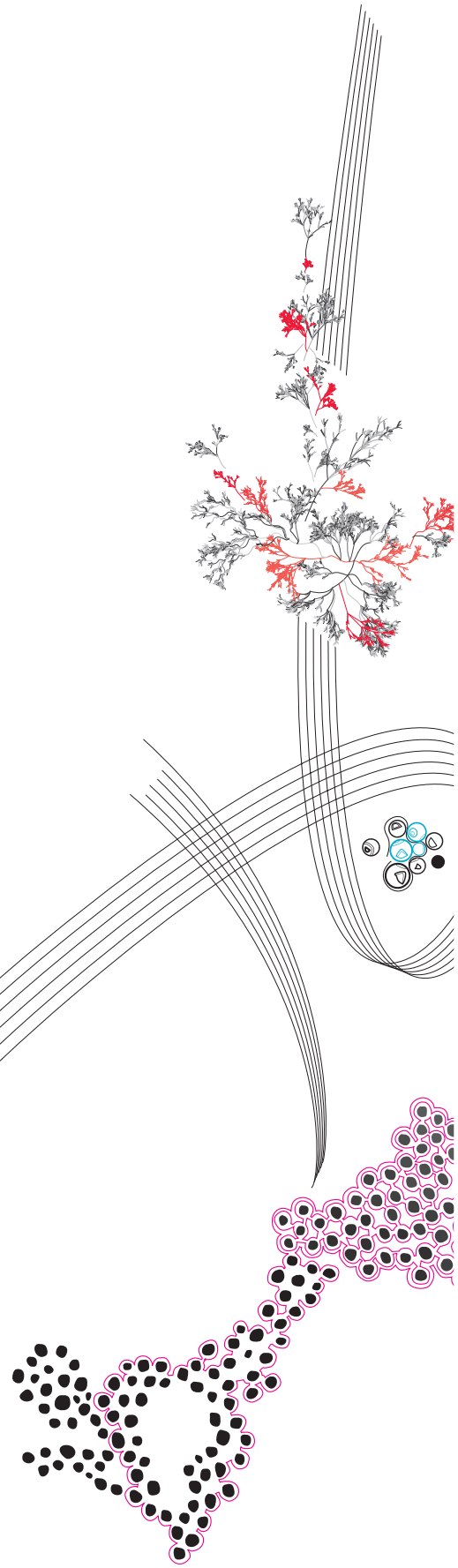

MSc Interaction Technology
Final Project

Music Interaction Technology as a Learning Support for Pre-Service Teachers to Listen Better

A case study on music education at the PABO

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Abstract

The quality of music education in primary schools is insufficient due, amongst other things, to a lack of musical background and skills of teachers, which should be acquired at the pedagogical academy for primary education (PABO). Currently, music education at the PABO is being improved by dedicating more hours to music classes, having better expertise in teachers, having more opportunities to practice, and implementing music technology. In this thesis, the latter is used to contribute to this improvement process. The aim of this thesis is to design a learning environment for pre-service teachers that supports them in improving their listening skills, such that they can eventually recognise rhythmic behaviour without additional support. Based on literature and experts' statements, a simulated learning environment, including a haptic feedback wearable, was designed. Both designs were tested simultaneously in a within-subject empirical study, where participants were tasked to identify an incorrectly playing student, with and without the support of haptic feedback, in a simulated class of students performing rhythmic exercises. Directly afterwards, the designs were evaluated in a semi-structured interview. The results showed that the learning environment as a whole would be a valuable tool for training purposes, as its versatility and controllability would allow an educator to manipulate learning situations for their students. The wearable with the haptic actuator on its own did not prove to be effective in better or quicker identification of the incorrect player. However, no statistical significance could be determined due to inaccuracies in measurement and a small sample size. Participants did experience more confidence with the support of the haptic feedback, and the feedback provided embodiment of the rhythm, which might have helped in recognising and understanding the reference to which the rhythmic behaviour of the class should be compared. However, optimisation of the haptic feedback and more testing is needed to study its actual effectiveness in a similar setting. This research was a first step into a new field of application for musical haptic feedback and has shown merit for further research in this area.

Acknowledgements

With this thesis, I conclude my master's study of Interaction Technology at the University of Twente. I would like to use this section of the report to thank several people in particular, who have lent their support during the process of this thesis research. First of all, I would like to thank my supervisors Dennis Reidsma and Benno Spieker for our biweekly meetings in which they shared their expertise and advice, and in which we brainstormed together about the various possibilities for the direction of my research. Our meetings were particularly valuable to me when at times I started to lose track of my research vision a bit, as I would always come back from the meetings with renewed inspiration and motivation to continue. In the final stages of my research, your feedback, along with that of my second examiner Nicola Strisciuglio, helped me dot the i's and cross the t's so I could finalise a report that I can be proud of.

Second, I would like to thank all people who participated in my research, whether it was as an interviewee in my pre-study or a participant in the experiment of my final project. I appreciate the time and effort you took out of your day to help me with my research. In particular, I would like to thank the two music education experts that I consulted throughout different stages of my research, who will remain nameless to assure their anonymous participation. I am grateful for the many detailed insights you have provided me with and the fact that you were always there, willing to help out.

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Chapter 1

Introduction

This chapter contains a revised section of an earlier and separately submitted pre-study report. In this chapter, some of the previous findings are summarised and the section is revised with a new research question and study outline.

Music is encountered in all aspects of everyday life, whether it is singing and dancing in your room, listening to ambient music during dinner or running to the beat of the radio at the gym. Involvement with music often starts at a young age, either within the home environment or at school. Especially the latter shows to be valuable. Multiple studies have proven that music education from an early age has both instrumental and intrinsic benefits, and the two are heavily intertwined [2][3][4]. The complexity and challenging nature of playing an instrument stimulates motor development and the creation of cross-over connections in the brain, generally resulting in a higher IQ [5]. Especially through focused hearing exercises, sound and meaning are linked and children become better at filtering out noise and focusing on valuable information. This results in a positive effect on the understanding of language [3][4][5][6][7]. In addition, according to author and teacher in music didactics Vrolijk, playing music together greatly stimulates personal development, as children learn to become aware of each other's behaviour and, as a result, train their own inhibition and adjust to the situation around them [4]. It also stimulates practice in verbal and non-verbal communication and research has shown that early musical training in children results in better emotional recognition [4]. Vrolijk also explains that other positive effects of music education are the forming of a musical identity, which can help in choosing social groups, and better awareness of other cultures through exploring music from those cultures [4]. Lastly, having music lessons in school gives all children the opportunity to become familiar with playing instruments and gaining the accompanying benefits, even if their societal background restricts their ability to play an instrument outside of school [3][4].

1.1 Music in primary school

Music education in primary school is centered around singing, listening, performing, moving, reading and notating, and composing and improvising [3][4]. This is practised using instruments from the Orff-instrumentarium, boom whackers, guitars, ukuleles, keyboards, everyday materials such as plastic bottles, pens and key chains, and with body percussion such as clapping, stomping and beating on the chest. In addition, nowadays often digital tools are used as well, such as composing app Garageband[1] or video platform Youtube [8].

[1] Garageband: https://www.apple.com/nl/mac/garageband/

Figure 1.1: *Orff-instrumentarium[1]*

Yet, having the appropriate instruments do not guarantee good classes. To achieve high-quality music education, highly skilled and competent teachers are needed, both on a teaching level and a musical level [2]. In their manual on primary school music education, Van der Lei et al. [3] argue that 'To be able to lead a group of children playing musical instruments, it is necessary that one way or another, you have gained experience in playing instruments yourself. In addition, a set of good ears (What is going right? What is not?), feeling for quality and the ability to stimulate children are also important.' A similar belief was reflected in the pre-study to this thesis, where primary school teachers and specialised music teachers agreed that playing an instrument yourself plays an important role in being able to produce quality music classes. It is believed that it gives the teacher a feeling for, and knowledge about music that is key in designing and guiding music lessons, especially if their instrument can be used as an accompaniment for the class [8]. Besides, it takes skills, experience and affinity with an instrument to be able to hear specific playing behaviour of others, let alone give feedback on the matter [8].

In addition, teachers have to master the subject well enough to be able to think on their feet and improvise, as throughout a class, lessons often need to be adjusted on the spot to the children's needs and interests, which is hard to do with little experience [8].

1.2 Pre-study

Up until 2018, teachers' own music education fell short in providing them with these skills. The pre-study of this thesis pointed out that for students at the pedagogical academy for primary education (PABO), relatively few music classes were taught compared to other subjects, and in those few classes, they were taught to sing a list of children songs and experiment with some of the instruments used in primary school. However, this experimentation never lead to mastering an instrument or being familiar with it enough to cover it in class themselves. Besides, no didactic aspects were taught or practised [8]. As a result, PABO students were on their own in teaching music, and the ones without a prior musical background were lacking the skills and knowledge to properly teach music in practice.

In addition to this, pre-service teachers are often aware of their lack of competence in music and, as a result, have little confidence in their ability to give classes on the subject matter. Studies have found that around the world pre-service teachers and current teachers self-report that they lack both musical skills and subject knowledge [8][9][10][11][12][13][14][15]. As a result, teachers opt for other creative classes such as arts and crafts, and music classes become an afterthought [8].

1.2.1 Improvement programs

The overarching issue of a lack of quality music education was recognized by the foundation Méér Muziek in de Klas, which has been working on a new policy for the PABO since 2019, with the aim of improving pre-service teachers' music education. Measures that are being put into place are an increase in the number of hours dedicated to music education, better expertise of PABO teachers and internship supervisors, more opportunities for internships and practice, close collaboration with conservatories and broader implementation of music technology [16].

Although these measurements should result in higher quality music education, first at the PABO and ultimately in primary schools, large-scale structural changes like these often take time to develop.

1.2.2 Thesis contribution

This thesis will contribute to this trajectory by exploring how teachers can be supported in learning how to listen better and recognise rhythmic behaviour in a class setting in the early stages of music education, as the lack of that skill was identified as a key aspect causing insecurity for current teachers.

1.3 Research Questions

The aim of this thesis is to design a learning environment for pre-service teachers to improve their listening skills, such that they can eventually recognise rhythmic behaviour on their own.
Previous literature research has found haptic feedback to be a potentially suitable aid for supporting such a learning process. Therefore, this study will consider a learning environment in which haptic feedback technology will be deployed.
The main research question for this study is:

'How can a learning environment involving haptic feedback be used to enable the learning process of rhythm recognition for pre-service teachers in a classroom setting, such that they will eventually listen better without this technology as well?'

To answer this question better, this study will distinguish two sub-questions:

1. How should a learning environment be designed in order to help with improving pre-service teachers' listening skills?
2. How can haptic feedback contribute to recognising rhythmic behaviour of students in a class setting?

1.4 Outline

To answer these research questions, additional literature research and testing will be done. In Chapter 2 of this report, background literature and the context of this research are explained, to understand this thesis better. Chapter 3 discusses examples of related work, to spark inspiration for design choices and to find the research gap that this research intends to fill. Afterwards, the aims and objectives of this research are refined in Chapter 4. In Chapters 5 and 6 the design of respectively the learning environment and the empirical test are described, and the results of the test are analysed in Chapter 7. Next, a critical reflection on this research is executed and avenues of continuation for future work are discussed in Chapter 8, and finally, this thesis ends with a conclusion in Chapter 9.

Chapter 2

Background

This chapter covers background information regarding the setting to which this research is tailored, and the characteristics of haptic feedback and its purpose. This information is partially gathered from the pre-study of this research and partially from literature.

2.1 Research setting

Considering this thesis aims to contribute to improving the quality of music education at the PABO, naturally, this research takes place in the setting of the PABO. More specifically, in a PABO music class where the students learn how to teach music to a group of students. Below, a sketch of the setting is presented that is based on prior work of J. Kruijshaar [17] and a statement by an expert on the topic: former PABO educator B. Spieker. The parties involved in the scenario (Figure 2.1) are the teacher (purple hat), the educator (green hat) and the class.

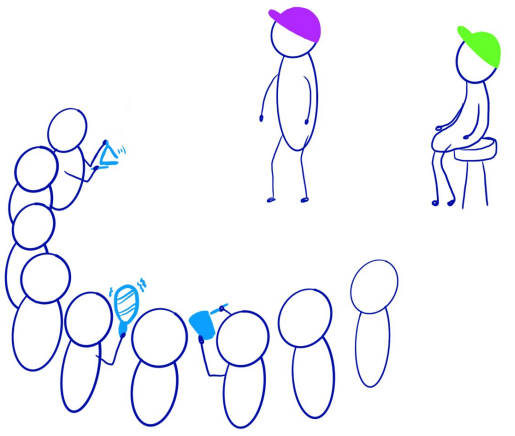


Figure 2.1: *Scenario sketch of the setting at a PABO music class*

2.1.1 The teacher

The teacher is a student from the PABO class who is practising how to teach music to a class. The teacher's objective is to initiate musical activities, guide the class through exercises, monitor the playing behaviour of the class, decide whether adjustments to the exercise should be made and decide on which feedback to give to whom, when and how. Feedback can be given either to an individual student or to the whole group. The teacher learns how to perform these different tasks from the educator.

2.1.2 The educator

The educator is a PABO teacher who, in activities such as this practice session, primarily monitors the teacher and gives feedback to them to improve their competence and confidence in teaching, but who also monitors the class and gives instructions to initiate and organize class activities. The educator's feedback is based on the behaviour of the teacher as well as that of the class.

2.1.3 The class

The class in the scenario consists of the other students of the PABO class and they are the practice class for the teacher. The class plays musical instruments, often similar to those used in primary schools, and gets feedback from the teacher. In return, if they have any feedback on how the teacher is doing, they can communicate this to the teacher after an exercise. In addition, non-verbal feedback from the class can be picked up by the educator during activities, which the educator can then take into account in their own feedback to the teacher.

The aim of such a music class is for the teacher to learn how to guide students in making music together and to improve their own competence in both making music and teaching music. This is achieved through feedback specific to them. A pleasant side effect is that although the PABO students participating in the class do not get the hands-on experience of teaching a class, they do gain more experience with musical instruments and they pick up on the feedback given to the teacher. In addition, they can experience for themselves what type of feedback towards the class is most effective. Therefore, the class can also improve their competence in music making and teaching during the music classes.

2.1.4 Feedback loops

Considering PABO students often do not have any musical background themselves, it can be difficult to hear and recognize specific musical behaviour from the class and give the appropriate feedback. Besides, the workload of the teacher is rather high during class and they have to spread their attention thin: listen attentively to the musical performance, process and incorporate feedback given by the educator and the class, give feedback to the class, and when necessary, exercise didactic skills. In this process, there are multiple flows of information between the different parties involved. For clarity, each type of information flow is presented separately in the following sketches. Each of these types of information forms a feedback loop for the parties involved and such feedback can either occur before an assignment is given in the form of instruction (feed forward), during the assignment on the spot (concurrent feedback) or after the assignment is finished as a form of evaluation (terminal feedback).

