Integrating Passive and Active Practice for Augmenting Piano Education

A Framework for Passive Haptic Rehearsal

by Noah Teuscher

Abstract

Passive haptic learning (PHL) is the technique of training the muscle memory of a user through repeated vibrotactile stimulation, even when the user directs their attention towards other tasks. Teaching users to play piano songs is a promising application of PHL; however, the benefits of playing the piano require users to actively play the instrument. In this paper, I discuss passive haptic rehearsal, in which active piano practice is augmented by sessions of passive stimulation, and present a framework developed to realize passive haptic rehearsal in an integrated digital setting.

Introduction

Playing the piano has many positive benefits, from general welfare to mental health [9]. However, the process of learning to play the instrument is very time-intensive, often creating a significant barrier to learning, especially for inexperienced or self-taught musicians.

Passive haptic learning (PHL) is the technique of training the muscle memory of a user through repeated vibrotactile stimulation, even when the user directs their attention towards other tasks. By increasing retention and allowing learning to happen passively, PHL can speed up the learning process and lower student frustration [2].

Over the past decade, numerous studies have demonstrated the potential of PHL as a method for piano skill acquisition [2, 5, 7, 8, 10]. However, these studies have all shared several common drawbacks, especially with respect to the simplicity of their pedagogical methods.

In order to be successful as a consumer solution, PHL must be usable by real students learning difficult material. Now that basic efficacy of PHL as a method has been established, a primary research task has become integrating PHL seamlessly with existing and emerging modes of practice.

In pursuit of this goal, this paper explores passive haptic rehearsal, in which students learn songs through a combination of active practice and passive training sessions to reinforce developing skills. A framework is presented which synthesizes passive rehearsal with active practice through a newly developed integrated learning environment.

Related Work

The potential of passive learning stems in large part from the fact that it is “caught, rather than taught” [6], thus allowing users to acquire new skills—or reinforce learned skills—even when there is a lack of sustained mental focus or attention [11]. Early studies explored PHL in comparison to active practice and confirmed that passive training does not occupy the user’s attention during sessions [4, 5]. It has also been demonstrated that passive learning occurs even when it is not accompanied by audio cues, thus allowing the gloves to be a fully discrete system [7].

Learning, of course, is only one part of the equation; students must also be able to recall the notes. Recent work has shown that there is no significant difference in recall between sequences learned passively and those learned actively. Furthermore, when paired with audiovisual cues, sections of a song learned passively can be recalled better than those learned actively [2].

As a body of work, existing literature on PHL establishes the technique as a very promising method for piano education, especially given its ability to successfully teach notes with no other external cues or devices and without active attention from the user.

But these studies also share several limitations. First, test subjects have primarily been complete beginners playing basic note sequences. While some more recent work has expanded from simple, one-handed note sequences to full, two-handed melodies with chords, the difficulty level of all previously researched curricula has remained elementary at best [10]. Moreover, previous studies have been almost completely passive—that is, they test only the efficacy of passive training, using active practice almost exclusively for control or evaluation.

These limitations were not without reason; they existed primarily in order to maintain the internal validity and quantitative nature of early studies, and because of the technical and time constraints of tasks like hard-coding tactile files.

But if PHL is to take the next step towards becoming a viable music education system, it must be capable of working in tandem with other modes of practice and emerging technologies. It must be capable not just of It is with this goal in mind that we built the following passive learning framework.

Passive Haptic Rehearsal Web Application

Passive haptic rehearsal involves students augmenting active practice with subsequent passive practice sessions to reinforce what they have learned [12]. It is one potential method of integrating passive learning into existing practice structures that could allow students to learn full signs with significantly less (active) practice time and frustration. We have developed an interactive learning framework that implements passive haptic rehearsal to test its effectiveness.

The centerpiece of this framework is a web application, written in VueJS and Flask, which provides an integrated passive and active piano education experience. It allows users to manage a library of scores and connect to important peripheral devices.

The application allows users to upload songs in MusicXML, a common format for existing digital scores. Once songs are uploaded, they are processed in three significant ways. First, fingering patterns are generated for each song. Fingerings are necessary for PHL because the gloves must know which finger to vibrate for any given note, but they are generally not provided in existing scores. Second, the song is broken into small ‘chunks’, or segments of notes of a predetermined length which are repeatedly stimulated in passive training [8]. Third, the song is processed into a tactile file format for passive training which will be discussed in detail below. Uploaded songs are stored in a library for easy access. After selecting a song to practice, users can engage in both active and passive sessions.

<u>Active Practice</u>

For active practice, the web application aims to provide a useful set of tools and cues in multiple modalities without distracting from the keyboard itself. First and foremost, the sheet music for the current song is displayed, complete with the fingerings generated on upload.

