A Saxophone Teaching Glove: Introducing Haptic Feedback Amongst Beginner Musical Enthusiasts

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ABSTRACT
Playing the saxophone can be a rewarding activity, however it is also time consuming, especially learning it and doing so through a traditional manner. This is further exacerbated by the requirement of learning music notation before even producing any sound. A new trend of autodidactism is rising, as opposed to formal education, especially now with times of pandemic. This causes numerous new issues to surface, such as lack of motivation and loss of motivation and connection between student and teacher. Our prototype aims to allow players to play the saxophone by mimicking hapticly sent movements while also supporting their recording by those who want to teach others without relying on musical notation. Based on our tests, results indicate that there is a strong preference for slow methodical learning for those without any experience and fast and rhythmical learning for those with. The study indicates that Saxophone practitioners are welcoming towards haptic technology. However, this raises the question on the different kinds of haptics and feedback each person prefers.

KEYWORDS
Haptic, Music Tutoring, Saxophone, Wearable Computing, Human Computer Interactions

1. INTRODUCTION
Playing an instrument is a popular activity amongst people of all ages [1]. Learning to properly play a musical instrument is a lengthy process and the effort required in order to be able to play decently acts as a barrier of entry for many. Because of that, people use guidance in the form of a musical teacher. Using formal education can be difficult due to the need of finding a capable lecturer, but also due to financial investments. Whereas informal education, and specifically autodidacticism and online platforms, allow for more flexibility, plethora of resources and teachers, and are seen as cheaper alternatives to the former. For these reasons, as well as due the current pandemic, this method of learning has been increasing in popularity [2]. However, remote learning can cause certain unforeseen complications, which can lead to developing bad habits and forms during practice. These issues can hinder progress, cause confusion due to not being able to comprehend what the lecturer is doing and be soon followed by demoralization, which in turn, can make the person give up entirely [3].

There are different methodologies when it comes to learning efficiently in the human computer interaction field, with some focusing on haptic wearable technology. Many of the contributions by Thad Starner influenced investigation in various fields, but also in music, which caused the publishing of the “PianoTouch” [4] and “ShIFT” [5] papers. These papers look at the performance gains from a quantitative perspective, on specific instruments such as a piano or a flute. Whereas we propose looking at the problem from a different view - the building and testing of a haptic solution and how it affects people trying to learn to play the saxophone. We want to try to understand what scholars and practitioners alike would need and what effects we can observe through the use of our solution. We find the topic can be further contributed by focusing on a solution which both aims to abstract away the complexities of learning to play an instrument, as well as enhancing the awareness that teachers and students can have on each other.

The paper itself, would follow on how we achieve that by illustrating the process of building a glove prototype, our tests with it and the conclusion that we came up with. The paper is divided into several sections which outline the process in chronological order. The reader will be introduced to a more concise view of what has already been done in the field and what the latest findings are. Then there will be an emphasis on the design decisions we took, as well as specification on how and why we chose to build the glove and the various use cases it supports. Said glove will be used in conjunction with semi-structured interviews and usability tests based on qualitative methodologies. Lastly, we would try to observe how the different participants behave, how the glove is used and what their thoughts on it are. Based on said observations, we will try to identify what effect it has both on them and the learning process and propose a direction for future research.

It is important to note that we will not tackle breath control and will support only one hand, thus limiting us from using the full range of a saxophone. Furthermore, the ongoing lockdowns affected us in regards to planning meetings, tests and interviews. Therefore, we will keep our tests limited to the notes that would be taught in the initial lessons to students and emphasize on online interviews and very limited in-person tests.

2. RELATED WORK
During the span of the year 2020, there was a mass lockdown [6] caused by the outbreak of a virus. This required a lot of changes to occur in the teaching sphere, such as not allowing physical lessons and moving to a remote style of practicing and learning. That by itself has caused many dissatisfaction and challenges. A study by Kris Ho and Victor J. Rodriguez [7] was conducted in a span of a year in China, where the authors explored how this switch to online lessons has affected both the

students and teachers. The paper concludes that one of the biggest struggles for both parties is the lack of physical presence, intimacy and proximity. The connection, both emotional and personal, between teacher and student has gone. That is something which cannot be achieved through the means of remote lecturing.

Based on these findings, we were interested in seeing what kind of effect an attempted re-establishing of this lost connection would have on learning through the use of haptic technology. Following the experiment of G. W. Young, D. Murphy, J. Weeter [8], we can point to the fact that users have a strong preference on the use of haptic feedback over its absence in a musical context. Furthermore, we can compare the difference between only visual, only haptic and both at the same time in a study conducted by A. Balandra, H. Mitake, T. Yoshida and S. Hasegawa [9]. We can clearly identify that utilising both has overwhelming benefits compared to its singular counterparts.

Those papers suggest that both consciously and subconsciously we gravitate towards the additional use of haptic feedback and its benefits in our activities. Based on the "PianoTouch" project [4], we know how this technology aids in the learning process. In conclusion to the paper, the authors suggest the utilisation of an instrument, which would have an equal amount of finger to button mappings, such as the flute. The study "ShIFT" [5] was conducted based on that specific recommendation. They argue that traditional instrument learning is a lengthy and inefficient process. They point out that while there are existing haptic solutions, they fail to succeed due to having limited or partial motion learning. The argument for which is that other solutions focus on the fast learning process or do not take into account the different arm lengths and breathing patterns. Because of that they had a custom made flute that served as a tutor and compared learning rates in participants. There is a 30% increase in learning speed for a song within 30 minutes using the prototype device compared to videos.