Table 2.1: Feedback flows of (non)verbal information

	Pre exercise *(feed forward)*	**During exercise** *(concurrent feedback)*	**Post exercise** *(terminal feedback)*
Teacher	F1: explains exercise to class	F1: gives feedback to class	F1: gives feedback to class and explains improvement for next exercise
Educator	F2a: gives advice to teacher	F2a: gives feedback to teacher F2b: gives feedback to class	F2a: gives feedback to teacher F2b: gives feedback to class
Class	-	F3b: gives feedback to educator	F3a: gives feedback to teacher

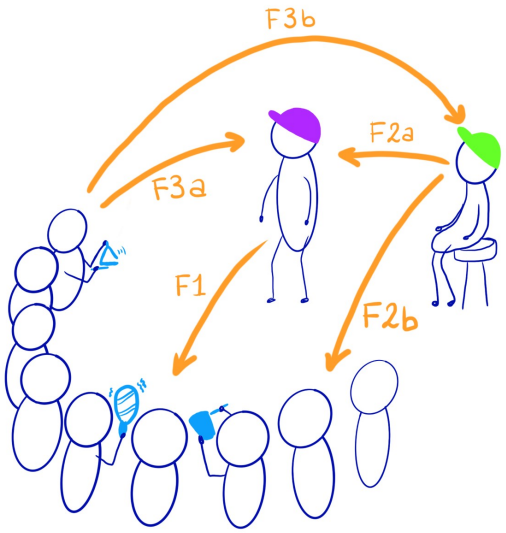


Figure 2.2: *Model of (non) verbal information flow*

The (non) verbal information flow is the primary feedback loop, which, on the one hand, consists of spoken feedback, and on the other hand of body language, facial expressions, and gestures such as beat timing and conducting. Through the different phases of the music class, different flows in the models are active. The flows per phase and party, and the information given are presented in Table 2.1. The use of verbal or nonverbal feedback may be more suitable in specific phases than in others. For example, verbal feedback could be a strong tool for discussing experiences in the post-exercise phase, whereas during the exercise, nonverbal communication could be more suitable due to its uninterruptive nature towards the music [8]. However, for simplification purposes, there is no distinction between these two types in Table 2.1.

Table 2.2: Feedback flows of auditory information

	Pre exercise *(feed forward)*	**During exercise** *(concurrent feedback)*	**Post exercise** *(terminal feedback)*
Teacher	F1: demonstrates assignment	F1: joins in to demonstrate or adjust the assignment (e.g. playing a new rhythm for others to mirror)	F1: supports their own (non)verbal feedback musically (e.g. mimics what went wrong and how it should have sounded)
Educator	-	-	F2: supports their own (non)verbal feedback musically
Class	-	F3: makes music	-

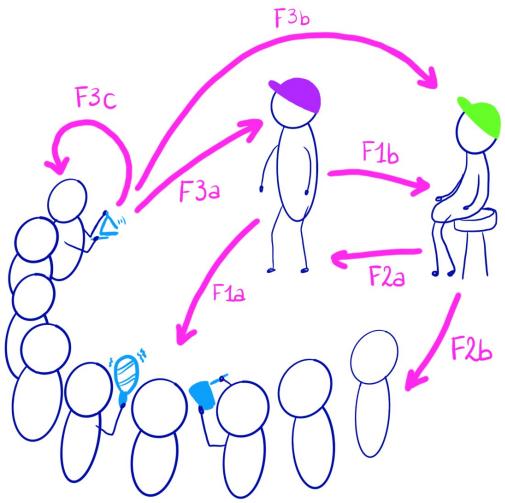


Figure 2.3: *Model of auditory information flow*

The auditory information flow is active when some or all of the three parties make music. It gives real-time information about the musical quality and behaviour. All three parties can hear this information and use it to base their feedback on and adjust their behaviour to. This requires active hearing from all participants. Table 2.2 illustrates the different flows within this model.

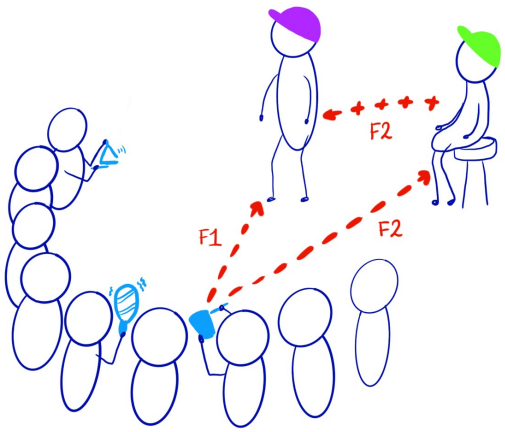


Figure 2.4: *Model of sensor information flow*

Table 2.3: Feedback flows of sensor information

	Pre exercise *(feed forward)*	**During exercise** *(concurrent feedback)*	**Post exercise** *(terminal feedback)*
Teacher	-	F1: reads data directly from the class F2: reads annotated data from the class via the educator	F1+2: uses data as a base for feedback to the class
Educator	-	F2: reads data directly from class, annotates it and sends annotated data to teacher	F2: uses data as a base for feedback to the teacher and class
Class	-	-	-

A third information flow that could take place, is that of sensor information. Such a flow could apply if sensor technology is used to measure the musical behaviour of the class, such as the moment of striking and the amount of force of each strike on all percussive instruments, and the pitch in case of pitched percussive instruments (e.g. glockenspiel, handbell, boom whacker, etc.). Although in this research no evidence was found that such technology is already being used in music classes, it is a relevant flow to keep in mind in this study, considering its involvement of technology. If sensor technology is applied, there are two options for information flow: either the measured data goes directly to the teacher (F1) or it goes only to the educator first, who can then send it through to the teacher with possible notes and marks added to the data (F2). The annotated data is depicted in Figure 2.4 as +++. Table 2.3 explains how this data could be used in the different phases.

Although the different types of information flow are presented separately, they do influence each other. For example, the feedback that the educator gives to the teacher in the (non)verbal information flow, may depend on what the educator receives from the sensor information and auditory information as well. In addition, the outcome of the post-exercise phase serves as input into the pre-exercise phase in case a new exercise is given that builds upon previous exercises. This is an iterative process until final termination by the teacher or educator. However, although this iterative scenario is practised in the teachers' education, at primary schools it is often skipped due to the limited time that is available for music classes [8]. In these cases, the first post-exercise phase is the final phase of the class. Finally, in these models, any form of feedback coming from or directed towards the class can be applied on both an individual level and/or a (sub)group level.

2.2 Feedback theory

Evidently, educational feedback plays a crucial role for pre-service teachers, and within this classroom setting, feedback technology could help focus attention purposefully and support the teacher's learning trajectory. In this research, the focus is put especially on gaining the awareness of and feeling for rhythm in a classroom setting with multiple audio sources at once. However, feedback can come in many different forms, each with its own properties, which should be chosen carefully to acquire the desired effect. Some of the key factors for effective feedback are timing, frequency, content and modality [18].

2.2.1 Timing

For timing, the main options are: before the activity takes place (feedforward), during the activity (concurrent) or after (terminal). Research has pointed out that for training, terminal feedback is most effective, as it gives a clear overview and does not influence the task whilst it is being carried out [18]. Concurrent feedback, on the other hand, can create a form of dependency as it gives immediate support during the task. Still, for the application of rhythm recognition, concurrent feedback seems the most suitable option as the task complexity is rather high and it would be difficult to remember all the notes and the behaviour of multiple students in order to reflect on it afterwards. Besides, concurrent feedback has been proven useful in the early stages of learning [18], which is the phase on which this study is focused.

2.2.2 Frequency

The most effective frequency of feedback is highly dependent on the skill level of the teacher. For relatively high-complexity tasks, which is often the case for novices, a high frequency of feedback works best. However, when the learning effect becomes larger and the tasks become relatively less complex, the frequency should be phased out accordingly [18]. This technique also decreases the dependency on the feedback over time.

2.2.3 Content

Generally speaking, the content of feedback can be split into two categories: 1) Knowledge of Results, where the feedback indicates whether the outcome is correct or incorrect, and 2) Knowledge of Performance, where the feedback indicates *what* is going right or wrong [18]. Considering the application at hand is focused on novice teachers who need help recognizing the right or wrong playing behaviour of students, the feedback that is needed falls under the former category. For more advanced teachers, knowledge of performance might also be useful, but that is outside the scope of this research.

2.3 Haptic feedback

A suitable modality for this application could be haptic feedback [8]. Haptic feedback can manipulate the sense of touch (tactile feedback) or the sense of bodily position (kinesthetic feedback) [18][19]. In this research, the term 'haptic feedback' refers to the former. Simply put, tactile feedback communicates via sensations through the skin, and the field covers a variety of different forms of feedback, such as force, thermal, electro-tactile, vibrotactile and ultrasound tactile; each with their own accompanying experiences and applications. This versatile type of feedback is often used to enhance experiences and make technology more life-like. It is also a popular method for directing someone's attention, as is intended in this research. Some well-known examples are vibrations in smartphones and smartwatches as alerts for incoming calls or other messages.

Haptic feedback is a fitting tool in the field of interaction technology and it is becoming more and more popular in research and interaction technology applications. However, it is not yet a modality that is widely explored in different applications.

2.3.1 Haptics & Audio

Nonetheless, the theoretical background gives reason to believe that haptic feedback and audio are a natural combination.

First, music naturally has a physicality to it. Not only do we feel bass tones in our chest, but we also use our feet to tap along to the beat and get chills when an orchestral music piece reaches a build-up. Besides, when playing an instrument, the haptic feedback that a performer gets from their interaction with the instrument, such as bowing a violin string, directly relates to the 'feel' with which the instrument is played [20]. It is no wonder that we often describe the characteristics of a sound using tactile-related terms, such as 'smooth, cutting, hard or soft' [20].

Secondly, experiments have shown that, under the right circumstances, audio and touch have similarities in the way that they are processed by our brain [20][21]. This bimodal integration of sound results in a larger sensitivity for these signals, thus creating an enhanced perception of sound [21][22].

On the other hand, a downside of using haptic feedback is that it might be difficult to intuitively convey the right message. In the pre-study of this thesis, it was found that many examples of similar feedback applications in a musical setting heavily relied on sight [8]. This choice can be explained by the fact that humans rely on sight, much more than on other senses [23][24]. Therefore, well-designed visual feedback would be a more obvious choice to convey information. However, the downside to a visual approach is the visual attention that it requires. Next to their hearing, teachers also use sight to observe the class' behaviour. Therefore, giving visual feedback could distract the teacher from having their own observations in class. In contrast, the pro of using haptic feedback is that haptics are known for their undisruptive nature, which is desired during a musical performance. It makes them a suitable option for feedback when other senses, such as sight and hearing, are already busy [25], as is the case in the current research setting.

Still, haptic devices call for a cautious design, as extreme choices can become distracting. For example, a loudly buzzing vibration motor can interfere with audio, despite its haptic purpose. Hence, smart design choices need to be made to make use of the undisruptive nature of a haptic feedback system.

All in all, these characteristics make haptic technology a valid and suitable modality for giving feedback in the music class scenario of this research, provided that the technical design choices are well-made.

Chapter 3

Related Work

In this chapter, existing related work in the field of haptic feedback and learning environments will be reviewed, in order to gain some insights into technical design choices and their applications. In this review, a distinction is made between related work in academic research and commercial products.

3.1 Academic research

In academic research, the application of haptic feedback in the musical domain is not yet widely studied. However, some examples can be found in fields with similar characteristics to this research. In this subsection, examples of the training of instrumental skills, and the enhancement of musical experiences are reviewed and discussed.

3.1.1 Training

Multiple researchers have studied how haptic feedback can support the training of musical skills, but interestingly, it is currently primarily applied for improving bodily movement associated with playing an instrument, rather than for listening skills. One example is a study by Van der Linden et al. [26] on improving the bowing posture of a violinist with the use of concurrent haptic feedback. The haptic system made use of motion capture to analyse the playing behaviour and in turn provided vibrotactile feedback. Although this study focuses specifically on body movement and therefore gives little foreshadowing of the effect of vibrotactile feedback on rhythm recognition, it does also consider a more general view of the effect of real-time vibrotactile feedback on training, which might be relevant to the present study as well: '... it must be relevant to learning goals and should be used in conjunction with tasks which are the right level of difficulty. If these criteria are not met then the learner may feel overloaded and unable to attend to the feedback' [26].

Another form of training musical skills with haptic feedback that is found to be effective is passive learning. Multiple studies have reported the positive effect of getting haptic feedback regarding one task, whilst being busy doing another [25][27]. Especially for more complex rhythms, passive learning proved to be an effective method for learning the body movements needed to drum or otherwise tap the pattern at a later stage. Although these studies again focused on physical skills, the results of Bouwer et al. [27] also indicated a better *understanding* of the rhythms taught through passive learning. Seim's research [25] had similar findings, but it is difficult to conclude whether these outcomes truly indicate an understanding of the rhythm itself or rather the meaning behind the rhythm, as the exercises that indicated this outcome were language based (i.e. practising the "rhythm" of morse code). Nonetheless, the outcome of these two studies [25][27] indicate that 1) haptic feedback has the characteristic of effectively conveying feedback unobtrusively to other tasks at hand, and 2) it shows merit in the area of rhythm recognition and understanding.

A more similar study to the present one is that of the 'T-RHYTHM' system by Miura and Sugimoto [28], in which individual performers are supported by a vibrotactile rhythm, both in a solo setting and in an ensemble. The tactile rhythm is meant as a reference to keep to their own rhythm when other performers may play a different part. The concept of using a vibrotactile reference rhythm as support in an otherwise chaotic group setting is similar to the present research. However, this application is

designed specifically for a person playing the instrument themselves and not the one overlooking the whole, which may have different priorities and experiences. Besides, although it claims to have had a positive influence on the learning of, and understanding of rhythm, it could be argued that because the person receiving the feedback is also the one playing the instrument, the feedback again also has a direct effect on the correct physical movement, rather than on the auditory skills. Still, this research shows promising results for rhythmic support through haptic feedback.

Furthermore, a noteworthy finding in this research was that after continuous use of the haptic feedback, participants were unable to distinguish the vibrations from the haptic device as it had a numbing effect on the nerves. Although no specific duration of use was mentioned after which this occurred, this effect should be considered in the current study as well and can be limited by implementing regular breaks.

3.1.2 Experience enhancement

Aside from training purposes, haptic feedback is also often applied to enhance musical experiences. A well-known example of the effect it can have is the difference in musical experience between listening to a song on a cheap stereo or hearing it blast through concert speakers and feeling the bass tones vibrate in your chest.

Such experience enhancement through haptic feedback is mostly studied with the aim of creating a musical experience for deaf people, similar to that of hearing people. For example, Nanayakkara et al. [29] designed a vibrating chair for deaf people that directly translated incoming MIDI scores from a musical performance to full-body vibrations in the chair and found an overwhelmingly positive outcome. A takeaway from their study is their recommendation of using natural unprocessed signals to create a realistic experience, resembling vibrations felt directly from the instrument.

