Passive Haptic Learning

Project Overview

John Sullivan | November 2016

**Objective:**

Design and build a pair of *Passive Haptic Learning* (PHL) gloves and accompanying software interface to replacate and extend two studies of PHL for learning melodic and chordal piano material.

**Background:**

At the 2015 IEEE World Haptics Conference (WHC), Caitlyn Steim, Tanya Estes and Thad Sterner presented the paper “*Towards Passive Haptic Learning of Piano Songs*” [1] in which they describe two studies that evaluated the use of haptic stimulation to help users passively learn to play melodic and chordal piano passages. Following previous work by the authors and others around the use of haptic feedback for motor skill training, these studies compared PHL results across different conditions including haptic stimulation alone or haptic and audio stimuli together, one- or two-handed playing, and single-note melodies or chordal passages (with multiple notes played simultaneously).

Both studies were structured similarly: First, participants learned short piano excerpts. Second, they went through a period of *passive haptic rehearsal*, where they concentrated on an unrelated “distraction” task while receiving haptic stimuli through a pair of special gloves equipped with embedded vibration motors on each finger. The stimuli reinforced the phrases the participants had learned by tapping out the manual fingerings and timing throughout the period. During this phase, participants were subjected to different conditions : control, where no stimuli was given; vibration only; vibration and audio together; audio only. Finally, the participants were given three attempts to play the passage back correctly. A comparison between the number of errors between playing the passage at the end of the first phase and in the last phase (*error difference score*) provided the measure of effectiveness for the different conditions of passive haptic learning.

The first study, based on a previous expriment testing PHL for learning piano, examined whether using haptic stimuli alone (without audio feedback) in the second phase had an effect on the error difference score compared to haptic and audio stimuli togther. While all conditions improved the error difference score over the control condition, there was largely no difference between the conditions of haptic alone and haptic and audio together. Participants in the study also completed an evaluation of percieved workload during the distraction phase. Participants assigned a higher rating of distraction during the vibration and audio condition than with the vibration alone condition, suggesting that use of haptics alone is preferrable for passive haptic learning.

The second study examined two-handed, chordal playing, and specifically compared two strategies of learning two-handed pino performance : learning one hand at a time and then putting them together, versus learning two hand together from the outset. Previous research suggests that learning both hands together at the outset is preferrable, however in practice, learning one hand at a time is more commonly used, especially for more complex pieces. The study had particpants go through the same PHL expreiment, this time playing two-handed chordal music, under two learning conditions. In the first, the particpant learned first one hand, then the other, each followed by a disctraction phase, after which they attempted to play the entire phrase back with both hands togther. The second condition had partipants learn both hands together. Consistent with previous research, the both-hands-together condition returned fewer errors.

**Proposal :**

For this project, I propose to design and build a PHL glove system to replicate the two studies of Seim, et. al. The system will include a pair of gloves equipped with embedded eccentric rotating mass (ERM) motors attached to each finger to provide haptic feedback to the user, and a Max application to interface with the hardware (the gloves and a MIDI keyboard for playback) to send MIDI signals to the motors, record participants’ playback, provide the initial a learning phase, and analyze the results and calculate errors for different conditions.

Hardware : The gloves with be constructed using two ESP8266 Thing microcontrollers, one on each glove. They will receive the instructions to “play” the motors. Each glove will be powered by a LiPo battery.

**Why / What / How**

**Objective:** Replicate and extend *Towards Passive Haptic Learning of Piano Songs* by Caitlyn Seim, Tanya Estes, and That Starner [1]

**Passive Haptic Learning**: users can learn motor skills through haptic stimulation even when little or no attention is dedicated to learning. Stimulation is provided by a tactile interface and users focus their attention on another task while they passively learn.

Previous work: single handed piano melodies and 2-handed braille.

Paper examined:

* synchronized 2-handed chorded piano
* PHL without audio
* 2 methods of teching complex piano melodies via haptics

Passive learning is “caught, rather than taught”

Focus on multi-modal learning (audio and haptics)

Previous research: **one-handed single note** melodies:

* Subjects could learn 45 notes on average in 30 minutes.
* “Distraction tasks” included:
  + math and reading comprehension exams
  + scavenger hunts
  + memory games

Research on 2-handed Braille typing:

* chorded: requiring multiple simultaneous keystrokes
* *‘…participants could not sense simultaneous stimulation of multiple fingers with accuracy’*
  + Accurcy improved by sequentially stimulating each finger in a chord with temporal offests between chords.
* 32.85% average decline in error vs control.