Our aim was to develop a solution which, through haptic feedback, would affect remote learning, help strengthen the connection between student and teacher and tackle the barrier of entry in learning to play the saxophone. Through this, we try to gather the understanding of what design choices would cause positive effects on our focused elements. This spurred us into conducting research into what are the main struggles of beginner music enthusiasts [3]. After gathering data from beginners, teachers and autodidacts, we made a thematic analysis on extracted code words. In that report, we concluded that one of the biggest issues was the lack of personalisation, motivation and the high barrier of entry. This paper serves as a continuation, as we build our prototype based on the data we have gathered.

3. PROCESS AND METHODOLOGY

Our approach to creating the glove prototype, which would serve as the principal artifact for our research, made use of theory used as part of Research Through Design [10]. This allowed us to bring a relative structure to our informal approaches to designing and iterating over as the solution progressed. We made use of the Design Thinking process [11], which was useful to identify and investigate problems while not enforcing specific practices on us thanks to its ambiguous elements [12]. The sort of problems we looked at are described as "wicked problems" [13], due to the fact that they are not simple to describe without the same awareness that the involved stakeholders have.

In order to evaluate the effect that our proposed solution has, we began by using Qualitative Research Design [14] methods, to help us collect data from users and attempt to confirm its accuracy. We designed different tasks, during which participants were encouraged to make use of the "Think aloud protocol" [15], which helped us better understand their thought process. These would then be followed by semi-structured interviews in which we got feedback on their experiences and asked them for their own wishes. Some which we implemented and used in later meetings and others which we kept as possible future work.

The knowledge we are producing contains rich data, presented both through our interpretations as well as of those whom we have interacted with. This is also visible through the described process of designing and developing our solution as well as the artifacts created to support us in these activities. We did this in a rich and vivid way in an attempt to present said tacit knowledge as well as to support our experiential approach to our project.

3.1 Design

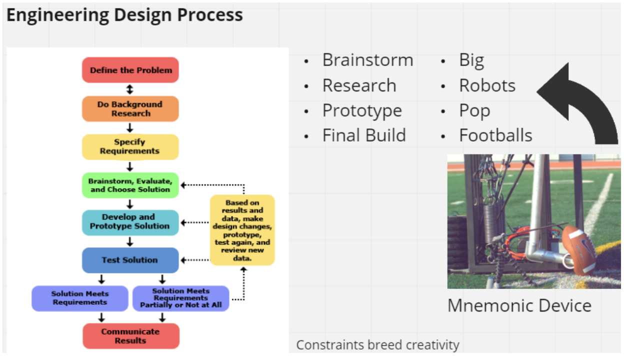

Figure 1 - The Engineering Design Process

In our initial design activities, we used the "Engineering Design Process" [16], a principle in engineering useful in order to come up with a solution for a problem. It is similar to the "Steps of the Scientific Method" [17], however, the Steps of the Scientific Method focus directly on the exploration of specific observations and generating answers. The Engineering Design Process, on the other hand, emphasizes the importance of designing, building and testing the built artifact. Both these principles, similarly to Research through Development, have the advantage of encouraging iterative work and they act as a guide, not a stringent regulation.

We further encapsulated the steps in the principle to Brainstorming, Research, Prototype and Final Build. It would be important to emphasize that even later in the other phases of our project, we went back and made changes, but this was the structure we followed for our initial work. The brainstorm step resulted in Figure 2, which shows our proposed solutions and quick descriptions on how they could be achieved. The solutions are each under a main theme we gathered from our previous project [3]. We did this in the form of an open discussion that helped us to better describe the problem. Further down the line, in the research step, we looked at similar problems and how others have tackled them.

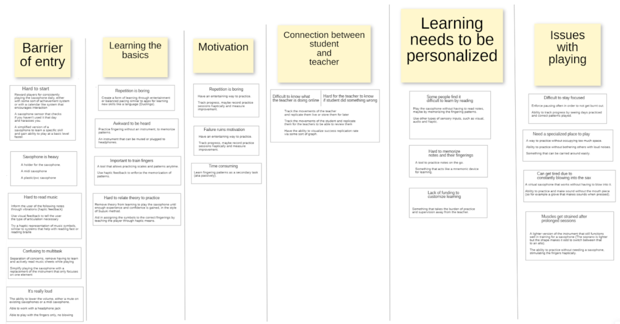

Figure 2: The main themes and proposed solutions

Each theme was arranged during our previous work and were interconnected to a certain degree. This meant that many problems were related and therefore solved by taking similar actions and, by targeting one problem, we could cause an effect on others.

3.1.1 Downselecting

Figure 3: Ideas related to our themes and proposed solutions

Figure 3 shows our approach in researching existing solutions and ideas we found inspiring. The principal activity at the time was to generate a moodboard. We used mainly image searches, as it allowed us to condense the flood of information and quickly make decisions if something was interesting or not. Some elements of the topics we found were solutions to the weight and volume of a saxophone, tools to help in learning to play instruments, progress tracking and aiding motivation. Others were more of a visual inspiration, which we used later during the prototyping step.

The sources of inspiration shown above we directly used in the process of "Downselecting", which we looked at through the prism of the following questions:

- What is interesting to work on?
- What is interesting to present?
- What do we think we can help with?

By looking at how others had tackled similar problems and the design choices they had made, it showed us problems and possibilities that we would have otherwise missed.