Similar haptic musical systems can also be of value to healthy people. Research by Giroux et al. [30] showed a positive effect on both psychological and physiological valence and arousal in healthy participants in a similar vibrotactile chair as that of Nanayakkara et al. [29]. The enhancing effect of a multi-modal sensation, such as in these examples, relates back to the similarities of processing between audio and touch, as is explained in the previous chapter.

3.2 Commercial products

Figure 3.1: *Soundbrenner Core wearable (source: https://www.soundbrenner.com/pulse/)*

In the commercial field, two devices that particularly stand out in their relevance to this research are the Soundbrenner Core[1] and Pulse[2]. Both wearables provide support to musicians in the form of a

[1] https://www.soundbrenner.com/core/
[2] https://www.soundbrenner.com/pulse/

vibrating metronome. Their value lies in the adjustability of the beat and the ability to synchronise multiple devices with each other.

However, they are heavily designed towards expert musicians and, similar to most related work, are designed to provide feedback whilst the user is playing an instrument. Hence, although these devices have similar characteristics to the system description of this research, the targeted application is different from the one that is studied in this thesis. Besides, these wearables communicate a beat, whereas this study is focused on specifically rhythm recognition and understanding. Still, these devices emphasise the value of haptic technology for musical feedback.

3.3 Conclusion

The experimental findings discussed in this chapter show merit for embodiment of music through haptic feedback and a stronger identification and understanding of music that matches the feedback. These findings substantiate the choice of haptic feedback for the current application, where the feedback should support the recognition of the right rhythm.

However, all related work that was found focused their haptic feedback either on the performer or the audience. There was no similar scenario to that of the pre-service teacher, who has to learn through the feedback, unlike an audience member, but is not an active performer themselves, unlike musicians. Besides, all examples of training applications so far influenced the physicality of performing. No related work was found in which the haptic feedback actively and correctly supported better listening and understanding of rhythm. Hence, these missing characteristics which are crucial for the current scope will be tested in this thesis.

Chapter 4

Aims & Objectives

This chapter covers a recap and a small revision of the aims and objectives of this thesis, as a foundation for the following design phases.

As mentioned in the introduction, the aim of this research is to design a learning environment for pre-service teachers to improve their listening skills, such that they can eventually recognise rhythmic behaviour on their own.

Considering this aim, the objectives of this thesis are twofold: the first objective is to illustrate a prototype and task description of the concept of such a learning environment. The second is to provide empirical insights into the added value of haptic feedback in the accompanying learning process. The execution of these objectives will help answer the two sub-questions of this thesis:

1. How should a learning environment be designed in order to help with improving pre-service teachers' listening skills?

2. How can haptic feedback contribute to recognising rhythmic behaviour of students in a class setting?

Both questions can be answered simultaneously by designing the learning environment in such a way that it can be used for the empirical testing as well. The design choices made towards this end are described in the following sections of this report.

Chapter 5

Design & Realisation of Simulated Classroom

In this chapter, the design and realisation of a simulated classroom are described, contributing to answering the first sub-research question 'How should a learning environment be designed in order to help with learning how to listen better?' The aim of the design of the classroom was to make it resemble a real-life setting of a music class, with several students playing together. The design was therefore largely based on descriptions by experts in the field of music education, gathered in the pre-study of this report [8]. The full design consists of video, audio and haptic feedback.

5.1 Design

For the recordings of video and audio of the class, musical experts were filmed individually in front of a green screen playing rhythmic exercises on a Roland SPD SX drum pad[1]. Three separate rhythms were recorded, and for each rhythm, several recordings were made of correct and incorrect playing behaviour. The rhythms were composed by one of the experts, with the instruction of making them resemble exercises that they would also practice in primary school. The musical scores of these rhythms can be found in Appendix A. Later, the video footage was edited to recreate a spatial classroom setting with each of the performers representing a student, and all students playing together in a half-circle setup (see Figure 5.1).

In each scenario, the group composition consisted of seven students playing correctly, and one playing incorrectly. However, the order in which the students were presented in the class differed per scenario. In order to reenact incorrect playing behaviour, the performers were instructed to play either too fast, too slow or overall not the right rhythm. For each scenario, the selection of the incorrect play that was eventually included in the scenario was based on an estimation by the researcher of it being sufficiently different from the seven correctly playing students without being blatantly obvious. This estimation was made during the editing phase, when the class as a whole could be heard.

The audio was recorded in the DAW Reaper[2] in the form of a MIDI signal, containing a representation of the timing of each strike on the drum pad. After recording, an audio effect was added to the MIDI signals to create a sound similar to that of a wood block, which is part of the Orff-instrumentarium. This sound was created using the VSTi plugin 'Clog Boxes'[3]. These audio files were then manually synchronised with the video footage of each corresponding video recording.

[1] https://www.roland.com/nl/products/spd-sx/
[2] https://www.reaper.fm/
[3] http://www.alanvista.com/clog-boxes/

Figure 5.1: *Virtual classroom video screenshot*

The choice was made to keep the haptic feedback simple, both in the information that it contained and in the manner in which it was presented to participants. This decision was made to ensure that the feedback was understandable for musical novices, but also to eliminate unwanted variables for the tests. Besides, as this research is an initial exploration into the merit of haptic feedback as support in this application, there was no need for optimisation. Instead, a modality was chosen which was expected to work well enough to gain initial insights into its general effects. Therefore, a vibration motor was chosen, as it is a cheap and accessible actuator that is easy to use and allows for quick testing. The motor was controlled by an Arduino board and vibrations were kept consistent, closely mimicking the correct rhythm for each scenario as a direct reference to good playing behaviour.

The prototype for the haptic wearable consisted of an elastic band, joined together with velcro. In a pocket attached to the elastic band, a coin vibration DC motor (2.5-4V) was placed, which was connected to the Arduino using long wires, to ensure space to move for the person wearing the wearable. The velcro band was placed on the wrist of participants, which allowed easy access to put the wearable on and take it off. The elasticity of the wearable ensured a snug fit on a variety of wrist sizes, which was of importance to feel the vibrations well.

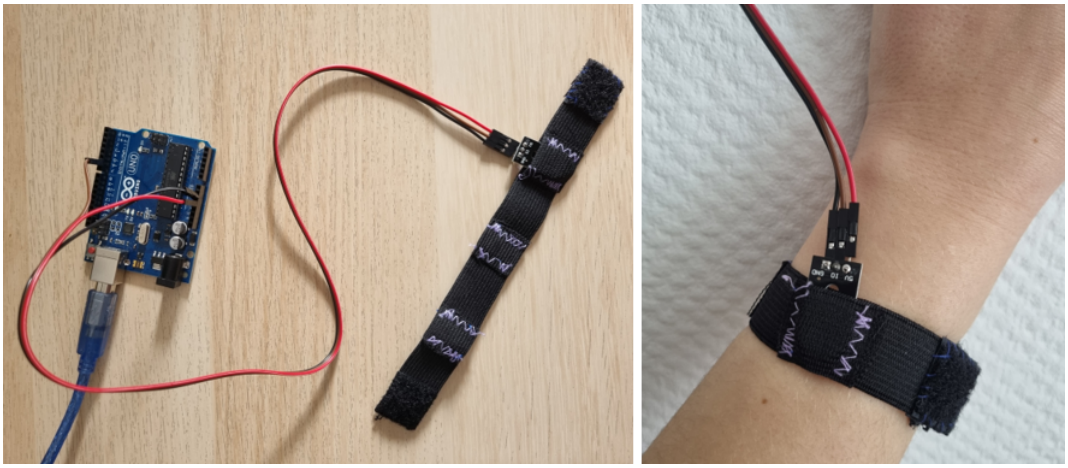


Figure 5.2: *Haptic wearable*

The vibrations in the wearable were synchronised with the video and audio recordings with the use of manually selected timestamps gathered from the MIDI signals. These timestamps were manually imported in the Arduino code, such that the signals activating the vibrations were sent out exactly on those timestamps. Each vibration had a duration of 100 ms. Although this hard coding approach was not an elegant solution for future flexibility of the system, it did suffice for the test at hand. The code can be found in Appendix B.

A crucial element of the learning environment was timing. To distinguish (in)correct playing behaviour, the audio, video and feedback must be synchronised perfectly, as they would be in real life as well. However, the difficulty lay in the fact that video, audio and feedback were presented in individual programs, which all needed to be activated individually but simultaneously. This challenge was solved by programming a timed 'click' of a keyboard, such that it pressed 'play' in each of the programs at the right moment and consistently each time the system ran.

5.2 Setup

For the setup of the environment, eight stage monitor speakers were used, each with the sound of an individual student. They were set up in a half-circle, creating a spacious sound environment in which the direction of each student could be heard, similar to a real class. The speakers were controlled by a Focusrite Scarlett 18i20[4] audio interface, which was connected to the Reaper software on a laptop.

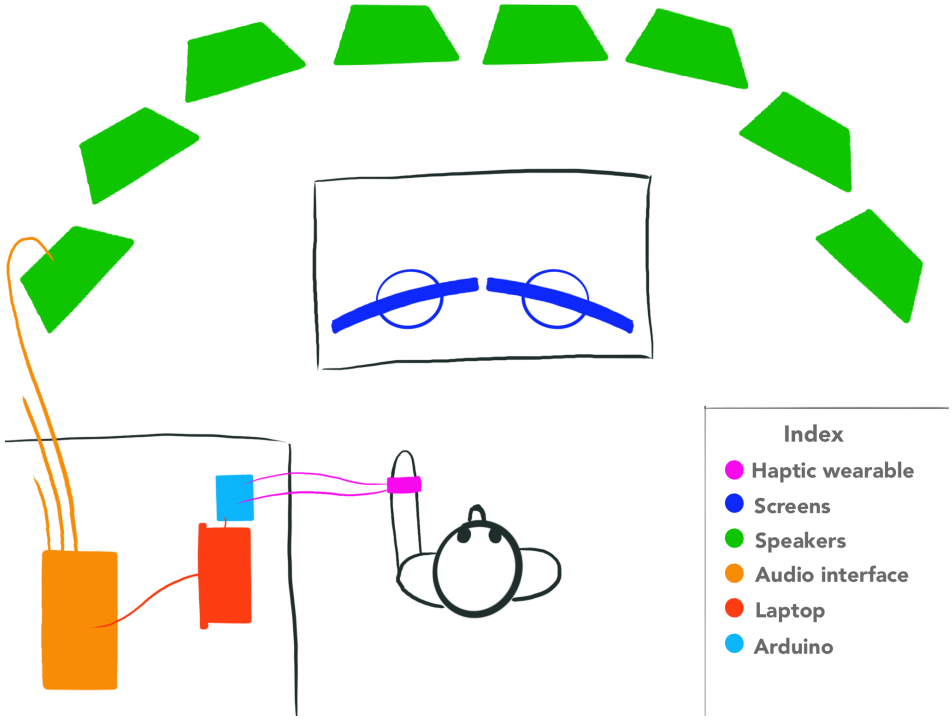


Figure 5.3: *Sketch of the experiment setup*

Figure 5.4: *Experiment setup: 1) two-screen video setup, 2) half-circle audio setup, 3) haptic wearable station*

[4]https://focusrite.com/en/usb-audio-interface/scarlett/scarlett-18i20

For the video setup, ideally, a similar setup would have been done as that of the audio, with a separate screen for each student, creating individual students with audio and video combined. However, the technicalities of such a setup were unachievable within this study. Instead, two computer screens with four students each were set up at an angle, to mimic the half-circle setup of the sound, and they were placed in front of the speakers. Participants stood in front of this half-circle setup, similar to how a teacher would stand in front of a class. The wearable was worn on the left wrist and the Arduino was set up on the side of the participant, just like the laptop and the audio interface. The full setup can be seen in Figure 5.4 and a sketch of the setup can be seen in Figure 5.3 for clarification.

5.3 Controlled environment

An important aspect of the simulated learning environment as the one described in this chapter is that it can be controlled. Because it was a simulated classroom, the learning situation and the accompanying feedback to the user could be 'perfect'. In a live setting, it could be influenced by the behaviour of the class and could have more unforeseen and unwanted scenarios. The simulation created a constant, controllable and reproducible environment, which was ideal for testing.

Chapter 6

Method of Empirical Study

In this chapter, the method of the empirical study is described, which was executed with the aim of answering the second sub-research question 'How can haptic feedback contribute to recognising rhythmic behaviour in a class setting?'

A within-subject empirical study was carried out in the learning environment that was described in the previous chapter. Participants were recruited through a personal network, with the requirement that they had no significant prior experience in playing a musical instrument, singing or dancing, to limit any prior rhythmical skills. To reduce personal interpretation of what experience would count as significant, the selection criterion for all participants was that the participant had had no classes in any instrument, singing or dancing other than mandatory classes in school. The latter was not excluded, because first, it would be difficult to find participants without music experience from mandatory classes in school, and secondly, considering these classes are mandatory, it would be expected that PABO students would have a similar background. In addition to these inexperienced participants, two experts were recruited, also through a personal network, for their insight into the value of the simulation and the feedback as a learning environment.

6.1 Tasks

During the test, participants were asked to envision the role of a music teacher and stand in front of the simulated class individually. They were then each presented with the footage of the three different rhythmic exercises, each once with and once without haptic feedback, resulting in six scenarios in total. Each scenario had a duration of approximately 30 seconds. For each scenario, participants were asked to pay attention to the playing behaviour of the class and identify the student playing incorrectly. They were instructed to indicate which student did not match as soon as they were sure, but it was emphasised that it was not a race. In case of doubt, they could also indicate which students they were not sure about and why. The indication was done verbally, and participants were encouraged to share any thought processes they had, but only after each scenario as to not interrupt the identification process.

Figure 6.1: *View of the participant*

6.2 Interview

Once all scenarios were done, participants were asked to answer a few open questions in a semi-structured interview regarding their experience with the feedback system. The predefined questions were used as conversation starters, and follow-up questions were formed on the spot, based on the participant's answers. The predefined questions were as follows:

1. Did you already have any previous experience with haptic feedback? If yes, what?
2. Can you explain what your experience was like with this haptic wearable?
3. For these scenarios, you could simultaneously use either sight and hearing, or sight, hearing and touch, depending on whether or not you had support from the haptic feedback. Can you explain what you based your decisions on of which student was playing incorrectly?
4. Did the haptic feedback influence *how* you listened and watched? If so, please explain how.
5. Would you recommend this form of feedback as a support for people with little musical experience? Please explain why/why not.
6. What would you change or add to this current feedback system to improve it?

In practice, the first question was asked before the experiment in order to adjust the explanation of the haptic wearable if needed. For example, a participant without prior experience with haptic feedback might have more questions or be more nervous about using the wearable than a participant with prior experience.

For the experts only, an additional question of 'Would you recommend this testing environment as a training setup for people to practice with teaching music classes?' was asked to evoke a discussion about the possibilities of the environment as a whole. This question was limited to the experts, as only they would have experience in training to teach music classes and thus would have possibly valuable insights on this topic.