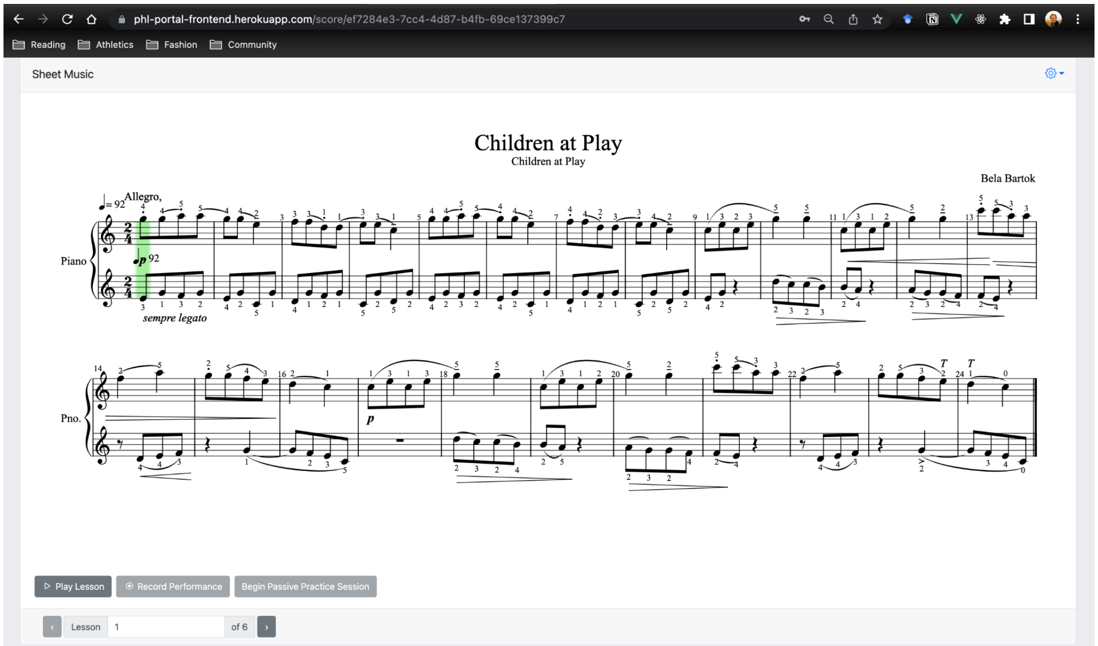

Figure 1: ‘Children at Play’ interactive sheet music displayed in web app

When the user presses ‘Play Lesson’, the audio of the lesson plays and a visual cursor moves through the sheet music in sync. In order to augment an active practice session, users can plug their device into a compatible MIDI keyboard, upon which a connection is automatically established through the web-midi protocol. Then when the user plays the lesson, in addition to the visual cursor, MIDI signals will be sent along the output channel of the connected device. Audio will play from the keyboard along with any other visual features, such as light-up keys.

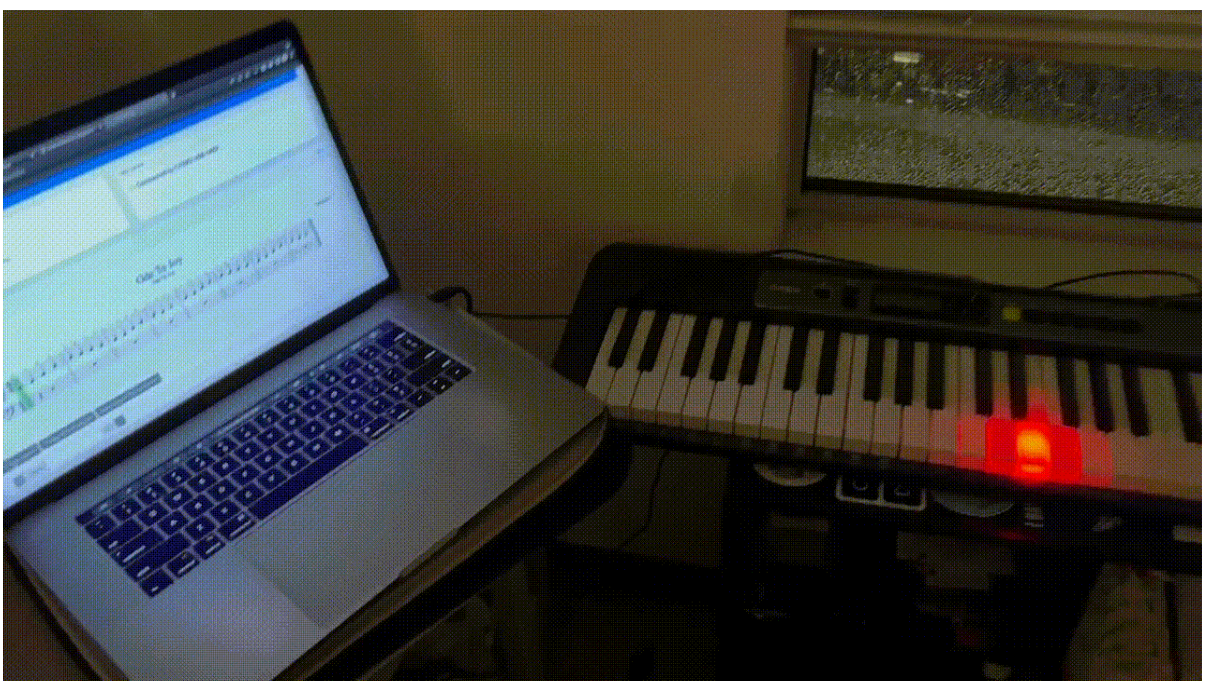
Figure 2: Active practice session for ‘Ode to Joy’ with a connected Casio LK-S250 keyboard