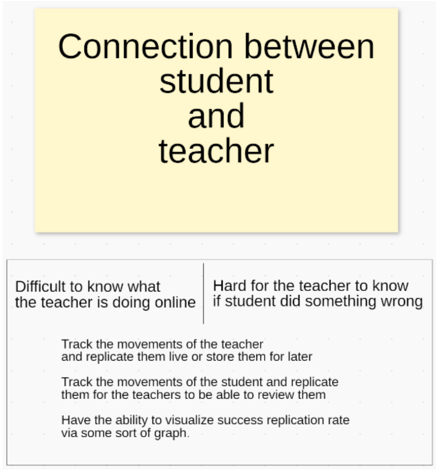

Figure 4: Selected target Theme

Continuing, our work focused primarily on the "Connection between student and teacher" as shown in Figure 4. However as the themes are interconnected, our solution could affect the other themes as well. We kept this in mind during our interactions with participants through interviews or discussions. Having developed a more concrete definition, the next step was generating a list of requirements we would need in order to fulfill the possible solutions. We afterwards separated these requirements into essential and non-essential requirements that were not vital to have a working solution, but would be, what we considered, nice to have.

3.1.2 Refining

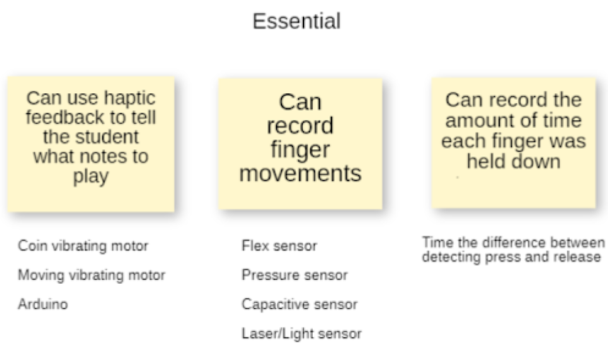

Figure 5: Essential requirements and how to tackle them

Underneath each requirement are listed ways we thought we could achieve them. To note is that at this stage we had not yet decided on the physical build. Our focus was on what it would have to do, and our abstract thoughts on how we would achieve it.

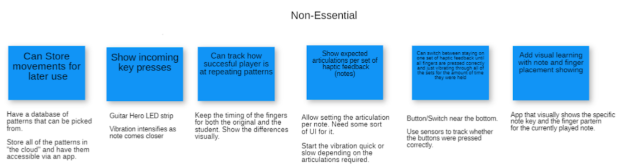

Figure 6: Non-essential requirements and ideas how to tackle them

Figure 6 contains the non-essential requirements we generated and, similarly to the essential ones, underneath each of them we have listed ideas on how to possibly tackle all of the problems. By having them written down, the argument would be that we could form a better image of the solution we chose and whether some of the non-essential requirements would need to be upgraded to essential.

An important element for us was maintaining fluidity. In the context of the requirements, this meant that any of the non-essential requirements could be prioritized, and any of the essential ones could be demoted. This could be either as a direct result of our work or from conversations with experts in different fields.

Fluidity in the context of our entire project meant that we needed to allow ourselves the possibility to later turn a design decision into a requirement without it blocking development. This was aided by the multiple processes we looked at, which encouraged iterative activities to be taken.

3.1.3 Ideating

At this stage of the process, we were in the Ideation phase of the Design Thinking process [18]. This is equivalent to the activities commonly used during the early prototyping step of the Engineering Design Process. We began thinking "outside the box", looking for alternative ways to view the problem and identify innovative solutions. During this phase we put an emphasis on Braindumping ideas when alone, and building upon them later with activities like Brainwalking or Challenging Assumptions.

The importance of ideating became further clear once we attempted to integrate user context into our design. We tried to see whether our ideas were relevant and if they would survive activities such as Challenging Assumptions. We did this through interactions with saxophone players and experts in the field of design and engineering.

In order to improve our awareness of the user context, we continued by developing user personas [19] and using them to better understand how a user may go about completing their goal and help us better visualize their motivations.

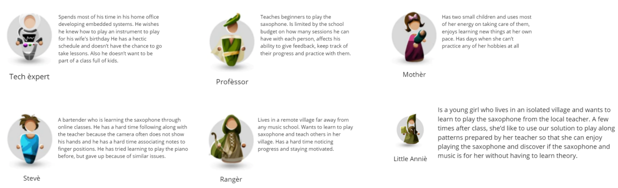

Figure 7: Personas we generated

We used each persona in at most two scenarios because it is recommended to have scenarios specific to the persona involved and not too generic [20]. We also used them with Hero Task Flows, which helped us understand the motivations of the user and describe each step they would take towards completing a goal, defined as their "Happy Path" [21].

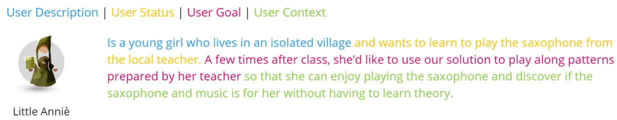

Figure 8: "Little Annie" user scenario

The user scenario created for the "Little Annie" persona, shown in figure 8 helped us gain insight in the way a person could use our solution. This could be in order to discover a new hobby while living in a place without readily available traditional education options. As well as giving her the ability to skip learning theory and see first hand, if saxophone playing is for her.

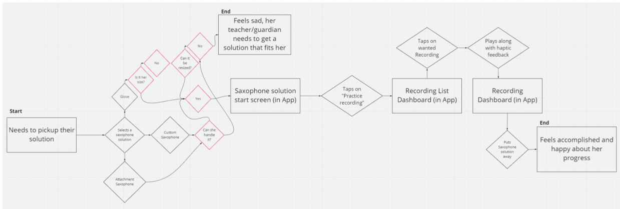

Figure 9: "Little Annie" Hero Task Flow

Figure 9 shows the Hero Task flow based on the "Little Annie" user scenario. Our focus while creating them was to get an understanding of what actions each persona would have to take in order to fulfill their goal. By leveraging the flexibility of this type of a task flow, we added elements straying from the Happy Path in order to clarify possible pitfalls based on our design choices. This helped us both during data gathering when discussing the project as well as during development.