6.3 Protocol

Before participation, the general premise of this research and the tasks of the experiment were explained to the participants. They were given the opportunity to ask questions if anything was unclear, after

which they were asked to sign an informed consent form. Both the information brochure and the consent form can be found in Appendix C.

Once consent was given, the participant was instructed to stand in front of the simulated class and was introduced to the simulation and the feeling of the feedback through a practice scenario. This was done to gain familiarity with the possibly odd feeling of haptic feedback so that it would not be a distraction during the test itself.

After the practice scenario, the six test scenarios were presented. To avoid any learning effect, the order in which the scenarios were presented, differed per participant. In addition, for every participant, the scenarios with and without haptic feedback were alternated, but the starting state differed per participant. For example, one would start with rhythm three with haptic feedback and another would start with rhythm one without it. The alternation between scenarios with and without feedback created small breaks of the haptic wearable, which reduced the chance of a numbing effect, as was found to be a risk in the 'T-RHYTHM' project [28]. During the scenarios without haptic feedback, the wearable was taken off completely to avoid unnecessary distraction and to create a natural control state.

During the identification assignment, participants were observed, and timed with a stopwatch. In addition, their answers and any other relevant comments about the experiment were noted. During the experiment, no feedback was given about the correctness of their answers, so their approach to the assignments would not be influenced. After the final scenario, the interviews were done in a comfortable face-to-face seating arrangement and the participant's responses were noted and summarised. During the interviews, any comments that were emphasised or otherwise stood out to the researcher were annotated. After the interview, interested participants were told in how many scenarios their identification was correct, and all participants were thanked for their participation.

This empirical study was approved by the ethics committee of the faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente.

Chapter 7

Results & Interpretation

In this chapter, the results of the empirical study are presented and analysed.

7.1 Participants

For the evaluation, the group of participants consisted of eleven people, of which ten were university students and one was a university of applied sciences student. For most participants, their (study) background varied from others. The age range of these participants was between 22 and 28 years old. The two experts that were consulted and participated in the empirical study as well, were two music teachers (in training). These experts were also consulted for their expertise in initial interviews in the pre-study of this thesis. The experts are included in the analysis of the data along with the other participants as the relatively small sample size does not allow for the exclusion of outliers.

7.2 Quantitative data

The first quantitative variable that was recorded, was whether participants could identify the virtual student who was playing incorrectly. In Table 7.1, the percentage of right, wrong and missing answers are depicted, per rhythm and separately with and without haptic feedback. The results between with and without feedback are overall quite similar, although for rhythm 2 the performance with haptic feedback is much worse than without, and for rhythm 3, it is exactly the other way around.

It is, however, noteworthy that over all three rhythms, the percentage of wrong identification is lower when participants were supported by haptic feedback. In these cases, they did not answer correctly either, but instead withheld from answering. This lack of identification suggests some uncertainty and could indicate a distracting or confusing nature of the haptic feedback. However, a lack of identification is arguably a preferred outcome over identifying the wrong person. Especially when put in context: addressing a student who is playing correctly as if they are not, may be a worse outcome than not giving feedback at all. Naturally, an even more preferred outcome would be that the haptic feedback showed a better percentage of correct identification than without, but that cannot be seen from this sample.

Table 7.1: Identification of the student playing incorrectly

	With haptic feedback			**Without haptic feedback**		
	Right	*Wrong*	*No answer*	*Right*	*Wrong*	*No answer*
Rhythm 1	92%	0%	8%	92%	8%	0%
Rhythm 2	77%	0%	23%	92%	8%	0%
Rhythm 3	92%	8%	0%	77%	23%	0%

Table 7.2: Raw response data of each participant per scenario; showing response time (in s) and correctness of identification (green=right, red=wrong, white=no answer)

	1h	1c	2h	2c	3h	3c
P1	11.35	27.48	31.30	15.00	N.a.	30.19
P2	19.97	15.71	-	15.25	32.10	33.29
P3	15.94	11.60	14.68	23.64	36.03	22.23
P4	11.54	12.85	8.92	10.12	16.77	17.43
P5	19.51	16.77	30.51	15.42	32.87	19.46
P6	11.14	8.66	-	12.27	13.74	13.50
P7	16.88	9.83	17.27	14.01	16.69	29.92
P8	16.70	13.36	21.48	10.85	29.16	15.07
P9	7.30	8.39	18.66	12.51	13.43	24.78
P10	12.26	11.85	23.82	24.62	26.01	21.95
P11	12.64	15.99	25.73	21.46	26.19	29.98
P12	-	19.53	24.70	25.15	15.61	24.70
P13	26.07	22.87	-	16.18	20.87	24.88
Average	15.11	14.99	21.71	16.65	23.29	23.64

The second quantitative variable that was recorded, was the response time of each participant. In Table 7.2 the raw response times are depicted in seconds per participant and for each scenario. The scenarios are identified by the number of the rhythm (1,2,3) and whether they were with haptic feedback (h), or without (c). In addition, green cells indicate that the participant correctly identified the student who was playing incorrectly, and the red ones indicate a wrong answer. For white cells, no answer was given, although specifically for P1 in scenario 3h, the lack of an answer was the result of the setup not working correctly. Hence, this data point is missing and is not included in the analysis.

A rather large difference in response time between a scenario with and without haptic feedback can be found for rhythm 2. In these scenarios, being supported by haptic feedback shows a much longer response time. Remarkably, this is also the scenario in which the most participants were unable to identify any student as differing from the others. Where the uncertainty was previously obvious from the lacking responses, it is now also seen in the longer response times.

Although both quantitative variables give *some* indication of the effect of the haptic feedback, they should be analysed with caution. First, the recording of response times was done manually, which is not a perfectly accurate method. Besides, most participants identified students with a sentence along the line of 'I think the person who is playing differently is player X'. The timer had to be stopped somewhere during that sentence, but it was difficult to keep this timing consistent. A more accurate approach would have been to stop the timer at the start of each sentence, but that would have led the timer to be stopped at every sound made by the participant, even if it was not the sentence in which the identification was done. Another option could have been to use automated timing, where the participant would stop the timer when they wanted to give their answer, for example by pressing a button. However, with the used approach, the timing data is not accurate enough for analysis of any small differences. Only for large differences in response times that exceed the inaccuracy of the recordings, the data could be useful for analysis, such as for the second rhythm.

Still, considering the small sample size, no statistical analysis can be done on the data. Hence, only *implications* can be derived from the quantitative data gathered in this research, but no significant conclusions can be drawn.

7.3 Qualitative data

Although no specific effect of the feedback could be interpreted from the quantitative data in terms of performance, there were some interesting findings in the data gathered from the interview responses (see Appendix D), observations during the test, and any separate comments made by participants at any point during the evaluation.

For this qualitative data, a distinction is made between the effect of the haptic feedback specifically, which is based on all participants, and the value of the simulated learning environment as a whole, which is based on a discussion with the experts and further reasoning which was sparked by that discussion.

7.3.1 Haptic feedback

The effect of the haptic feedback was discussed during the interviews and was observed during the experiment. The effect can be divided into the influence that it had on participants' experience during the overall experiment and the influence that it may have had on the participants' approach towards executing the identification task. Both aspects are analysed in this section.

Confidence boost

First and foremost, a contrast was found in the confidence with which the identification was done. Although both with and without the haptic feedback, participants were often able to identify the right student, the interview data showed that 6 out of the 13 noticed a form of security from the feedback and felt more confident in their identification with the haptic support than without. Besides, although the experts did not explicitly experience this effect themselves, they both theorised that this confidence boost from the feedback could indeed be the case for beginners. The same effect was observed during the tests, as participants generally exuded more confidence in their body language and in the way they spoke when they identified the mismatching student when they had support from the haptic feedback. With the haptic support, the description of the student (e.g. 'It's the second one to the left') or the act of pointing to them was more direct, whereas without the feedback, answers seemed more doubtful (e.g. 'I think er- it might be this one? Or not. Yes, I think it's this one').

In the interviews, participants explained that the feedback helped them identify the right rhythm more quickly and as soon as they focused on the mismatching student, they recognised almost instantly that this person was playing incorrectly. "With the feedback, I could immediately see whether it [the playing behaviour] was right or wrong so there was no need to compare them [the students] to each other anymore", said participant 3.

Without the haptic feedback, 3 participants described that their approach was to compare every two students to each other until a mismatch was found. The difficulty in these cases was that participants experienced doubt when the student they were using as a reference also did not play the rhythm perfectly. In contrast, the constant and theoretically perfect reference of the haptic feedback made it easier to spot mistakes straight away, according to participants 3 and 13. Interestingly, in the measured data, neither method seems to cause a particularly longer identification process, as would be expected from the participants' descriptions.

Another factor that may have contributed to the increased confidence was the physicality of the haptic feedback. 5 participants explained that it was easier to embody the music and identify and understand the rhythm when they felt the rhythm from the wearable. Participant 12 stated '...it helped internalise the rhythm through the physicality of the vibrations and the fact that it was easy to tap along to the feedback with my own foot'. This finding corresponds with the experience-enhancing characteristic of haptic feedback that is explained in the chapter Related Work (ch. 3) of this thesis. An enhanced perception of the reference rhythm will have increased certainty of the reference rhythm as a means of comparison for the students, strengthening the effect of confidence, as is explained in the previous point.

However, with this enhancement, again it would be expected to find a better performance, perhaps in the form of a faster identification, considering the reference was more clear. Yet, no such effect can be found in the response times. Then again, the data was not accurate enough to conclude anything.

Use of the senses

Interestingly, the approach of most of the participants did not differ much between the scenarios with and without the feedback. The interview answers pointed out that the majority of the identification process relied heavily on sight. A similar impression was gathered from the observations due to participants' body language of bending towards the screen and staring attentively. However, it was difficult to observe hearing or feeling behaviour, so it is likely that the observations were skewed towards seeing behaviour. Therefore, the observations alone were not conclusive.

From the interviews, it became clear that participants who were able to hear the direction from which the mistakes were coming, used that sense first to steer their attention and then used their sight to compare students until they found one that did not match with the others. This was often done from left to right or per screen, which meant that the location of the student in the classroom may have influenced the response time, although this cannot be seen in the timing data. In these cases, the addition of haptic feedback was often an extra background layer that added to the certainty, but for most, it was a rather unconscious factor. Only at the beginning of a scenario did 4 participants, from the 8 who said they could hear the direction of the mistakes, recall paying specific attention to the feedback to gain an impression of the reference rhythm.

For participants who were not able to hear the direction of the mistake, the haptic feedback played a more balanced role together with sight. In these cases, the identification was often done by looking across the room one by one and comparing each student to the reference rhythm in the haptic feedback. In the scenarios without haptic feedback, they would purely compare the sight of different students to each other and find the odd one out.

Only one participant, who was not an expert, said they did not pay attention to the haptic feedback at all because their hearing was good enough to simply rely on the combination of hearing and sight. All other participants found the haptic wearable a useful addition to this exercise and would recommend it as a supporting device for people with a bad sense for music.

Vibration design

The vibrations themselves were overall received positively, although they could be a bit ticklish depending on the placement on the wrist and depending on the person. Luckily, the elastic band allowed for an easy adjustment to a more pleasant spot. However, opinions were divided about the spreading of the feedback over the body. Some participants would have preferred having haptic feedback on both arms, either to create a more holistic experience or even to have the feedback on each arm correspond to the same arm in the drumming motion, so it would match even better with sight. Others preferred having feedback on only one arm, as it was in this setup, because they expected two arms to cause an overload of sensing, especially if it would offer different information between the different spots. In addition, having the vibrations on one arm was identified as a similar experience to that of receiving a message on a smartwatch and therefore automatically triggered a response of having to pay attention. Although this effect is a fitting one for the intention of the wearable, it is expected that it will fade away after longer use of the wearable, especially with faster rhythms, where the vibrations are more frequent. Still, it should be noted that no other options for placement were tested in this study, so all other preferences mentioned in the interviews were speculations.

Overload vs. Steadiness

Throughout several of the interviews, the subject came up of the value of the haptic feedback in more chaotic scenarios. Within the current experiment, scenario 2 was experienced as being more chaotic, which was unsurprising as in that scenario, there was visually and audibly less synchronicity between the correctly playing students than in the other scenarios. Based on the experience with this scenario, some participants speculated about how the haptic feedback might influence the experience in a more chaotic scenario where, for example, more people would play incorrectly or where the class would be more restless in general. Although not all participants brought up this point, 5 found that if the scenario became a bit more chaotic and was more difficult to follow, the extra sense of touch caused an overload of the senses and made it even more difficult to get a grasp of the situation. However, 3 participants in return suggested that the overload may not be the case if users were more used to the

wearable. This might have simply been achieved by adding multiple practice scenarios before the test. In addition, reducing the vibrations to a shorter buzz, more similar to a tap, could create a calmer experience for the user. A shorter vibration would also fit better with the woodblock sound of the recordings, as was pointed out by participants 5, 6 and 12.

On the other hand, 5 participants, of which a few initially addressed the confusing effect of the feedback, also reasoned that in a chaotic situation, the reference of the right rhythm through the haptic feedback was an anchor to which they could hold on and which caused more stability for the situation. This was also reflected in the evaluation: in the scenarios in which the majority of the virtual class played rather synchronously, most participants could manage to rely more on their hearing than on the feedback, as the right rhythm was heard clearly; but in the scenario where the class was less synchronised, participants focused more on the haptic feedback. Although this is a logical shift, it should be monitored that this does not lead to laziness where users stop relying on their hearing completely, as the main objective is to improve their hearing through *support* by haptic feedback.

Since both sides to this discussion about the effect of the feedback in a more chaotic setting are largely based on scenario 2, in which the "chaos" was rather minimal, and which was only a single instance, these findings should be regarded as speculations only. Still, it is an interesting fine line to keep in mind in similar designs to keep the pleasantness and the effect of the system warranted.

7.3.2 Simulated learning environment

Although the simulated classroom was used as a testing environment in this study, it was originally designed as a learning environment. However, any supportive effect it might have on a learning process could only be tested in the long term, which was not possible in the current study. Still, the potential value of the environment was discussed with the experts, based on some characteristics that could be experienced in the test setting as well. For example, the controllability and reproducibility of the environment were useful in the empirical tests to keep testing circumstances constant throughout the different tests, but these same characteristics could be valuable in the context of training as well.

The simulated environment helps to eliminate interruption by unwanted factors and allows for a focus on specific training situations. Both experts involved in the empirical study, highlighted the pleasantness of being able to focus only on the rhythmic exercises without having interference of human (mis)behaviour as could be the case in a live class. One of them noted 'It is an accessible way of practising the senses within a class setting without having to worry about real students and didactics. It gives space to make mistakes and to take the time to listen'.

From this response, a comforting effect of the simulated environment can be interpreted, as distractions are stripped and it was indicated that the fear of making mistakes is reduced. It is not unlikely that these characteristics, combined with a suitable difficulty level of the exercises, make for an environment which can help boost confidence, as the tasks seem accessible to the pre-service teacher. Besides, feeling free to make mistakes may help advance a learning process.