Lastly, users can receive feedback on their progress over time. Recorded performances of songs can be uploaded in MIDI format. These performances are evaluated by a scoring algorithm based on dynamic time-warping, which produces ratings for their timing and rhythm [12]. The results are then displayed to the user. The integration of performance evaluation allows users to receive crucial, real-time feedback on their progress, and researchers to gather contextual data even without bringing subjects into the lab.

<u>Passive Practice</u>

To engage in passive practice the user wears PHL gloves. These vibrotactile haptic feedback gloves are soft, faux leather driving gloves, each equipped with five vibration motors (Precision Microdrives 310-103) at the base of the fingers and a 3D-printed case at the back of the palm to protect the electronics from sweat, dust and other damage [12].

Figure 3 & 4: Vibrotactile PHL glove, with and without cover

To begin a passive practice session, users connect a device running the web application to a PHL glove over Bluetooth Low Energy (BLE). The web application uses web-bluetooth, allowing it to establish BLE communication through compatible web browsers and thus run on various devices (including laptops, tablets, and phones) without native code. The glove advertises a custom BLE Service and Characteristic with basic read-write properties enabled, allowing the device to scan only for active PHL gloves loaded with our firmware.

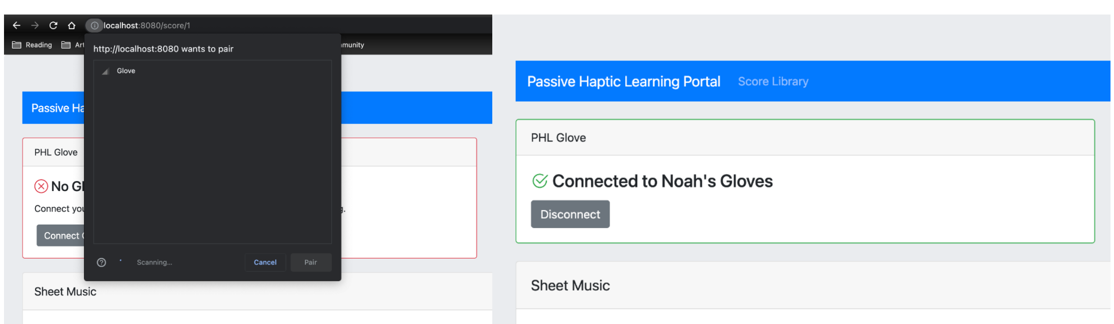

Figure 5 & 6: Searching for and connecting to a PHL glove with web-bluetooth

Once a connection is successfully established, users can begin a passive practice session. To do so, they select a variety of parameters such as session duration and which lessons to train. The song is then transferred to the connected glove in a custom tactile file format. This format was designed primarily to limit the size and complexity of firmware, and to be flexible and extensible such that future changes or additions to the capability of the glove can be handled easily.

```
***
fb3c03a6 30 3 16000
1 13 24
1 2 3
2 2 2
***
---
1 00000 00100 500
2 00000 00100 500
3 00000 00010 500
4 00000 00001 500
5 00000 00001 500
6 00000 00010 500
7 00000 00100 500
8 00000 01000 500
9 00000 10000 500
10 00000 10000 500
```

Figure 7: Tactile metadata and first 10 stimuli for ‘Ode to Joy’

The tactile file format consists of two sections: first the tactile metadata, surrounded by asterisks; second the tactile stimuli data, surrounded by hyphens. The metadata includes important information about the song and the session parameters selected by the user. The stimuli data provides the raw motor values and durations of vibration for each note in the song.