Following the Engineering Design Process, we looked at prototyping. We did this, and used the insights gained, to create basic paper prototypes of our different ideas.

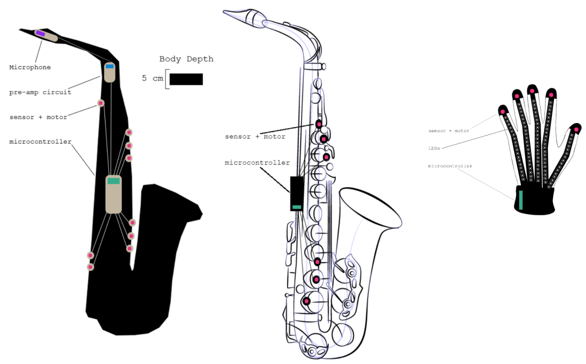

Figure 10: Left to right, Custom Saxophone, Attachment Saxophone, Glove

We discarded the Custom Saxophone idea early in the process after we realized that we would be required to make it produce sound, in order to make it a viable training solution. This would simply be out of the scope of this project. If not, participants would have to use it to practice fingering patterns and then put it away when wanting to actually see if their fingering patterns were in the correct form to produce sound.

The second prototype, the Attachment Saxophone, would work by clamping our solution unto an existing saxophone. We discovered the principal fault with this design after a discussion with a saxophone teacher. She explained that they do not hold their fingers on the buttons at all times, instead hoving above. This would be a problem as the buttons would vibrate and the participants would either not be able to feel them or they would have to be forced against habit

The glove prototype had its own limitations. Problems occurred to us in our designs in regards to difficulties charging while using. As opposed to the other designs, the weight was another problem, as each finger would be affected directly, similarly if the build would be too bulky. This issue had us switch between sensors, and whether to use an actual glove or build our own open-glove solution. We ended up going with the latter. We decided to continue work using this prototype. It also seemed like the fastest build we could make, which would allow an increased amount of iteration.

After designing these prototypes we decided that a second iteration was needed on our attempt to understand user context. We did this through a more visual approach, using comic panels.

Figure 11: Teacher recording songs for students comic panels

Figure 11 shows one of the 30 comics that we created during this time. The idea was to keep them simple and straightforward, without the text and diagrams of our previous attempt. This was needed in order to use them as better communication tools with those outside our team as well as to help us quickly arrange use cases through a visual manner.

We used these comics as a way to try to understand what dimensions intersect in possible use cases that we could provide. There were multiple sets, however we decided to focus on one specific combination. The first dimension we focused on was "Need" → "Convenience", which represented the extremes between scenarios where our solution would fulfill a need. The second dimension was "Single" → "Poly", which represented the extremes between the number of people affected while our solution would be used at one time.

We worked on deciding where on the spectrum of these dimensions we wanted our solution to be, so we created 3 design concepts based on the glove prototype. Our plan was to start with the most basic of the 3 concepts, Tutor, as it did not involve any sensors and would act as a foundation. From feedback we continued developing unto the more complex concept, Record, which implemented recording of movements in its functionality. As of writing this paper, the last concept milestone, Live, was not reached. It involved us building a second glove at the very least and having the gloves communicate in real time, using them to dictate movements from one participant to another.

3.3 Development

The initial build for the Tutor design concept used a winter glove. We quickly observed that for anyone with fingers of different lengths or thicker palms than ours, it would be hard or even impossible to use. We also had issues with wires getting disconnected and taking a long time to repair or replace, due to it all being on one body. The haptic sensations were sent to the user through eccentric rotating motors [22], which had the problem of getting stuck in the glove.

When working on the Record design concept, we took these problems into consideration and tried to solve them with our new build. Each finger is now handled by an independent module that can be soldered to the board, which is worn as a bracelet. This allows us to handle a broader hand size range, as each module can bend or straighten depending on the needs of the user. We also use coin motors, which do not have any moving parts and as such, will not get stuck into anything. Most of these design changes are visible in figure 12.

The initial version of this solution used flex sensors, which work by giving different values as their resistance changes through bending. These sensors are common in other implementations in related work and we had assumed they would be similarly useful for ourselves. Our assumption became challenged during an online interview with a saxophone teacher, where she expressed worry after seeing the videos of us using the glove. This made it clear that, in the case of a saxophone, such sensors are not reliable enough. In their stead, we used pressure sensors. We added the capability to calibrate the glove when a person would put it on, to detect the strength at which they would press on a saxophone. We did this after presenting the new version to some of our peers and realizing that, if they did not press as hard as we would, the glove would not identify their actions properly.

"*it is because in the video you showed me, you had to move quite a bit, but as saxophone players, sometimes we barely move the fingers, instead almost using something like, like the gravity. I guess, think... of it like when pressing on a keyboard, you would think that your fingers always bends, but it sometimes...is the whole hand that moves.*"

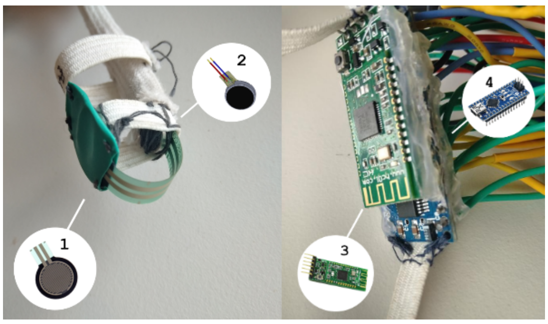

Figure 12: Modular Finger and board bracelet

In order to guarantee that all of the involved stakeholders understood the planned implementation, we created a design diagram shown in figure 13. We also used it as an aid in discussions with those initiated in development, as a way to quickly explain what our planned logic was.