Although one of the experts found that the environment could do with some improvement in the form of more scenarios and a more individual student setup, such as having an individual pair of screen and speaker per student, both concluded that the simulated learning environment would be a valuable tool for training in teaching music. Especially the controllability was identified as the key factor in its value, although the value of other characteristics was not dismissed.

Finally, the insights gained from discussing the value of the environment for training purposes with the experts, have inspired further reasoning of the benefits of some characteristics of the environment and the practical value they may have. These topics are further discussed in the next chapter.

7.4 Summary

Although no statistical significance could be derived, the quantitative findings of the evaluation of this research indicate that the haptic feedback wearable as designed in this study is not a fitting solution for more accurate identification of an incorrectly playing student in a music class. However, qualitative data show that haptic feedback has merit for improving the confidence of the teacher in this process,

which was identified in earlier research as being one of the main limitations in music education. In addition, the embodiment of the music that the haptic feedback creates, added to a better awareness of and feeling for the rhythm. Especially this latter aspect, may improve the musicality of the pre-service teacher and thus have a long-term impact as well. The simulated learning environment as a whole, shows promise as a valuable tool in training situations, as it gives an educator control over training situations and the ability to create a learning environment that is suitable for teaching pre-service teachers with limited musical experience.

Chapter 8

Discussion & Future Work

In this chapter, the implications and limitations of the evaluation are discussed, along with the practical relevance of this research. In addition, possible avenues of continuation are explained and recommendations are given for future work.

8.1 Technical limitations

During the evaluation, a few technical limitations occurred. First, two vibration motors broke. The original vibration motor broke rather early in the evaluation process and its backup followed the same day. Unfortunately, this led to one evaluation being cancelled. This participant is therefore not included in the result section of this report. The breakage was due to bad quality of the motor, hence, a different type of vibration motor was used for approximately the last 75% of the participants. The difference in vibration motor was hardly noticeable in the wearable and therefore the results can be analysed similarly.

Secondly, the timing of the software involved in the evaluation was difficult to get exactly right, which might have been a limitation for the effect of the haptic feedback. Although this timing was a focal point in the design of the system, it was rather difficult to get the video, audio and feedback perfectly synchronised. As all three were run in a separate program, little could be automated. The asynchronicity was partially due to the manually selected time stamps, which always include some impreciseness, and partially due to the fact that all programs had a slightly different and inconsistent time to start up a sequence, seemingly depending on the prior run time of the program. Having each program up and running well in advance seemed to cause the least delay, but still, it created some variation between different evaluations and even between scenarios within one evaluation session. Although for most cases this variation was rather minimal, some participants did notice, and it could have influenced their experience.

Thirdly, it should be considered that the number of screens used in the test setup could have influenced the outcome of the test. In the results of the evaluation, it was found that many participants relied primarily on sight, rather than on other senses. It could be reasoned that this was influenced by the fact that the two screens were positioned front and centre, arguably making it an easy focal point in the setup. As mentioned in the design of the simulated learning space, it was already considered upfront that a more ideal setup would have had an individual screen for each student and would be spread around the room in a half circle, lining up with the speakers; but such a setup was unachievable with the graphical processing properties of the hardware that was available for this study. The main argument for the half-circle setup was that it would be more realistic to a real class than the two-screen setup would be. However, it was not expected that the two screens in the middle would potentially have such an influence on the behaviour of many participants. Still, this is only a hypothesis based on observations, which calls for further testing.

Finally, although the evaluation in this study gave some insight into the use and effect of the learning environment for rhythm recognition on short term, unfortunately, it was not possible to study the long-term effect. Developing a feel for rhythm takes time, so in order to properly assess the effect of the learning environment, a long-term study should be carried out. Considering the limited time available for this thesis, such a long-term study is appointed for future research.

8.2 Design & Methodological Limitations

In addition to these technical limitations, there are three main discussion points in the study, which are discussed at large in the following subsections.

8.2.1 Scenario difficulty

In hindsight, it was difficult to measure the influence of the haptic feedback, because it seemed to depend greatly on the difficulty of the scenario, as experienced by each participant. If participants found a scenario rather easy, they would not rely on the haptic feedback much as they were able to hear or see the mistakes fairly easily. In a more difficult scenario, they would rely more on the haptic feedback. However, which scenarios were found easy or hard differed per participant. Some found all scenarios hard, some only a few or one in particular, and one participant found them all easy. Participants reported that scenarios were found especially easy if the rhythm itself was rather simple, but also if all correctly playing students played extremely synchronously and only one person played incorrectly. In these cases, the wrong student stuck out quite obviously. This issue was considered beforehand and could be avoided by having a larger variety of scenarios with different divisions of correct and incorrect students. Perhaps even having some scenarios in which no one plays incorrectly, to have participants also identify *whether* something is off, instead of just *who* is off. In addition, scenarios with multiple parts playing at once or with play-along music were considered, as could be encountered in music education in primary schools. However, the decision was deliberately made to keep the test scenarios rather simple.

First, it was discussed that the scenarios should not be too easy or too hard for participants, but it was difficult to find an appropriate balance. Considering the focus group consisted of novices, simple scenarios were considered the most suitable.

Secondly, in view of the research, simple scenarios reduced the chance of including undesired variables in the testing environment. The simplicity helped keep the focus on the research questions at hand. Lastly, the production of each scenario cost a lot of time and effort; first in getting the video, audio and haptic feedback working properly individually and secondly in synchronising all three aspects. Hence, creating a larger collection of scenarios, which could accommodate more difficulty levels, was unrealistic for the time span of this research.

8.2.2 Limited view

In line with the scenarios, the haptic feedback itself also followed a simple and consistent design, in order to reduce the number of undesired variables. Especially considering this research is an initial exploration in its application of the haptic feedback, it was not necessary for the feedback to have the optimal design, but instead, a design was made which was easy to execute but which it was still very likely to give some useful first insights into its effect.

However, with these choices made regarding the design of the feedback (i.e. timing, frequency, content and modality), other options remain unexplored in this application. Some of the other options that were considered are included as recommendations for future research in the next chapter.

8.2.3 Target adjustment

Finally, when looking at the aim and the execution of the empirical study of this thesis critically, in hindsight, perhaps the tasks given during the study did not match the target that was initially set. In this research, the target group consisted of novices in music, similar to pre-service teachers who are just starting with their own musical training. However, when looking back at the pre-study [8], recognising rhythmic behaviour of others is not recognised as a natural starting point for true laymen. Instead, students often start by clapping along with simple rhythmic exercises and learn to embody rhythm themselves before being able to recognise it in others. Therefore, although design choices were targeted towards true novices, the tasks in the empirical study did not reflect the same target group.

The test, as it was designed in this study, could still be a useful tool for testing and training listening skills, but perhaps only after students have already had some experience in internalising rhythm beforehand. The current group of participants was not selected on these prerequisites.

A different approach for the current target group within the setting of this thesis could have been to use the learning environment and haptic feedback as support in the personal internalisation of rhythmic exercises, rather than having to focus on others. Alternatively, with the tasks kept the same, but a slightly more experienced target group, there may have been fewer limitations for the design, as more experience often leads to understanding a subject in a broader scale of situations [31]. Hence, the design could have been made more complex, but perhaps more fitting for the supporting role it was attempted to be.

8.3 Avenues of continuation

Despite the limitations discussed above, in the current study, four main themes were identified that could provide inspiration for new or follow-up research. These themes are discussed in the following subsections.

8.3.1 Theme 1: Viewing behaviour

As briefly mentioned before, it became apparent from observations and the interviews that many participants relied heavily on sight when identifying the mismatching student. Interestingly, a common approach was to compare students to each other from left to right. This approach seemed manageable with the relatively small class that was depicted in the simulation, but it leads to wonder if the same method would work in a larger classroom, more similar to a real class. It is likely that in a larger class, the same approach would take much longer, and thus, it does not seem to be an efficient method of identification. Therefore, it might be worthwhile to study whether the same behaviour is observed from participants when testing with a larger class, and if so, how users can be guided in zooming in on the mismatching student quicker, without them becoming dependent on the support.

Looking back at the current study, if it was known beforehand that participants would rely so much on sight, perhaps it would have been interesting to include eye-tracking technology to measure more precisely what they based their identification on and in general how they viewed the class.

These study subjects could be the base of new research towards viewing behaviour of teachers in front of a music class, which might help in understanding the teacher's behaviour better and ultimately adjust learning situations better to their behaviour.

8.3.2 Theme 2: Confidence

Another theme that became apparent from both observations and the interviews was the confidence with which the participants picked a student from the class. As mentioned before, in the pre-study of this thesis it was found that a big issue for pre-service teachers is a lack of confidence in their own capability of teaching music, and as a result, music classes are often skipped in primary school. Therefore, gaining confidence is an important theme in the improvement of music education of pre-service teachers.

In the current study, confidence was primarily raised due to the constant reference of the haptic feedback on which participants could rely, giving them more security about which rhythm to compare students' behaviour to. Although this effect was intended in the design of the feedback system, it was not a primary variable that was tested in the current study. Therefore, it might be interesting to dive deeper into the subject in further research. The current outcome raises questions of whether it is possible to steer even more towards increasing confidence, perhaps with the use of the training environment, and how.

Still, an important side note is to pay attention to the chance of users becoming too dependent on the feedback. In the current study, the increase in confidence was directly related to the haptic feedback being present in real-time during the exercise. However, the ultimate aim is to use the haptic feedback as a support in training such that users can eventually also recognise the rhythmic playing behaviour *without* the haptic feedback. Therefore, dependency on the feedback should be avoided or otherwise be phased out correctly.

8.3.3 Theme 3: Embodiment

Another important theme that was reflected in the outcome of the interviews was the embodiment of the rhythm. This theme was rather prominent in the design of the feedback and it was one of the substantiations for the choice of haptic feedback, so it was expected to be found in the analysis. Still, the outcome of the interviews indeed showed that the embodiment of the rhythm through the haptic actuator was experienced by participants as a positive effect of the feedback that improved the awareness and understanding of the rhythm at hand.

However, given that the current research was a broader one, not specified to only the effect of the embodiment from the wearable, it could be valuable to conduct further research into the optimisation of the embodiment effect. For example, some aspects that were reflected in the interviews were that of the placement of the actuator and the duration of the vibration itself, which was greatly dependent on the personal preferences of the participants. In hindsight, perhaps the desired embodiment could have been enhanced further by creating a more whole-body experience with multiple synchronised actuators across the body. An additional advantage of such an approach is that it could provide more variety in the feedback that is given. For example, variety in the spacing of the feedback could allow for indicating the direction of specific students, or different actuators could provide feedback on different data. Still, these were only speculations as in the current study no other options than the single actuator on the wrist were tested.

Improvement of the embodiment effect of the feedback could potentially improve the understanding of and familiarity with different rhythms, perhaps leading to a better general feel for rhythm and a smoother learning process. However, further research into this subject specifically, needs to be done to confirm or deny these effects.

8.3.4 Theme 4: (Incorrect) Playing behaviour

Lastly, an interesting theme that could be found in the context of this research is that of (in)correct playing behaviour and how it is defined. In this study, a variety of options were tried: playing too fast, too slow or something different in general. The latter could result in the performer not even trying to play the right rhythm, or trying to follow along but missing a few strikes or bursting out in a random improvisation every now and then. However, each option had a different impact. During the assembly of the virtual class, it became apparent that in some scenarios the faulty play became obvious fast, for example, when the random play differed greatly from the original rhythm. Others took a bit longer. Specifically, for playing too slow or too fast, the mismatch would become increasingly obvious as the difference would increase over time.

Although all of these options could be plausible for real classes and therefore could be valuable to use in testing and training scenarios, they each have their own implications. On the one hand, the playing behaviour influences the difficulty of a scenario, as is explained earlier in this chapter, but in reality, it also calls for different feedback that needs to be provided by the teacher. For example, a student playing too loud may benefit from different feedback from the teacher than a student who is playing too fast or who is not following the rhythm at all. Therefore, especially if the pre-service teacher also needs to practice giving feedback to the class, the choice of playing behaviour may be an important factor.

In addition, it may be questioned what exactly is wrong behaviour. For example, in the scenarios used in this study, one student played particularly different than the others, but within the seven that played the correct rhythm, there was still a slight variation in play. Although close, they were not perfectly synchronised. This design choice was made deliberately as it felt more realistic when students were not all playing identically. However, this choice may have influenced the outcome of the study. The scenario that was found the most difficult, scenario 2, had more variation in play by the students that were playing the correct rhythm. That might indicate that participants were not only unsure about the one playing incorrectly, but also about which ones counted as playing correctly. Hence, the definition of correct and incorrect play could be up for discussion and should be defined well in order to test similar applications.

Following this train of thought, it might be interesting to continue research into the effect that different playing behaviour of the class may have on the experience by the teacher, and how the playing behaviour ultimately influences the feedback that is needed from the teacher to the class.

8.4 Practical relevance

The discussion with the experts during the evaluation about the benefits of the simulated learning environment, combined with general reasoning, sparked thoughts about the practical relevance that the learning environment may have. The value of having a controllable environment for the current application was already discussed in the interviews, but the variety of possibilities this creates for training purposes was not yet analysed.

First, the fact that specific scenarios can be reproduced, allows for the possibility of repeating specific training situations exactly as they were. This could be a useful tool for putting any terminal feedback given by the educator into practice. After the feedback from the educator is received, the scenario can be played again and the PABO student can practice the same learning situation with the additional feedback.

Another benefit of the environment is that the controllability gives the educator options for a variety of exercises, based on the available scenarios. In the current study, it was used specifically for rhythmic exercises, but a similar approach could be used for training with melody or didactic skills.

Besides, even within the realm of rhythmic training, the educator could alter the difficulty of the training, corresponding to the student's skill level. In the current study, the elimination of distracting factors was seen as a useful characteristic for beginners, but seeing that the scenarios could be altered, it could also give the possibility to purposefully add them along the way to increase the difficulty for more advanced students.

Along the same lines, the educator could opt for varying the feedback, depending on the pre-service teacher's progress. If done well, any possible dependency of the pre-service teacher on the concurrent feedback could be phased out gradually.

Looking back at Van der Linden et al.'s [26] theory that for feedback to have an impact, it should be connected directly to specific tasks at the right level of difficulty for the user, this controlled environment creates the possibility for just that, as its reliability makes it so that scenarios, tasks and feedback can be perfectly combined to fit the user's learning progress.

Finally, taking a broader view of the practical relevance of the learning environment, a similar setup might be useful for training other teaching skills not specifically related to music as well. In addition, the simulated group of people may offer a more comfortable environment to practice and stimulate confidence in scenarios where the user needs to face and address a group of people, such as in presenting or public speaking. However, for these instances, naturally, the scenarios need to be tailored for the specific task and the subject at hand, and the design of the feedback, either through the haptic wearable or an educator, needs to be meaningful to the specific learning situation. Therefore, the current design could not be used for these subjects directly as it is, but it may inspire similar learning environments in other subject areas.

