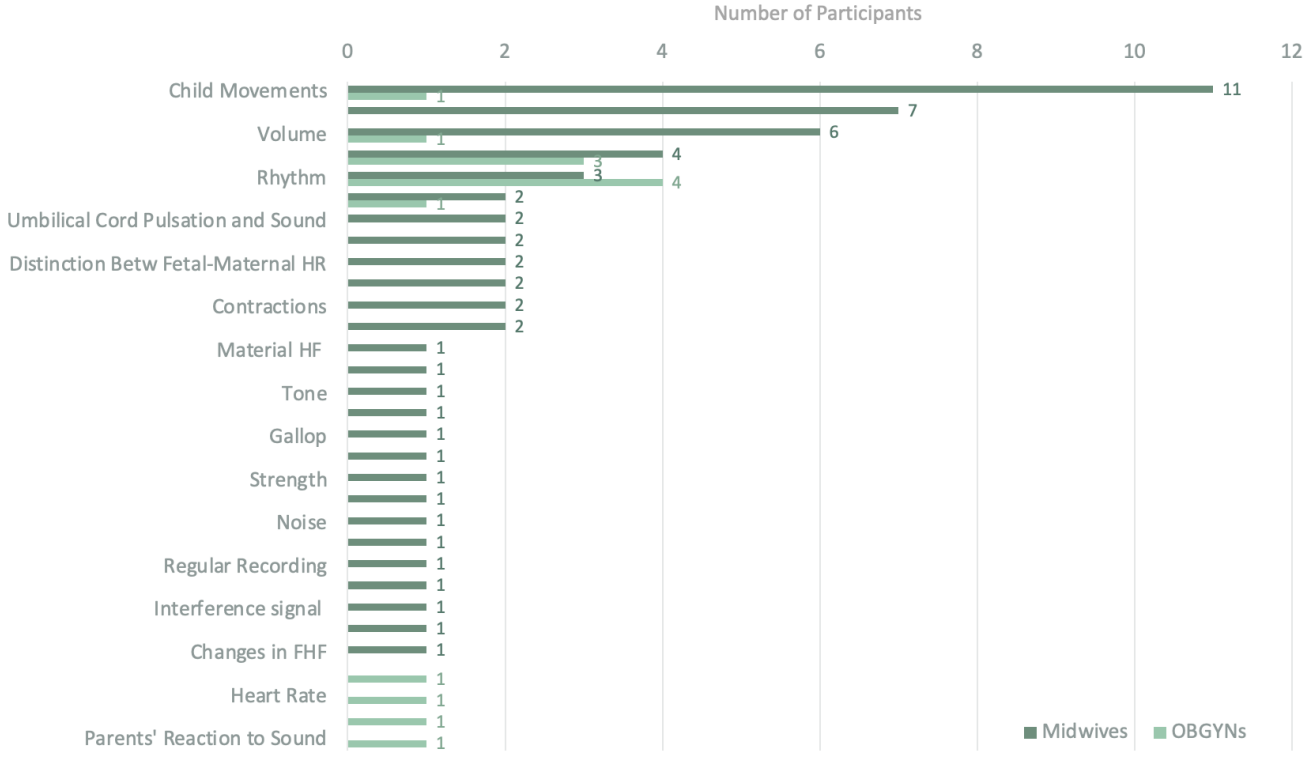

Figure 3: Survey responses to "When you are listening to the fetal Doppler sound, what do you listen for besides fetal heart rate?

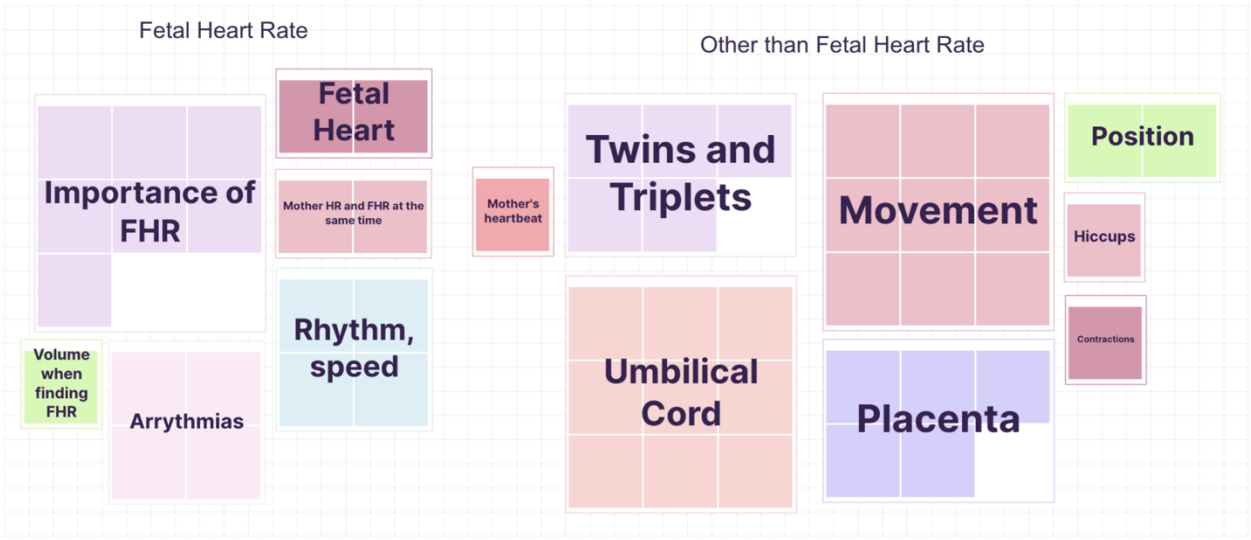

Figure 3: What midwives listen for, as clusters of excerpts from interview transcripts

Figure 4: How might we balance “clarity” vs “reality” in audio interventions?