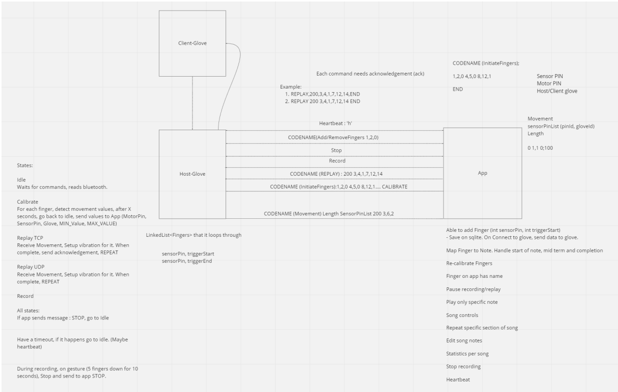

Figure 13: Design Diagram

Shortly after starting development, we had an online interview with an electrical engineer, who was interested in this phase specifically of the project. Our idea for the way the gloves work came into focus during this conversation. Using the design diagram, he expressed worries on the complexity burden we were putting on the arduino. He also recommended us to look into BLE [23] based communication modules instead of regular bluetooth ones.

Translated from Lithuanian - "*I see what you are making. But careful with too much complexity on Arduino, it is bad. Worse if you don't have a way to debug quickly*"

Translated from Lithuanian - "*... look into BLE. I understand bluetooth is common, but less battery use will help. Figure out your data limits early, and prototype a lot*"

We ended up using the recommended module as, even though it has less data transfer capabilities than regular bluetooth, it fits well inside our needs.

As it is shown in figure 13, the software is developed on two platforms, the glove is based on a Finite State Machine [24] and changes between states when given instructions by the Android application. Following feedback, the logic of each state has been iterated upon since development. One such change is the recording of movements. Originally, once a finger would be pressed, every subsequent finger press would be part of the original movement. This meant that to switch between notes, a player would have to lift all fingers up and then press them down again. The current implementation records a new movement each time a finger is pressed or lifted, allowing for a more organic behaviour to how saxophone players actually use the instrument.

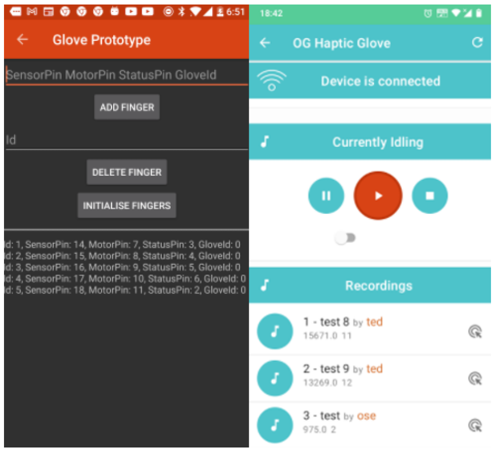

Figure 14: On the left the initial android app, on the right, the later one

Figure 14 shows the original app we developed to control the glove on the left side, which was enough for us to do our work. This quickly became redundant due to it not translating well to those we presented our solution to. Elements such as color theory [25], user friendliness and responsiveness were not prioritized and this caused distractions. We received their feedback and, before iterating over it again, we got an interview with a professional UI designer who pointed us in the right direction in regards to designing a proper application. Some of their techniques we were already using in the project as a whole, but now we would contextualize them on the android experience specifically. Techniques such as the Hero Task Flows to better understand the menu navigation, a cleaner UI using complimentary colors and making use of more visual feedback to the user when they would send commands to the glove. The result can be seen on the right side of Figure 14.

3.4 Data Gathering

We used interviews in order to gather our data as it is an efficient way to gather information on participants' experiences while also gaining insight on their personal perceptions and interpretation of reality. They are semi-structured because it allows us to not pre-define the entire conversation and instead use open ended questions from our own guide. This allows us to keep the conversation going without enforcing our own perceptions onto the participant. On-site interviews are a principal focus of ours because that is how we get to see others experience our haptic solution. Then we discuss it, which allows them to have a more in depth understanding of what it is, how it works, and what changes they would prefer.

A typical interview begins by having a short discussion, where we ask them what they expect from the session. In a first interview, this question can be interesting as an idea fuelling source, due to their answers not being grounded by previous experiences with our project. Afterwards, they are asked to put on the glove and experience the modes we have developed, using the Think Aloud Protocol [15] during the entire time. This is done by them playing different recordings, creating new ones. If the interview involves two participants, one of them takes the role of a teacher and the other of a student, in an attempt to teach each other a pattern. Once this is complete, the participant is asked about their experience, while using non-leading questions. All interviews are recorded with multiple devices and are later transcribed verbatim, which helps us better understand their train of thought and emotions through the entire process.

Early in the project, we were not able to book enough meetings to have others experience the glove and receive feedback through on-site interviews. In order to combat this, we started filming ourselves using the glove and posted the videos on online saxophone enthusiast websites as well as sending them directly to people we knew personally and analyzing their feedback.

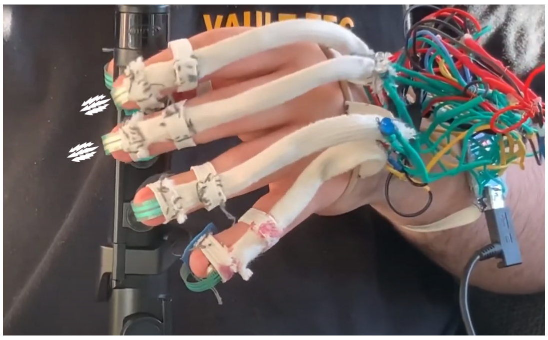

Figure 15: A frame from the videos we sent for feedback

Figure 15 shows a frame of the videos we had sent. In it there are 2 icons in front of the index and middle finger. They are used to make it clear to the watcher which finger is currently being guided. During the production of these recordings we followed the Participant Observation method [26], where we would use the Think Aloud Protocol, fulfill tasks and give our own feedback. This was helpful in the way of generating data, since we are part of the audience we were hoping to affect, namely complete beginner enthusiasts. But it was also useful in order to figure out what elements of our tests and interviews would work and what would be redundant to pursue.