8.5 Future work

Based on this thesis research, several potentially interesting areas for further research and improvement could be identified for future work: 1) context enhancement, 2) optimisation of the learning environment, 3) optimisation of the haptic feedback, and 4) expansion of the application.

First, for contributing to a broader and more clear context for the design of the learning environment in the current application, it might be interesting to develop new research into the avenues of continuation described earlier. The deepening of knowledge on each of these themes helps understand the experience and the behaviour of the teachers better, possibly leading to a more effective design for specific learning situations that improve the learning process of pre-service teachers better.

Next, to optimise the learning environment for training purposes, an improvement could be the individuality of the simulated students, to make the simulation more realistic, and possibly reduce the user's dependency on sight. Although it was stated that further research into sight would be interesting, considering the vital role it seemed to play in the identification of rhythmic behaviour in a class, it was also discussed that the large dependency on sight may have been due to the current setup. Therefore, it might also be useful to study the effect of a more spacious setup, where the emphasis on visuals is lowered. This could be done by using individual screens for each student, matching with the current setup of individual speakers, or perhaps with the use of virtual reality (VR) or augmented

reality (AR). Furthermore, the environment could be improved by making it more enriched and there should be more samples of learning situations, from which educators can make use. It should also be developed with more automation, to ensure the synchronicity of the currently individual video, audio and haptic feedback.

To optimise the design of the haptic feedback for the current application, first, an exploratory study should be done on the different forms of haptic feedback, to identify their characteristics, pros and cons, and the effect they could have. There are many different possibilities varying in the timing, frequency, content and modality, even within just the field of haptic feedback. Some options that were considered in this research can be found in Appendix E as a source of inspiration. The most promising options should then be used for A/B testing to find the most effective one for the current application.

In addition to these optimisation studies, it could be interesting to study the application of the technology in a broader setting, as in reality, teachers are not always statically standing in front of the class and purely observing. For example, it could be studied how feedback should be optimised when the teacher is not only listening but also playing along with the class. Does that change the experience? And finally, a broader view of the modality could be taken as well. Perhaps even optimised haptic feedback on its own is not effective enough for the learning process, but a combination of haptic and, for example, visual feedback might be.

Chapter 9

Conclusion

This research aimed to design a learning environment for pre-service teachers to learn how to improve their listening skills, such that they can eventually recognise rhythmic behaviour on their own. The two sub-questions that were answered along the way, were as follows:

1. How should a learning environment be designed in order to help with improving pre-service teachers' listening skills?

2. How can haptic feedback contribute to recognising rhythmic behaviour of students in a class setting?

A design for both the learning environment and the haptic feedback system were tested in a within-subject empirical study. In a simulated music classroom setting consisting of video, audio and haptic feedback, participants were asked to identify the incorrectly playing student out of a group of students performing rhythmic exercises. This identification was done with and without the support of a haptic wearable. Afterwards, their experience with the haptic feedback was discussed in a semi-structured interview.

Although no significance could be established from the quantitative data due to inaccuracies and a small sample size, no remarkable difference was found in the accuracy and timing of the identification with and without haptic feedback. The qualitative data indicated that with the support of haptic feedback, participants were more confident in their identification than without, partially due to the fact that the haptic feedback helped embody the rhythm better. Besides, it was experienced as a steady reference, which could be valuable in more chaotic musical scenarios. However, the haptic feedback also ran the risk of becoming a distraction and adding to any chaos if the timing was not exactly right, and it took participants some getting used to in general. Therefore, similar haptic feedback wearables should be designed with caution.

All in all, the current design of the haptic feedback did not seem to be an effective aid for particularly more accurate or faster identification of rhythmic behaviour of students in a class setting, but it did indicate merit for a better understanding of rhythm and more certainty in such identification, which could potentially enable a smoother learning process. As the design for the haptic feedback wearable was not optimised in this research, its effectiveness was far from perfect, but perhaps an improved design could also give better results.

The design of the learning environment as a whole is thought to be especially valuable for training purposes. The versatility of the simulation and the fact that it is a controlled environment would make it a promising tool for educators at the PABO as they could manipulate learning situations to practice with their students. Still, the design should be improved in future work.

All in all, this research was a first step in studying a new application for haptic feedback in music, with the aim of improving music education, and there is much more to be discovered in this field.

Bibliography

[1] KunstenHuis Idea, "Primair Onderwijs De Bilt Creatieve workshops voor het team Gebruik van Orff-instrumentarium," 2019. [Online]. Available: https://kunstenhuis.nl/scholen/primair-debilt-concept/creatieve-workshops-team/orff-instrumentarium/

[2] J. Herfs and E. Van Hoek, "Muziek is anders," Amsterdamse Hogeschool voor de Kunsten, Amsterdam, Tech. Rep., 2013.

[3] R. Van der Lei, F. Haverkort, and L. Noordam, *Muziek Meester!*, 4th ed. ThiemeMeulenhoff, 2015.

[4] R. Vrolijk, *Nieuw geluid*, 2nd ed. Noordhoff, 2013.

[5] M. Mieras, "Wat muziek doet met kinderhersenen," Jeugd cultuurfonds Nederland, Tech. Rep., 2011.

[6] L. Groeneveld, "De effecten van muziekonderwijs op basisschoolleerlingen," BSc thesis, Wageningen University, 2013.

[7] A. C. Jaschke, H. Honing, and E. J. Scherder, "Longitudinal Analysis of Music Education on Executive Functions in Primary School Children," *Frontiers in Neuroscience*, vol. 12, p. 103, 2 2018.

[8] H. van de Ven, "Research Topics : Towards designing a technological music aid in teaching pre-service teachers to listen better," Pre-study, University of Twente, 2022.

[9] F. Seddon and M. Biasutti, "Non-music specialist trainee primary school teachers' confidence in teaching music in the classroom," *Music Education Research*, vol. 10, no. 3, pp. 403–421, 2008.

[10] S. Hallam, P. Burnard, A. Robertson, C. Saleh, V. Davies, L. Rogers, and D. Kokatsaki, "Trainee primary-school teachers' perceptions of their effectiveness in teaching music," *Music Education Research*, vol. 11, no. 2, pp. 221–240, 2009.

[11] S. Burak, "Self-efficacy of pre-school and primary school pre-service teachers in musical ability and music teaching," *International Journal of Music Education*, vol. 37, no. 2, pp. 257–271, 2019.

[12] P. A. De Vries, "Music without a music specialist: A primary school story," *International Journal of Music Education*, vol. 33, no. 2, pp. 210–221, 2015.

[13] G. Stunell, "Not Musical? Identity Perceptions of Generalist Primary School Teachers in Relation to Classroom Music Teaching in England," *Action, Criticism, and Theory for Music Education*, vol. 9, no. 2, pp. 79–107, 2010. [Online]. Available: http://act.maydaygroup.org

[14] H. Holden and S. Button, "The teaching of music in the primary school by the non-music specialist," *British Journal of Music Education*, vol. 23, no. 1, pp. 23–38, 2006.

[15] D. Russell-Bowie, "What me? Teach music to my primary class? Challenges to teaching music in primary schools in five countries," *Music Education Research*, vol. 11, no. 1, pp. 23–36, 2009.

[16] Meer Muziek In De Klas, "Alle pabo's in Nederland geven studenten weer structureel, kwalitatief muziekonderwijs," 2019. [Online]. Available: https://www.meermuziekindeklas.nl/nl/nieuws/alle-pabos-in-nederland-geven-studenten-weer-structureel-kwalitatief-muziekonderwijs/4694/

[17] J. Kruijshaar, "Visual feedback support for pre-service teachers in guiding a music class," BSc thesis, University of Twente, 2020.

[18] D. B. Postma, R. W. van Delden, J. H. Koekoek, W. W. Walinga, I. M. van Hilvoorde, B. J. F. van Beijnum, F. A. Salim, and D. Reidsma, "A Design Space of Sports Interaction Technology," *Foundations and Trends® in Human–Computer Interaction*, vol. 15, no. 2-3, pp. 132–316, 2022.

[19] S. Choi and K. J. Kuchenbecker, "Vibrotactile display: Perception, technology, and applications," *Proceedings of the IEEE*, vol. 101, no. 9, pp. 2093–2104, 2013.

[20] E. Gunther and S. O'Modhrain, "Cutaneous grooves: Composing for the sense of touch," *International Journal of Phytoremediation*, vol. 21, no. 1, pp. 369–381, 2003.

[21] C. Bernard, J. Monnoyer, M. Wiertlewski, and S. Ystad, "Rhythm perception is shared between audio and haptics," *Scientific Reports*, vol. 12, no. 1, pp. 1–12, 2022. [Online]. Available: https://doi.org/10.1038/s41598-022-08152-w

[22] S. Merchel, A. Leppin, and E. Altinsoy, "Hearing With Your Body: The Influence of Whole-Body Vibrations on Loudness Perception," 2009.

[23] I. Rock and C. S. Harris, "Vision and Touch," *Scientific American*, vol. 216, no. 5, pp. 96–107, 1967.

[24] S. Asmervik, "All senses matter," in *Proceedings of the International Conference on Universal Design*, H. Caltenco, P.-O. Hedvall, A. Larsson, K. Rassmus-Gröhn, and B. Rydeman, Eds. Lund: IOS Press BV, 2014, pp. 17–25.

[25] C. E. Seim, "Wearable vibrotactile stimulation: How passive stimulation can train and rehabilitate," Ph.D. dissertation, Georgia Institute of Technology, 2019. [Online]. Available: https://smartech.gatech.edu/handle/1853/61253

[26] J. Van Der Linden, R. Johnson, J. Bird, Y. Rogers, and E. Schoonderwaldt, "Buzzing to Play: Lessons Learned From an In the Wild Study of Real-time Vibrotactile Feedback," 2011.

[27] A. Bouwer, S. Holland, and M. Dalgleish, "The Haptic Bracelets: Learning Multi-Limb Rhythm Skills from Haptic Stimuli While Reading," *Springer Series on Cultural Computing*, pp. 101–122, 2013. [Online]. Available: https://link.springer.com/chapter/10.1007/978-1-4471-2990-5_6

[28] S. Miura and M. Sugimoto, "T-RHYTHM: A system for supporting rhythm learning by using tactile devices," *Proceedings - IEEE International Workshop on Wireless and Mobile Technologies in Education, WMTE 2005*, pp. 264–268, 2005.

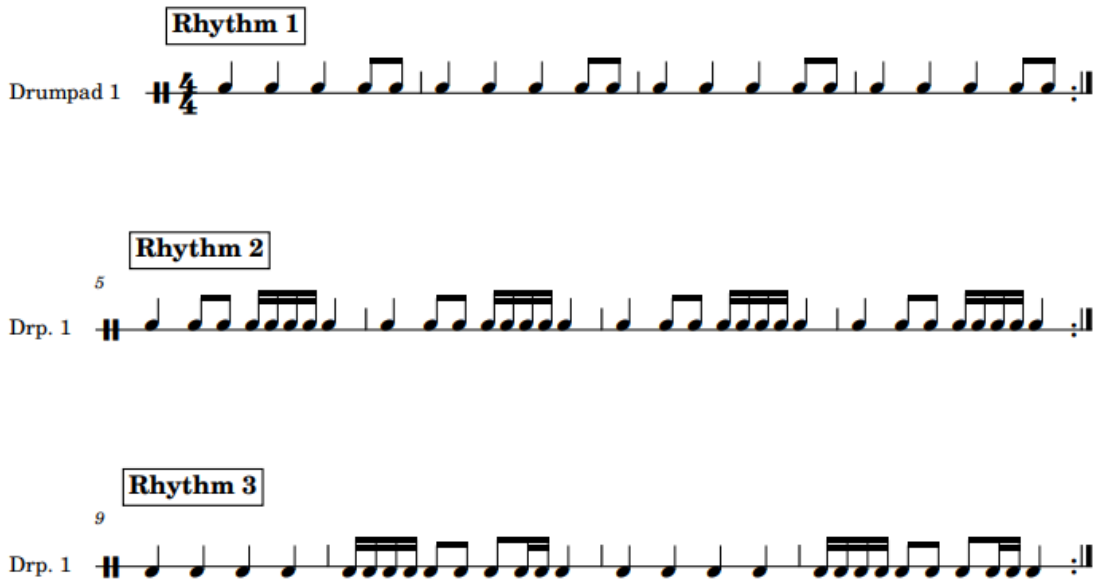
[29] S. Nanayakkara, E. Taylor, L. Wyse, and S. H. Ong, "An enhanced musical experience for the deaf: Design and evaluation of a music display and a haptic chair," in *Conference on Human Factors in Computing Systems - Proceedings*. New York, NY, USA: Association for Computing Machinery (ACM), 4 2009, pp. 337–346. [Online]. Available: https://dl.acm.org/doi/10.1145/1518701.1518756

[30] F. Giroux, J. Boasen, S. Sénécal, M. Fredette, A. Q. Tchanou, J. F. Ménard, M. Paquette, and P. M. Léger, "Haptic Stimulation with High Fidelity Vibro-Kinetic Technology Psychophysiologically Enhances Seated Active Music Listening Experience," in *2019 IEEE World Haptics Conference, WHC 2019*. Institute of Electrical and Electronics Engineers Inc., 7 2019, pp. 151–156.

[31] S. E. Dreyfus, "The five-stage model of adult skill acquisition," *Bulletin of Science, Technology and Society*, vol. 24, no. 3, pp. 177–181, 2004.