Tactile Metadata

Song Data

fb3c03a6	30	3	1600000
Song ID	Number of stimuli	Number of lessons	Duration (ms)

Lesson Start Indices

1	13	24

Order of Lessons

1	2	3

Number of Lesson Repeats

2	2	2

Figure 8: Tactile metadata reference table

Tactile Stimuli Data

…	…	…	…
7	00000	00100	500
8	00000	01000	500
…	…	…	…
Stimulus Index	Left Hand Stimuli	Right Hand Stimuli	Duration (ms)

Figure 9: Tactile stimuli data reference tables

Lesson start indices denote which index in the tactile stimuli marks the beginning of each lesson. The stimuli data itself is broken into each hand and represented as 5 bits. Each bit corresponds to one finger, sorted from finger 1 (thumb) to finger 5 (pinky), with 1 for motor on and 0 for motor off.

In each practice session, each lesson is stimulated in the order defined and then repeated its respectively defined number of times before moving to the next lesson. Once all lessons have been stimulated, the full practice session will repeat. This will continue until the lesson duration (defined in the original metadata) is reached, or until the user turns off the gloves manually.

The transfer protocol begins with the web application sending the tactile metadata. If the ID already exists (because the song has previously been transferred to the glove), the glove notifies the application, and the transfer is complete. If there is an error, the glove ceases transmission. Otherwise, the device proceeds with a line-by-line transmission of the tactile stimuli data over the BLE connection. Once the final line is sent, the glove signals to the device that the transmission has ended (either successfully or unsuccessfully).

Once a successful transfer is complete, the songs are saved on the glove. The gloves establish a BLE connection between themselves and play the lessons independently; once a passive training session has been started, the gloves no longer require connection to any external devices, allowing users to continue passive training while engaging in various daily tasks.

Upcoming Study

My research team is currently preparing to run an initial user study. While originally planned to be run this semester, various issues—for example, toxic fumes released by the glue used in our glove devices—have pushed back the timeline on this study. That said, through user research, interviews with piano instructors, and iteration amongst our team, we have thoroughly planned the format and goals, which we have presented in a forthcoming position paper [12]. We plan to receive feedback on our design at a workshop and undertake the study in the upcoming semester. As such I will provide a brief overview of the study here.

The purpose of our study is twofold: to evaluate the effectiveness of passive haptic rehearsal as a specific form of passive haptic learning, and to gather data and feedback on the efficacy and usability of our newly developed framework.

Our subjects will be hobbyists or self-taught piano learners without formal lessons. We selected a study curriculum under the constraints that study participants should not have heard the melodies before, and the songs should be difficult enough so as not to be trivial and run into a ceiling effect (subjects will be disqualified if they have learned the pieces), yet easy enough that even subjects with relatively less experience can reasonably learn most of the songs; we settled on Children at Play and Young Men's Dance by the composer Bartok.

Subjects will be provided with a pair of PHL gloves, a Samsung Galaxy Tab A8 with Google Chrome (web-bluetooth and web-midi compatible), and a Casio SK-L250 keyboard with light-up keys.

The study will last two weeks, with participants being required to log 30 minutes of active practice and 2.5 hours of passive rehearsal each day. Subjects will be brought into the lab for in-person evaluations at the beginning, midpoint, and end of the study. These evaluations will include both recordings of the subjects' performance of curriculum songs, and various structured and unstructured surveys about their experience and the system [12].

Discussion & Future Research

The existence of our integrated framework for processing existing MusicXML scores into tactile format opens the door for future PHL researchers to explore questions that have remained unavailable to previous researchers. It allows the rapid testing of PHL on songs that are far longer and more complicated than anything tested thus far and allows that testing to occur in a distributed online environment. Furthermore, because the tactile file is generated algorithmically, researchers can quickly and iteratively alter the pedagogical minutia of PHL by tweaking individual variables and run rapid user studies.

I propose 3 major areas of pedagogical inquiry under-developed in the current literature which might be pursued, and I hope that the following overview can serve as a guide to future researchers in the area.

The first is *stimulation pedagogy,* or the best pedagogical methods for the transfer of information through tactile stimulation. Some work has been done in this area; for example, it has been shown that overlapping spatio-temporal patterns are more successful than time-synced tactile information at imparting information to users [3]. Yet many questions remain, especially with respect to piano learning specifically. Exploratory questions include: What should be the degree of correlation between the rhythmic timing of a musical piece and the timing of stimulation pedagogy? Is it possible to impart musical information beyond finger patterns (i.e., dynamics, texture) through vibrotactile stimulation?