The people we chose as participants were from various backgrounds and musical expertise, with most of them aged between 20 to 30 years old. We also got the opportunity to extend our network, eventually managing to have our project brought before members of the military orchestra of Lithuania, a saxophone teacher in Italy, an electrical engineer, a couple of students from Lithuania and even the Director of the Academy of Music in Vilnius.

All of the activities that we took in regards to acquiring data we recorded from a number of camera angles which later allowed us to transcribe both the second by second conversation as well as the actions and reactions that the users we were observing had at all times. Some of the interviewees had problems discussing complex topics outside of their mother tongue. Luckily, we were able to have a translator during these interviews which helped us lead the conversation.

4. RESULTS

Based on the video and audio recording, transcripts and suggestions from our participants, we made an analysis, in which we managed to structure the data into several distinct categories, each focusing on a different aspect of the project. Throughout the data acquisition process we managed to conduct 9 interviews, which encompass people with varying levels of experience. Those that have no musical knowledge or practice, those who have minimal exposure to saxophone or have experience in another instrument, similar or otherwise, and finally saxophone players with several years worth of playing. Each of those will be split and examined in different groups - 1, 2 and 3 correspondingly. Several additional interviews were done, however, unlike the previous ones, those were done remotely and as such, the user was not able to test the prototype. Instead, those volunteers have been video called and shown the item, with either us or another volunteer using the glove and showcasing the functionality. Most of the interviewees were professional saxophone players and teachers, their remarks have been taken into consideration. Lastly, we have provided detailed description of the item, as well as recorded videos of its usages, which have been submitted to various professional and amateur saxophone player groups. Their feedback, while useful, will not be regarded as strongly in this section, but will instead be focused on the discussion part of the paper.

4.1 Data Analysis

In order to be able to produce viable and truthful data, we went through several steps of a data analysation process. Firstly, we wrote down notes and observations of the main arguments, movements and complaints that our interviewees had. They served as our initial reactions and were very basic. After each, we would discuss among ourselves and share our findings, while the information was still fresh. After writing down the transcripts of the interviews, we gathered it together with all of the online comments and suggestions we have received. We extracted all of the key ideas and codings we could find and grouped them together based on their connection to each other and the uniqueness of their topic. We managed to assign them to 3 main categories - “Gamification”, “Positive vs Negative Feedback” and “On Beat vs Slow Learning”. Some of the main points we based our findings on are written in the rest of the results sections.

4.2. On-site Interviews

We asked the participants to test the glove, which was separated in the following sections:

- “Slow Learning” mode, where they would have to follow along a recording, and be guided through it by vibrations which would only continue to the next section if properly followed.
- “On Beat” mode, which would have the glove vibrate through all of the recorded movements without waiting for input from the user.
- Record mode, where a song would be played by the participant and the glove would save it in the database for later use.

After the test, we asked them to give their feedback on the test and any additional information they may be able to convey.

4.2.1. First Impressions

Following the interview guidelines, we asked all volunteers to equip the glove and give their first impressions of it. Based on the feedback from them, we were able to identify what each of them possibly wanted the glove to be able to do without being too biased from the current design and functionality. A majority of the people have played a game called "Rocksmith" [27], in which users are being taught how to play the guitar by using their actual guitar and software which detects the notes played. The chords are falling down on the game screen and the user is supposed to time them correctly, similar to our "On Beat" mode. Based on that, there were expectations of gamification of the learning process.

"*We are gonna teach me, like… how to play you know... sorta like Rocksmith but for saxophone… like umm, gamification of learning something. I dunno, it is probably gonna shock me or something and show me that I am doing it wrong.*"

"*I am not sure - I guess I will put on this glove and play some game… maybe I will see the chords come down and I have to press them similar to Guitar hero or Rocksmith...*"

"*...probably if it is gonna do something it will detect how… what pressure or maybe rather what key I am pressing on the saxophone if it is called, I am not sure. And… maybe it can give me some suggestions after on how to play… unless you have some feedback. I mean, I can see some LEDs, so maybe show me if I am pressing it correct or not...*"

Another point we have got is people who expected this to strictly be used as an enhancement for learning. Their expectations were that the glove would detect movements and give feedback on their performance at the end of the session or song. All of that points towards the desire to have a combination of statistical analysis and gamification of the process.

One of the reasons for which we chose the current design of the device was because people have different hand sizes and a simple glove would not suffice. Instead we focused on making sure to have support for a decent amount of hand lengths. However, we did not take into account how much of a factor the width would play in this. Because of that, we had participants that had the gloves' handles be too tight or too loose. While those were limited cases, they had a big impact on some of the data we gathered. One of the issues was those with bigger fingers would have to press harder for the data to register. It is entirely possible that the participants might have pressed too hard during the calibration phase, so those results need to be further investigated and as such they are not regarded as a huge issue.

Due to the different hand sizes, the volunteers felt the vibrations in various spots on their hands, as illustrated in Figure 16. All of the people that had loose fitting glove, felt the vibrations on the whole finger, while those who had it too tight, felt it in the middle of the finger. All other participants had the glove fit them well and felt the vibrations at the tip of the fingers. The motors are at the top of the finger, where the nail is and as such the vibrations are indirectly felt through the bones, which explains one of the volunteers, who felt it from the fingertip until the end of the palm.