Appendix A

Rhythm scores



Appendix B

Arduino Code

```
String myCommand;
int vibPin=6;
int ledPin=13;
int value=0;
bool status=true;
int ref=0;
int t=0;
int diff=0;
int myDelay=0;

//Timestamps per rhythm -> these timestamps are relative to each other,
    not in actual time
int arrayX[]={1, 1, 1, 1, 1, 1, 1, 1, 1, 1}; //simple array to test code
int array1[]={400,      600,    650,    600,    300,    250,    650,
    600,    550,    300,    350,    550,    600,    550,    300,    350,
        600,    500,    700,    300,    250,    650,    600,    550,
    350,    300,    600,    650,    550,    300,    250,    650,    600,
        600,    300,    300,    600,    600,    600,    300,    300,
    650,    550,    600,    300,    300,    600,    600,    600,    300,
        300,    600,    600,    600,    250,    300,    650,    550,
    600,    300,    350};
int array2[]={1660,     540,    380,    190,    170,    170,    190,
    540,    590,    340,    230,    140,    200,    200,    570,    550,
        340,    230,    160,    150,    200,    580,    570,    340,
    210,    160,    180,    200,    570,    540,    400,    190,    160,
        170,    190,    570,    560,    370,    190,    180,    170,
    220,    540,    560,    370,    200,    160,    190,    200,    570,
        530,    360,    230,    150,    180,    200,    540,    570,
    360,    200,    190,    160,    210,    530,    580,    390,    190,
        190,    160,    210,    510,    570,    380,    200,    180,
    180,    190,    530,    570,    360,    190,    200,    160,    190,
        530,    570,    370,    210,    170,    180,    190,    540,
    550,    370,    210,    180,    200,    180};
int array3[]={1340,     730,    730,    760,    710,    170,    160,
    180,    180,    380,    380,    370,    170,    200,    790,    830,
        790,    710,    710,    170,    160,    170,    200,    360,
    400,    330,    200,    190,    780,    810,    770,    780,    700,
        170,    200,    160,    190,    370,    330,    370,    210,
    170,    750,    770,    780,    800,    740,    190,    160,    180,
        160,    370,    380,    360,    200,    160,    770,    800,
    770,    750,    740,    180,    180,    160,    200,    390,    320,
```

```
        380,    190,    160,    760,    790, 790};

void setup() {
Serial.begin(115200);
pinMode(vibPin, OUTPUT);
pinMode(ledPin, OUTPUT);
}

void loop() {
while (Serial.available()==0){  //Only act if the Serial port is active
}

//extra scenario to test code
myCommand=Serial.readStringUntil('\r');     //read Serial input

if(myCommand=="START0"){                    //if 'START0' is entered in
    Serial Monitor, start sequence for scenario 0
  Serial.print("This is scenario 0");
  delay(2000);                              //built-in delay to account
     for timing of clicking sequence
  Serial.println("Start");
  for (int i=0; i<sizeof(arrayX)-1;i++){
    t=arrayX[i];                            //get value of next timestamp
    delay(t-myDelay);                       //wait until time of next
        timestamp has passed
    digitalWrite(vibPin,HIGH);              //activate vibration motor
    digitalWrite(ledPin,HIGH);              //activate LED as visual
        check

    myDelay=100;
    delay(myDelay);                         //vibrate for 100ms

    digitalWrite(vibPin,LOW);               //turn off motor
    digitalWrite(ledPin,LOW);               //turn off LED
  }
}

//scenario 1
if(myCommand=="START1"){                    //if 'START1' is entered in
    Serial Monitor, start sequence for scenario 1
  Serial.print("This is scenario 1");
  delay(2000);
  Serial.println("Start");
  for (int i=0; i<sizeof(array1)-1;i++){
    t=array1[i];
    delay(t-myDelay);
    digitalWrite(vibPin,HIGH);
    digitalWrite(ledPin,HIGH);

    myDelay=100;
    delay(myDelay);

    digitalWrite(vibPin,LOW);
    digitalWrite(ledPin,LOW);
  }
}
```

```
//scenario 2
if(myCommand=="START2"){                          //if 'START2' is entered in
    Serial Monitor, start sequence for scenario 2
  Serial.print("This is scenario 2");
  delay(2000);
  Serial.println("Start");
  for (int i=0; i<sizeof(array2)-1;i++){
    t=array2[i];
    delay(t-myDelay);
    digitalWrite(vibPin,HIGH);
    digitalWrite(ledPin,HIGH);

    myDelay=100;
    delay(myDelay);

    digitalWrite(vibPin,LOW);
    digitalWrite(ledPin,LOW);
  }
}

//scenario 3
if(myCommand=="START3"){                          //if 'START3' is entered in
     Serial Monitor, start sequence for scenario 3
  Serial.print("This is scenario 3");
  delay(2000);
  Serial.println("Start");
  for (int i=0; i<sizeof(array3)-1;i++){
    t=array3[i];
    delay(t-myDelay);
    digitalWrite(vibPin,HIGH);
    digitalWrite(ledPin,HIGH);


    myDelay=100;
    delay(myDelay);

    digitalWrite(vibPin,LOW);
    digitalWrite(ledPin,LOW);

  }
}

else{}
}
```

Appendix C

Informed Consent Form

Participant informed consent form

Principle researchers: Hester van de Ven and Benno Spieker
Organization: University of Twente, faculty EEMCS
Project: Master thesis and PhD research
Date:

This form contains two sections:

1) An information brochure in which the purpose of the study is briefly explained and it is explained how your data will be used and what your rights are. Please read this carefully and if there is anything you do not understand, ask for an explanation.
2) A consent form, in which you are asked to verify your understanding of, and agreement to, participating in this study.

Information brochure

In this brochure, I would like to inform you about the research you have applied to participate in. For my master thesis for the study Interaction Technology, I am doing research into how haptic feedback can support the learning process of rhythm recognition for pre-service primary school teachers. This study contributes to a larger PhD research by Benno Spieker on the application of music technology in music education. With this user test, I hope to gain insight into the effect of data presented through haptic feedback on rhythm recognition in a classroom setting. During this session, a virtual classroom will be presented with audio and video of students playing rhythmic exercises. You will be asked to answer several questions regarding their playing behaviour, both with and without getting haptic feedback on the matter, based on what you hear, see and feel. This experiment will take approximately 30 minutes and your responses will be noted.

Information gathered from this experiment will be anonymized and will be used in my master thesis and for the PhD research it contributes to. Therefore, the anonymous data will also be shared with mister Spieker. All personal data is handled in a confidential manner, where it is not shared with any third parties without your explicit permission. You are free to decline to answer any question and at any point during the session, you can decide to stop, without having to give a reason and without it having any consequences for yourself. Furthermore, up to 24 hours after the experiment, you can choose for your data not to be used in the research. The anonymized data will be stored safely in a password protected environment and the signed consent form will be stored away in a locker (only accessible to people with proper authorization) at the university. This form will automatically be destroyed after five years at the latest.

This research has been reviewed by the Ethics Committee Information and Computer Science. To my knowledge, there are no risks in participating in this research. If you have any questions about the experiment or wish to withdraw from the research, feel free to contact me at h.v.vandeven@student.utwente.nl. If you have any questions about the use of your data within the larger PhD research, feel free to contact Benno Spieker at b.p.a.spieker@utwente.nl or Dennis Reidsma at d.reidsma@utwente.nl . If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

Thank you for you participation!

Consent form

Please tick the appropriate boxes

	Yes	No
Taking part in the study		
I have read and understood the study information dated ……., or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
Use of the information in the study		
I understand that information I provide will be used for a master thesis and findings from this thesis may be used in a larger PhD research.	○	○
I understand that personal information collected about me that can identify me, will not be shared beyond the study team.	○	○
I agree that my information can be quoted anonymously in research outputs	○	○

Signatures

_____	_____	_____
Name participant	Signature	Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

_____	_____	_____
Hester van de Ven	Signature	Date

Appendix D

Interview Responses

Participant 1

Layman

Q1: Did you already have any previous experience with haptic feedback? If yes, what? Not really.

Q2: Can you explain what your experience was like with this haptic wearable? It was a good experience. It made it easier to match the different modalities, especially when you can't really see what is going wrong.

Q3: For these scenarios, you could simultaneously use either sight and hearing, or sight, hearing and touch, depending on whether or not you had support from the haptic feedback. Can you explain what you based your decisions on of which student was playing incorrectly? Mostly sight and touch. I couldn't hear what was going wrong. Only without the feedback I also tried to hear the behaviour, but it was difficult. I couldn't hear the direction of specific sounds, but only the sound as a whole.

Q4: Did the haptic feedback influence *how* you listened and watched? If so, please explain how. With the feedback, I made the comparison between the haptics and what I saw and that made me find the mistake more quickly.

Q5: Would you recommend this form of feedback as a support for people with little musical experience? Please explain why/why not. Yes. It makes it easier to understand what is going on when you can't hear it. For me it was a lot more pleasant to rely on the feedback instead of the sound. Perhaps it wasn't that much quicker, but it was a nice check to see if it [the playing behaviour] was correct. That also gives more confidence, especially if you would have to call on someone in the class.

Q6: What would you change or add to this current feedback system to improve it? I can imagine the task would be more difficult if there would be multiple different instruments. With rhythm, this feedback works well, but perhaps with melodic exercises, it would not. Perhaps for melodic classes, you could also use louder or softer vibrations to give information about the melody. However, for a percussion class, I don't see anything that needs to be improved. Perhaps it would be nice to have the feedback on both arms for more embodiment and the general experience. Currently, the focus is specifically on the left arm, so that feels different than if you would be able to feel it throughout your whole body. Not particularly for better recognition, but for the experience.

Participant 2

Layman

Q1: Did you already have any previous experience with haptic feedback? If yes, what? I have tried haptic feedback earlier in my studies, but that was quite some time ago.

Q2: Can you explain what your experience was like with this haptic wearable? It was a really nice experience as support for keeping in time with the rhythm.

Q3: For these scenarios, you could simultaneously use either sight and hearing, or sight, hearing and touch, depending on whether or not you had support from the haptic feedback. Can you explain what you based your decisions on of which student was playing incorrectly? I mostly based it on hearing and touch. With the feedback, the hearing became easier to focus on. Then once I had a suspicion about the direction where the issue was, I also focused my sight on that area.

Q4: Did the haptic feedback influence *how* you listened and watched? If so, please explain how. It did influence my focus. Without the haptic feedback I had to use my sight a bit more next to my hearing, but that would be unhandy in a larger class where you don't have the overview. With the haptic feedback you are more in the rhythm, similar to feeling the bass in your body on a music festival.

Q5: Would you recommend this form of feedback as a support for people with little musical experience? Please explain why/why not. Yes I would, as it helped me. However, perhaps with the feedback on a different spot, as the placement on my wrist was a bit ticklish.

Q6: What would you change or add to this current feedback system to improve it? Perhaps an option to feel everyones behaviour individually, so you get a more complete impression of the class and thus also what exactly is going wrong.

Participant 3

Layman

Q1: Did you already have any previous experience with haptic feedback? If yes, what? Yes, a bit in my studies and in my Apple Watch.

Q2: Can you explain what your experience was like with this haptic wearable? At the beginning, it took some time to make the connection between sigh and touch. First, I had to see someone who was playing correctly and then I had the connection of the right rhythm. The feedback was useful for embodying the rhythm and being able to tap along myself. That was really pleasant for me.

Q3: For these scenarios, you could simultaneously use either sight and hearing, or sight, hearing and touch, depending on whether or not you had support from the haptic feedback. Can you explain what you based your decisions on of which student was playing incorrectly? Without the feedback, I would first focus on hearing and trying to see the rhythm. Then, when I though I saw someone who was not playing correctly, I would compare them to the person next to them. Then you would know if it was indeed incorrect. With the feedback, I could immediately see whether it was right or wrong so there was no need to compare them to each other anymore.

Q4: Did the haptic feedback influence *how* you listened and watched? If so, please explain how. Yes, I focused more on one person at a time with the feedback and I would immediately know if that person was wrong or right. That went a lot quicker than having to compare them one by one, and it also made me feel more sure of what I was doing.

Q5: Would you recommend this form of feedback as a support for people with little musical experience? Please explain why/why not. Yes. I am not sure if it would be weird to get this feedback if you're also performing yourself, but as a reference, which is was now, I would recommend it as it helped me in the identification process.

Q6: What would you change or add to this current feedback system to improve it? I liked the placement of the feedback as it was. Another option might be on both arms as you use both arms in drumming, but that would be too much info at once. The only thing I would change is to make the vibration a bit less loud as it was quite intense.

Participant 4

Layman

Q1: Did you already have any previous experience with haptic feedback? If yes, what? No prior experience.

Q2: Can you explain what your experience was like with this haptic wearable? It felt a bit funny, but not annoying. It was quite a nice addition, as long as it was synchronised well with the video and audio.

Q3: For these scenarios, you could simultaneously use either sight and hearing, or sight, hearing and touch, depending on whether or not you had support from the haptic feedback. Can you explain what you based your decisions on of which student was playing incorrectly? I focused mostly on sight. Hearing and touch were synchronised in the background in my head. I would use that to match my sight with. First, I scanned the whole class and when something stood out, I would focus on that. There was little difference between with and without haptic feedback, as it was mostly in the background and I focused primarily on sight.

Q4: Did the haptic feedback influence *how* you listened and watched? If so, please explain how. Not that I was aware of.

Q5: Would you recommend this form of feedback as a support for people with little musical experience? Please explain why/why not. It depends on the setting. In larger classes when more students play incorrectly it might be a bit too much with so much going on already. On the other hand, it could also help to give a clear reference within the chaos. However, in the current setting many students played correctly, so it was easy to hear the correct rhythm right away.

Q6: What would you change or add to this current feedback system to improve it? The first improvement would be to make it wireless as it was a bit annoying to be attatched to the Arduino. The placement on the wrist was nice. I can imagine this system being more difficult if the students were playing live and more chaotic as I would wonder what determines which behaviour you would want to follow then.

Participant 5

Expert

Q1: Did you already have any previous experience with haptic feedback? If yes, what? No.

Q2: Can you explain what your experience was like with this haptic wearable? Really fun! It felt a bit weird at first, but not annoying.

Q3: For these scenarios, you could simultaneously use either sight and hearing, or sight, hearing and touch, depending on whether or not you had support from the haptic feedback. Can you explain what you based your decisions on of which student was playing incorrectly? I started out quite visually. Later I would also listen to localise the mistake and then specialise visually again. So I focused most on hearing and sight. I did notice the feeling of the feedback and it did help getting into the vibe of the music, so it gave a hollistic experience. Still, for identifying the mistakes, I mostly based my decision on hearing.

Q4: Did the haptic feedback influence *how* you listened and watched? If so, please explain how. As I said, it did help that you could feel the music in your body. In the beginning, I did try to match sight an touch, but then I switched back to sight and hearing as I am familiar with that. Perhaps if I would have had the device longer and was more familiar with it, I would trust it more.

Q5: Would you recommend this form of feedback as a support for people with little musical experience? Please explain why/why not. Yes I would. I think it would give more confidence in knowing the rhythm and knowing what you are looking for.

Q6: What would you change or add to this current feedback system to improve it? I liked that it was a vibration because I automatically made the association of 'Hey, I need to do something or pay attention' similar to vibrating alerts in mobile phones. However, I would have preferred a tighter tap from the motor, instead of the current buzz, to match the audio better. I found it useful that the right rhythm was communicated through the feedback, so that was fine as it was.

Q7: 'Would you recommend this testing environment as a training setup for people to practice with teaching music classes? Yes, I think it could come in handy. Because it is a digital class, you can feel free to try stuff out, which you may not feel like in front of a live class. It was nice and necessary that you could hear the individual sounds with the speaker setup as it was. I would have preferred to also have individual screens matched with the individual speakers so the students in the simulation really seem like individual students.

Participant 6

Expert

Q1: Did you already have any previous experience with haptic feedback? If yes, what? Yes, with vibrations when my smartwatch gives an alert.

Q2: Can you explain what your experience was like with this haptic wearable? It was fun to use. It gives a playful element to the exercise and it puts focus on trusting your senses.

Q3: For these scenarios, you could simultaneously use either sight and hearing, or sight, hearing and touch, depending on whether or not you had support from the haptic feedback. Can you explain what you based your decisions on of which student was playing incorrectly? First, I used hearing to identify if the mistake was on the right or the left. Then I would try to match sight, hearing and, if it was present, also touch all at once. I generally only had to look at a few students before finding the mismatching one.