The second is *chunking pedagogy*, or how songs are best broken up into an optimal set of chunks or lessons for learning. This would also overlap with stimulation pedagogy to include questions about the way those lessons should be imparted. Exploratory questions include: Are there different "optimal chunkings" for active versus passive practice? Should chunks overlap with each other, or be entirely discrete? Are songs of different periods, genres, or difficulty best chunked in different ways? How many times should chunks be repeated, and in what order(s) should they be trained?

The third is *integration pedagogy*, or how passive training is best synthesized with active training. Our current suggestion is passive haptic rehearsal, which was arrived at in part by conducting user research through interviews of piano teachers. But it may be the case that an approach of passive haptic priming would be more successful. Exploratory questions include: What should the time ratio of active to passive practice be to optimize retention? When (chronologically) should passive training occur with respect to active training? How much time should pass between active and passive sessions?

Conclusion

This work presents passive haptic rehearsal as a method for synthesizing passive haptic learning with existing methods of active practice to augment piano learning for self-taught students. It provides an overview of a web application developed to realize passive haptic rehearsal in an interactive digital system. I discuss a user study that has been proposed to determine the efficacy of this system. I close by laying the groundwork for future researchers to utilize this framework by exploring three major areas of pedagogical questions that can drive the future of PHL research with respect to piano education.

Works Cited

[1] Eugenia Costa-Giomi, Patricia J. Flowers, and Wakaha Sasaki. 2005. Piano Lessons of Beginning Students Who Persist or Drop Out: Teacher Behavior, Student Behavior, and Lesson Progress. Journal of Research in Music Education 53, 3 (Oct. 2005), 234–247. https://doi.org/10.1177/002242940505300305 Publisher: SAGE Publications Inc.

[2] Rumen Donchev, Erik Pescara, and Michael Beigl. 2021. Investigating Retention in Passive Haptic Learning of Piano Songs. Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies 5, 2 (June 2021), 60:1–60:14. https://doi.org/10.1145/3463513

[3] Granit Luzhnica and Eduardo Veas. 2019. Optimising Encoding for Vibrotactile Skin Reading. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19). Association for Computing Machinery, New York, NY, USA, Paper 235, 1–14. DOI:https://doi.org/10.1145/3290605.3300465

[4] Kevin Huang, Thad Starner, Ellen Do, Gil Weiberg, Daniel Kohlsdorf, Claas Ahlrichs, and Ruediger Leibrandt. 2010. Mobile music touch: mobile tactile stimulation for passive learning. In Proceedings of the 28th international conference on Human factors in computing systems - CHI '10. ACM Press, Atlanta, Georgia, USA, 791. https://doi.org/10.1145/1753326.1753443

[5] Daniel Kohlsdorf and Thad Starner. 2010. Mobile Music Touch: The effect of primary tasks on passively learning piano sequences. In International Symposium on Wearable Computers (ISWC) 2010. 1–8. https://doi.org/10.1109/ISWC.2010.5665877 ISSN: 2376-8541.

[6] Herbert E. Krugman and Eugene L. Hartley. 1970. Passive Learning from Television. Public Opinion Quarterly 34, 2 (Jan. 1970), 184–190. https://doi.org/10.1086/267788

[7] Tanya Thais Markow. 2012.Mobile music touch: using haptic stimulation for passive rehabilitation and learning. Ph. D. Dissertation. Georgia Institute of Technology.

[8] Seim, Caitlyn. *Wearable vibrotactile stimulation: How passive stimulation can train and rehabilitate*. Diss. Georgia Institute of Technology, 2019.

[9] Tríona McCaffrey and Jane Edwards. 2016. "Music Therapy Helped Me Get Back Doing": Perspectives of Music Therapy Participants in Mental Health Services. Journal of Music Therapy 53, 2 (2016), 121–148. https://doi.org/10.1093/jmt/thw002

[10] Caitlyn Seim, Tanya Estes, and Thad Starner. 2015. Towards Passive Haptic Learning of piano songs. In 2015 IEEE World Haptics Conference (WHC). 445–450. https://doi.org/10.1109/WHC.2015.7177752

[11] Cliff Zukin and Robin Snyder. 1984. Passive Learning: When the Media Environment Is the Message. Public Opinion Quarterly 48, 3 (Jan. 1984), 629–638. https://doi.org/10.1086/268864

[12] Gemicioglu, Tan, et al. "Passive Haptic Rehearsal for Accelerated Piano Skill Acquisition." *arXiv e-prints* (2022): arXiv-2203.