We have also got complaints that the vibrations are too strong and can be very distracting. This amplifies the desensitization of vibrations on the fingers, causing long exposure to make the users fingers feel numb. Additionally, due to the strength of vibrations, in some cases, the whole saxophone would shake, causing distortions to the sound. These issues aside, all of the volunteers got used to the sensation and did not pay attention to it after a few notes, and were able to continue learning songs without obstacles. This data points towards limiting the vibration in both intensity and length and allowing the users to adjust to where they feel comfortable.

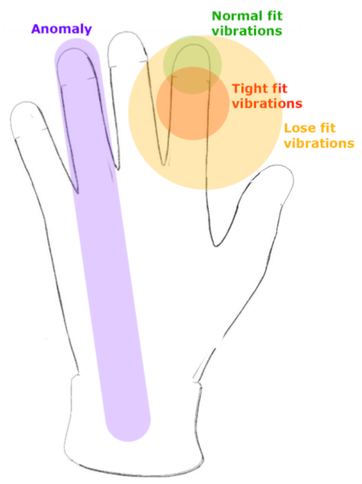

Figure 16 - Vibrations felt based on how the glove fits

4.2.2. First Test

During the first test, we asked the volunteers to use the "Slow Learning" functionality. All of them performed the task without experiencing any issues. Those who have not practiced any musical instruments regarded this style of learning as intuitive and easy to follow. The people in group 2 performed well, but there were expectations that this would be negative feedback learning, in which the user would have vibrations only if they misplaced their finger. They were able to quickly adjust to a positive style of learning, however, they had preferences for the former.

"*I think if you have the light be different colours, so like…it is going to be red if I press it wrong and maybe green if I do it correctly. But I dunno, I don't think I'd be able to see the lights when playing… maybe just like buzz when I do it wrong*"

"*...our teacher was really into doing stuff by the book, so he would stop if I made a mistake and I had to start doing the song again. So maybe the glove can like, do that.*"

"*A 'negative enforcement' model would start buzzing, say 100ms or so, after the beat starts if the button isn't pressed, until it is. I recon the brain wants to avoid the buzzing sensation. Buzzing is irritating and we're habituated by phones that go 'answer me to avoid this irritating buzzing'.*"

We saw the same results in the experienced saxophone players. It is important to note that most of the volunteers with experience, had formal style of training and some have further gone the autodidact path of self learning.

In addition, we noticed that those who originate from countries in the more Eastern part of Europe, gravitate more towards the negative feedback, indicating that this could also be a cultural preference. This, however, is unconfirmed and a larger sample size is required in order to provide adequate results.

Furthermore, as in this exercise the device continuously vibrates until the correct notes are pressed, a lot of the participants expressed a desire to switch to signals in bursts, where the vibration would be felt with intervals in between.

"*I quite like it actually. I really like that it doesn't allow me to continue unless I do it correctly, but I think the vibrations are too strong - like I couldn't really focus and figure out what is vibrating. Maybe if you like shock the finger it might be better you know… or maybe you can like… send the signals with some delay or interval… kinda like a beat, so like it will pulse every few seconds until I press*"

Overall, those who have no experience had strong preference for this task, as well as the positive type of learning, while the others had stronger preference for task 2 and negative type of feedback.

Table 1 - Distribution of preferences between groups

	Slow Learn / On Beat Preference	Negative / Positive feedback
Group 1	Slow Learn	Positive
Group 2	On Beat	Negative
Group 3	On Beat	Negative

4.2.3. Second Test

During the second test, we told the participants to use the "On Beat" functionality, where the song and notes would be played continuously without pause. Results from this task vary based on proficiency level, with group 1 performing the poorest. Overall, all of the groups had issues with following the songs. One of the issues is that the sensors are too big, which caused some of the participants to fail to put back their fingers on the buttons as they could not identify them easily. Additionally, as the saxophone in use is plastic, this caused the material to be slippery. As such, there is not enough resistance to hold the finger in place, making the vibrations move it slightly.

"*...wait.., I just need to… ugh, I can't find the button like… it feels like it is slippery or something...*"

"*The sensors thinggie or I don't know what it is, it's too big, like, my finger is smaller so it feels so weird. Maybe if it was finger shaped, sorta like a U shape it would fit better*"

The biggest issue that all participants felt was note spillage. Because there are constantly changing vibrations, certain fingers would feel as if they are vibrating while they are in fact not. The most common problems were the pinky if the ring finger was vibrating and the index finger, if both the middle finger and thumb were vibrating.

"*Wait, so I am not supposed to feel the pinky…* *puts hand on pinky* *...oh yeah, it is not vibrating, I dunno. During the test I could swear I felt it*"

"*I can clearly feel whenever each of the fingers vibrates independently, right, but for some reason I can also feel slight vibrations on my index. Not on any other finger*"

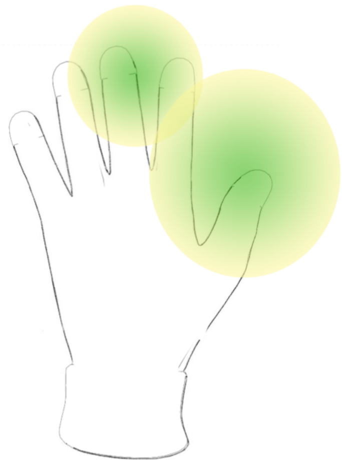

Figure 17 - Vibration spillage in the second scenario

For the first scenario, the likely cause was identified to be the weaker muscles of the pinky compared to the rest of the fingers. For the second scenario, the problem is that the index finger is in between two vibrating fingers as shown in Figure 17. This, however, is not observed on any other finger in a similar situation, indicating that due to the hand structure and thumb mobility and tissue connectivity, it likely causes more vibration to the muscles connected to the index finger.