Q4: Did the haptic feedback influence *how* you listened and watched? If so, please explain how. Yes and no. The influence varied a bit. In some scenarios, it provided an extra layer of certainty in experiencing the rhythm and spotting the mistake. However, when I found the scenario more difficult and I struggled a bit more with identifying all the behaviour, as was the case with rhythm 2, I got confused by how much input I was getting at once. Especially when the feedback is not perfectly synchronised with the audio and visuals, it can have a confusing effect, but also if the feedback has a high pace, is more complex or the music has a high rhythmic density.

Q5: Would you recommend this form of feedback as a support for people with little musical experience? Please explain why/why not. Yes. For beginners who are struggling with recognising the right beat, this can be a very useful extra sense, especially because you can feel it in your body. I expect even more so if you use it more often and get familiar with it. In order to correctly carry out rhythmic pieces, you have to internalise the rhythm and it needs to become tangible. This wearable helps with that and can give more assurance. Especially in pieces with more variation the stable reference can provide guidance. I think the internalisation is one of the primary principles for beginners and later, additional feedback can help expand to more complex rhythms. Still, the design needs to be correct to avoid confusion, but in the scenarios where I did not struggle so much, it worked very well.

Q6: What would you change or add to this current feedback system to improve it? The vibration was clear and recognisable because I am used to vibrations on my wrist from my smartwatch. Perhaps a shorter tap or buzz would be more suitable for the application. I think the current complexity of the feedback for these rhythms was at its maximum. It should not become more complex with additional information. Perhaps if you would also want to know what exactly is going wrong, it might be useful to also have the option to feel individual behaviour. However, for beginners, I think only feeling the reference that you are aiming for is more suitable as otherwise they would have to already know the reference themselves to make sense of any other behaviour, and that can be tricky.

Q7: 'Would you recommend this testing environment as a training setup for people to practice with teaching music classes? It could be very useful as a training setting. It is an accessible way of practicing the senses within a class setting without having to worry about real students and didactics. It gives space to make mistakes and to take the time to listen. Besides, it is playful and accessible, so it is more refreshing and more relaxed than a normal class setting.

Participant 7

Layman

Q1: Did you already have any previous experience with haptic feedback? If yes, what? Yes, in my studies and with my smartwatch.

Q2: Can you explain what your experience was like with this haptic wearable? It was not distracting, but I do not feel like I got anything out of it.

Q3: For these scenarios, you could simultaneously use either sight and hearing, or sight, hearing and touch, depending on whether or not you had support from the haptic feedback. Can you explain what you based your decisions on of which student was playing incorrectly? I based it purely on sight and hearing. I mostly used hearing to identify the direction from which the mistakes were coming. Then I tried to match it with my sight, for which I went from left to right or sometimes per screen untill something stood out.

Q4: Did the haptic feedback influence *how* you listened and watched? If so, please explain how. No. I barely paid attention to the feedback as I was already able to hear the right rhythm myself.

Q5: Would you recommend this form of feedback as a support for people with little musical experience? Please explain why/why not. No, I would not, as it did not help me.

Q6: What would you change or add to this current feedback system to improve it? I would not know what to improve for this application, as I did not need it. Perhaps it would be useful to target it for deaf people instead.

Participant 8

Layman

Q1: Did you already have any previous experience with haptic feedback? If yes, what? No.

Q2: Can you explain what your experience was like with this haptic wearable? The feedback from the wearable was useful in directly recognising the correct rhythm. Without the feedback, I had to hear it three times before knowing it.

Q3: For these scenarios, you could simultaneously use either sight and hearing, or sight, hearing and touch, depending on whether or not you had support from the haptic feedback. Can you explain what you based your decisions on of which student was playing incorrectly? I mostly relied on sight and touch. Less on hearing because it found that difficult. When the feedback was not present, it was almost completely on sight. Perhaps my hearing did subconsciously play a role as well, but not that I noticed. I did notice that for sight, I looked from left to right every time and went across the students one by one, so how long it took to respond may have been been influenced by where they were in the class.

Q4: Did the haptic feedback influence *how* you listened and watched? If so, please explain how. My approach was similar with and without the feedback, but the feedback did make it easier to spot mistakes because it was an extra sense to rely on.

Q5: Would you recommend this form of feedback as a support for people with little musical experience? Please explain why/why not. Yes, I think it could be helpful. I did still find it quite difficult to identify the mistakes, even with the feedback, but it did help a bit. It also gave me more confidence in the process.

Q6: What would you change or add to this current feedback system to improve it? I found the feedback helpful as it was, so I would not change it. Besides, both the feeling and the placement were fine, so no improvements there either, except to make it wireless.

Participant 9

Layman

Q1: Did you already have any previous experience with haptic feedback? If yes, what? I have felt it before, especially in game controllers, but never in a musical setting.

Q2: Can you explain what your experience was like with this haptic wearable? I had to get used to it for a bit. Once I was, the feedback helped me become one with the rhythm a bit more. However, I personally did not quite notice a difference with or without the feedback. If anything, I felt like I could focus better without the feedback because there were less senses to pay attention to at once. With the feedback, it felt a bit more chaotic. I also think it may have felt more natural to have it on my right wrist, as that would also be the arm with which I would naturally tap along to the beat.

Q3: For these scenarios, you could simultaneously use either sight and hearing, or sight, hearing and touch, depending on whether or not you had support from the haptic feedback. Can you explain what you based your decisions on of which student was playing incorrectly? In the beginning, I focused mostly on sight as hearing was quite difficult. After a few scenarios it became a mix of hearing and scanning. I would hear the general direction of the mistake and then match it with my sight. I did not notice the feedback playing an active role in the identification, although I think it may have been present in the background. I think it is a helpful layer when you have no idea what so ever yet, but once you get a sense of where about the mismatching student should be, you base your identification completely on sight and hearing as those are tasks that you are actively working on, and thus are also more actively aware of. In addition, the feedback may play a bigger role if multiple students were playing incorrectly, but in the current scenarios it was easy to hear the right rhythm as many people were playing correctly.

Q4: Did the haptic feedback influence *how* you listened and watched? If so, please explain how. It did not influence so much how I listened. Only in the beginning, I would compare what I was seeing, which was most often correctly playing students, with what I felt until I understood the reference rhythm. Then identification was done with sight and hearing. Without the feedback it was a different process of hearing and recognising the reference rhythm from the class as a whole. Especially in scenarios where students were not playing perfectly in sync, it was difficult to hear and determine the margin in which behaviour was still considered correct. With the feedback, this doubt was significantly less as you were certain that reference was right and could be trusted. As a result, you were more sure about what you were doing.

Q5: Would you recommend this form of feedback as a support for people with little musical experience? Please explain why/why not. I think it might. I don't think it solves the whole issue of the difficulty of recognising the incorrectly playing student, but it mostly helps in the beginning to organise the initial chaos, especially if students do not play very tightly. If the musical situation is confusing to you, the feedback acts as a common thread.

Q6: What would you change or add to this current feedback system to improve it? Perhaps the placement could be altered to both arms to match better with the sight of the two drum sticks and to create more embodiment through the body. Otherwise it seemed fine. It was nice to get only one reference in the feedback. For example, individual data of the students would become too chaotic.

Participant 10

Layman

Q1: Did you already have any previous experience with haptic feedback? If yes, what? Not really, although a bit in my smartwatch.

Q2: Can you explain what your experience was like with this haptic wearable? I am not very good at keeping rhythm, so the extra reference was nice. It was difficult to match it to each student individually, but in general it kept me in the beat, which made the identification easier.

Q3: For these scenarios, you could simultaneously use either sight and hearing, or sight, hearing and touch, depending on whether or not you had support from the haptic feedback. Can you explain what you based your decisions on of which student was playing incorrectly? First, I tried to identify the initial direction of the mistake by focusing on both hearing and, when it was present, also the feedback from the wearable. Once I knew the direction, it was easy to also see the specific student with the mismatching behaviour. The feedback did not directly make it clear who was the incorrectly playing student, but it did help in the first phase.

Q4: Did the haptic feedback influence *how* you listened and watched? If so, please explain how. With the feedback, it was a lot easier to hear the direction of the mistakes in the first step of the process. The feedback provided the reference and then I could hear what did not match.

Q5: Would you recommend this form of feedback as a support for people with little musical experience? Please explain why/why not. Yes, if I look at how it helped me. It does not directly point you to the person you're looking for, but it does help to get you going and it gives more certainty to how you experience the situation.

Q6: What would you change or add to this current feedback system to improve it? I would make the wearable wireless, but other than that it seemed fine to me. It was comfortable and easy to put on and take off. Besides, it was helpful to hear the reference rhythm, especially for the tasks at hand.

Participant 11

Layman

Q1: Did you already have any previous experience with haptic feedback? If yes, what? No.

Q2: Can you explain what your experience was like with this haptic wearable? It was an interesting experience. I think that the feedback helped me in the tasks that I had to carry out.

Q3: For these scenarios, you could simultaneously use either sight and hearing, or sight, hearing and touch, depending on whether or not you had support from the haptic feedback. Can you explain what you based your decisions on of which student was playing incorrectly? First, I used hearing to identify the direction from which the wrong playing behaviour was coming. Then I would rely on sight, and if the feedback was present, also touch to find the mismatching person in the direction that I heard. I often looked per screen and then either go person by person or compare a few to each other.

Q4: Did the haptic feedback influence *how* you listened and watched? If so, please explain how. With the feedback, I mostly compared my sight with the reference that I felt and hearing became a bit less prominent after I used it to detect the direction. Without the feedback, the hearing was still a bit more prominent in the second phase, but still, sight was the primary sense on which I relied for the identification in both instances.

Q5: Would you recommend this form of feedback as a support for people with little musical experience? Please explain why/why not. I think for beginners all help is welcome. The feedback was not intrusive, but acted as an aid. Especially when scenarios were a bit more chaotic the reference was useful to have. I can imagine that for a teacher perhaps also walking around and also being busy with different tasks in a noisy class, it could be a useful support.

Q6: What would you change or add to this current feedback system to improve it? I would make the wearable wireless and perhaps place it on the dominant hand, but other than that, it felt fine. Perhaps an alternative to indicate incorrectly playing individuals could also simply be an LED lighting up when the difference with the rest of the class becomes too large. On the other hand, with the reference rhythm, you could also sense what was going wrong, rather than just the fact that it did not match well.

Participant 12

Layman

Q1: Did you already have any previous experience with haptic feedback? If yes, what? I have worked with it a few times before in my studies.

Q2: Can you explain what your experience was like with this haptic wearable? In general, the experience was good, but for the scenario with rhythm 2, where students played a bit less synchronised, the feedback was more distracting than helpful. However, with the other scenarios, it was clear and helpful.

Q3: For these scenarios, you could simultaneously use either sight and hearing, or sight, hearing and touch, depending on whether or not you had support from the haptic feedback. Can you explain what you based your decisions on of which student was playing incorrectly? For the identification itself, I relied most on hearing and sight. I would try to hear the direction where the mistakes were being made and then try to match that with what I saw in that direction. Because I would generally not immediately find the incorrect player, I would compare every two students close to that direction to each other until I found a mismatch.

Q4: Did the haptic feedback influence *how* you listened and watched? If so, please explain how. Visually and audibly, my strategy was similar with and without the feedback. However, the feedback did help at the very beginning of each scenario to identify the reference I was going for. I recognised the reference more quickly, but the vibrations also gave a stronger feeling of the rhythm. After the first few seconds of identifying this rhythm I had internalised it a bit and then I went on to the identification with sight and hearing.

Q5: Would you recommend this form of feedback as a support for people with little musical experience? Please explain why/why not. I think I would recommend it, although I wonder whether it would become too distracting for larger classes where there is more chaos. However, in the current setting it was quite nice as it helped internalise the rhythm through the physicality of the vibrations and the fact that it was easy to tap along to the feedback with my own foot.

Q6: What would you change or add to this current feedback system to improve it? I would improve the system by offering more scenarios to practice with and to get familiar with the feedback. For the wearable itself, some improvements could be to make it wireless and to make the buzz shorter so it matches better with the sound, but perhaps also to turn the device it into something to hold or a glove. The placement on the wrist felt a bit awkward. For the content of the feedback, I think the reference rhythm was useful, but perhaps you could offer the option to switch between the general right rhythm and data more specific what is going wrong.

Participant 13

Layman

Q1: Did you already have any previous experience with haptic feedback? If yes, what? A little bit from my phone, such as tactile alerts.

Q2: Can you explain what your experience was like with this haptic wearable? It was an interesting experience. The feedback seemed to help me as I was able to connect it easily to other senses. However, at times the simulations and the feedback were not syncronised perfectly and in those cases the feedback was a bit distracting.

Q3: For these scenarios, you could simultaneously use either sight and hearing, or sight, hearing and touch, depending on whether or not you had support from the haptic feedback. Can you explain what you based your decisions on of which student was playing incorrectly? In the beginning of each scenario, I would focus on the haptic feedback to quickly understand the reference rhythm. After that, my focus shifted to hearing first, to hear where the mistake was coming from, and later also to sight, to find a match between what I was hearing and what I could see in that same direction. Without the feedback, I had to hear the correct rhythm on my own, which was rather difficult.

Q4: Did the haptic feedback influence *how* you listened and watched? If so, please explain how. Yes, the feedback gave an immediate clear interpretation of the reference rhythm which I could compare the students' playing behaviour to. That made it easier to find the odd one out.

Q5: Would you recommend this form of feedback as a support for people with little musical experience? Please explain why/why not. Yes, especially to get a feeling for basic rhythms and to gain support in more difficult situations. For example, I can imagine it being much more difficult in a larger class to hear what is going right or wrong and what the music should sound like. Especially, when your musical ear is not that great. At least with the feedback given here, you would be sure.

Q6: What would you change or add to this current feedback system to improve it? The placement on the wrist felt a bit weird and it was not always as sensitive. Therefore, perhaps a placement on the hands or another sensitive area might be better. Content wise, I liked having the reference communicated to me, and I would not add anything else as that could become too distracting.

Appendix E

Alternative Design Choices

These design choices were considered as possible alternatives and/or follow-ups to the current design.

Scenarios:

1. Simple rhythm
2. Intermediate rhythm
3. Difficult rhythm
4. Additional play-along music
5. Multiple parts simultaneously
6. Multiple instruments simultaneously
7. Multiple students playing incorrectly

Feedback content:

1. Correct rhythm
   (a) Single reference
   (b) Alternating between parts
2. Incorrect rhythm
   (a) Alternating between students (perhaps with the use of a button)

Feedback design:

1. Shorter/longer pulse based on synchronicity of the class
2. Strength of vibrations based on how quickly the teacher finds and corrects the mistake (i.e. harder vibrations when it takes long to offer extra support)
3. One actuator to indicate *that* something is going wrong, another one to indicate *what* is going wrong
4. Two spatially separated actuators, left and right, to give an indication of direction
5. Accent on the student closest to the teacher, when the teacher is walking around in the class