4.2.4. Third Test

During the third test, we asked the participants to record a set of movements, then replay them to see if they are correct. The three groups each performed the task without major issues and showed great interest in trying to interact with the functionality. During the calibration phase, some of the volunteers did not calibrate properly causing them to experience some minor issues such as the sensors flickering on and off, or missing movements due to not pressing hard enough. Those issues, however, were resolved after correct recalibration.

We managed to conduct three additional tests with the recording functionality, in which we could simulate a student and teacher situation. One of the participants was asked to record a set of movements, and the second one was to figure out the movements and see if they could follow instructions from the first. At this point all of the volunteers were accustomed to the vibrations and they have no issues following the instructions. We did not, however, have the possibility to test the glove between a professional teacher and student. As such, this test is largely lacking in data.

4.3. Online Interviews And Groups

For the online part of the interviews, we contacted several professional saxophone players, teachers and orchestra players, as well as saxophone communities with members of a multitude of proficiency levels. Those talks were fruitful due to gaining the perspective of established professionals with the latest prototype.

Translated from Lithuanian - "*I likes the idea, however I would prefer if the app could show the incoming Notes in the style of Tetris, because due to reaction time in the On Beat mode, even I would never be able to quickly enough move the fingers between notes*"

Translated from Italian - "*I usually hear some music from TV and then I try to replicate it but I never quite do it. I think On Beat would help me a lot because I don't have to bother with the notes and just focus on my breathing*"

One of the strongest comments is that even professionals would not be able to follow "On Beat" if they wanted to learn, due to reaction times. Instead, there was a strong desire to switch the "On Beat" method to show the incoming notes in a queue or in Tetris falling style, while completely removing the vibrations, as in that case they are obsolete. Besides the issues, the "On Beat" is very well liked, due to the guiding, which makes the user not have to focus on it and instead put their attention on producing correct sounds.

Translated from Lithuanian - "*I have children and I think this could be a way for them to approach playing without the extra learning*"

"Slow Learning" has been regarded as intuitive for the beginners and especially children, as they would not have to focus on so much extra learning. While all of the professionals have learned to read proper musical notation, they all agree that it was difficult to associate notes with fingers and buttons. Based on that stipulation, guided learning is regarded as a positive initiative.

5. DISCUSSION

The result of the study indicates that there is a disparity between the levels of expertise of saxophone playing and the expectations of how this haptic glove would affect it. When introduced to the device, the majority of the participants assumed that there would be a gamification of the process. This is true for both people who had similar experience, in forms of games such as "Rocksmith" [27], but also those who did not. This suggests that there is an increasing need for change in the way saxophone is being taught remotely. Further exemplified in the paper of K. Ho and V. J. Rodriguez [7], where the disconnect between teacher and student, has a severe impact in terms of motivation and performance.

Those findings are consistent with the works of A. Balandra et al. [9], where the use of multiple feedbacks has better overall performance. For example, while performing tasks, participants were lost without additional help, even after being told and shown what to do. This ties together with the desire for displaying the chord progression. However, unlike that study, we found that the additional feedback can be detrimental and distracting if applied incorrectly. In our case, the vibrations were deemed too strong by some and thus the volunteers focused on them, rather than the task. While people got accustomed to them, based on their suggestions, we can conclude that there needs to be some separation of functionality, which is in line with previous studies of "Cognitive Processing Theory" [28].

Based on the conducted tests, we can justify that vibrations might not be a good approach to signaling actions. They can be transmitted through the saxophone itself and could potentially cause distortions in the quality of the sound if they are strong enough. While there are projects [29, 30, 31] that make use of vibration as a form of reliable tactile feedback, the study of D. S. Pamungkas and A. Turnip [32] suggests that electro-tactiles would be a better solution for this device. This, however, can not be proven by this study, as the test did not include any sound production, and that issue has not been expected.

When it comes to the functionality of the device, the results suggest that there is a good reception for both "Slow Learning" and "On Beat". However, the preference of which is based on factors, such as skill level and age. The study shows that users who are either of young age or are complete beginners, when it comes to playing music, tend to gravitate towards the first functionality, while more mature and experienced users go to the other. Our interpretation is that people require more guidance the less they know, but this is seen as a nuisance once they get familiar with it. Additionally, there is a strong preference for having learning through negative feedback rather than positive. We have not found any correlation between that and age or experience, but rather the results point towards cultural differences. Nonetheless, this study does not have enough data to argue for a concrete point in that regard.

For future work, we would like to expand the device to be able to handle a larger amount of notes by utilising a pair of gloves, rather than the current singular. A point of interest would be switching to and testing other types of hardware components and seeing the effects they would have on the amount of movement, dexterity and usability while learning to play.

A further exploration of the differences of the "On Beat" and "Slow Learning" modes as well as the preferences towards negative and positive feedback would have a potential for continued research. Our design concepts also looked at the possibility of supporting live remote playing, which would be something that we would be interested in understanding how it would affect the connection between student and teacher, especially if implemented with remoteness in mind.

6. CONCLUSION

In the study conducted, the effects of using haptic feedback in the saxophone learning process were examined. A glove was designed to be able to handle various sizes of saxophones and hands, and its use has been tested through on site and remote interviews. The data revealed that this device has the capacity to further the studying by making use of the various modes of functionality, with each addressing different expertise and maturity levels of the user. However, due to constraints and issues, a further investigation is needed. It is therefore suggested that future research could be conducted on the differences between "On Beat" and "Slow Learning" as well as to expand to the addition of a second glove.

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