Hardware:

* System consists of pair of fingerless gloves with ERM motor on back of each finger near the knuckle.
* Piano keyboard for participlant playback (mapped to MIDI to record results)

**Initial Study:**

* compare 2 conditions: haptic with audio vs haptic without audio.
* 12 participants, 45 note song phrases of Jingle Bells and Amazing Grace (single note melodies).
* Each participant does each condition.
  + Users rehearse a song, first divided into 4 sections, then the full phrase, until they can play it error-free. (use lighted keys on keyboard for instruction)
  + Then they have 30 minute forgetting period with disctraction task, while experiencing either the haptic or haptic + audio stimulus. (Passive Haptic Rehearsal, tested with non-novice users)
  + After 30 minutes, the user removes the gloves and has 3 tries to play back the melody.
* Performances are recorded in MIDI format and evaluated using DTW to account for errors of substitution, insertion and deletion.
* using a paired t-test, compare errors between haptic-only and haptic+audio conditions.
* Results:
  + Findings showed no significant difference between the 2 conditions.

**Four Condition Study:**

* contrast 4 conditions in a follow-up study:
  + control
  + audio only
  + vibration only
  + audio+vibration
* within subjects study, 24 participants ***with no piano experience***
* Four newly generated musical phrases using “Wolfram Tones”:
  + Single note melodies with 22 notes.
* Structure:
  + (A) Practice (4) parts of the phrase -> eventually whole phrase
    - 1 try at each subsection
    - 5 tries with 2 subsections together
    - 10 attempts at full phrase
  + (B) 30 minute distraction task: take GRE examwith one of the 4 conditions (ctrl, aud, vib, aud+vib)
  + (C) Three attempts to perform the music phrase
* At end of section participants completed the NASA TLX assessment – evaluate percieved workload
* Recorded results were analyzed for error rates using DTW
* The best “C” attempt was compared with the final “A” attempt to yield error-difference scords before and after the distractin period.
* Results:
  + Error rate comparitsons to control:
    - **aud+vib** = large improvement over control (p-val: 0.02, effect size: 0.16)
    - **vib** = moderate improvement over control (p-val: 0.05, effect size: 0.11)
    - **aud** = minimal improvement over control (p-val: 0.08, effect size: N/A)
  + **Increase in errors:** 
    - control: 1.17
    - audio only: 0.54
    - audio + vibration, vibration only: 0.33
  + No difference found in GRE scores
  + Percieved “load” – NASA TLX: Effort and Frustration
    - Higher ***frustration*** rating for aud+vib condition than control.
* Discussion:
  + audio+vibration and vibration-only conditions significantly reduced errors
  + a+v increased frustration ratings, v-only did not.
  + Results justify the use of vibration alone to aid in learning and retention.

**Two-Handed Chordal Learning**

* Study was conducted, similar structure to study of PHL for Braille”
* Background: typically, piano students learn one hand at a time, but research suggests that learning both together is more advantageous. But practically, learning 2 handed is largely too challenging, thus the 1 handed model persists.
* Hypothesize passive teaching of both hands together.
* Study: within subjects for 8 participants, 2 sessions per subject for 2 conditions:
  + “LR” Left-Right condition: learn hands separately
  + “Sync” condition: learn both hands together.
* Learning periods split into 2:
  + LR: first left, then right
  + Sync: ½ of phrase, then second ½ of phrase
* Participants had ***no knowledge of piano***
* Structure:
  + (A) Pre-test: particpant shown the phrase one time, then have one try to play the phrase back
  + (B-1) 1st Learning period – 20 minutes.
    - Receive haptic stimuli (either “LR” or “Sync” condition, part 1) during a distraction task of playing an online game.
  + (C-1) 3 attempts to play given part (either single hand (LR condition) or ½ of phrase (Sync condition))
    - Before first try, audio is played
    - Before 2nd and 3rd tries, lighted keys show the phrase, but no audio
  + (B-2) 2nd Learning period – 20 minutes.
    - Same as B-1 with other hand or phrase
  + (C-2) 3 attempts to play ***entire phrase*** – both hands and both halves together
    - Before each attempt, lighted keys show the entire phrase, but no audio.
* ??? Passive Haptic Learning Stimuli: The fingers required to play each tone in the music are “tapped” using the vibration motors in the gloves. These haptic stimuli are synchronized with the tones of the music. Additionally this structure provides chord parsing information and action feedback: sequences yielding chords are separated by tones while keeping stimuli temporally tight, and users may have understanding of the tones to be expected when they “type” on the piano keyboard. Each tone of the song (or song part) is played into the participant’s earbuds, and the finger or finger required to play this tone are then stimulated sequentially. This process is followed by the next tone and stimuli until the end of the song (part), after which the system waits 20 seconds and repeats.
  + IE: tones are sounded to cue the chords, followed by the haptic stimuli?
  + **Each stimuli was presented sequentially: slightly staggered in time for perception.** 
    - “successfully passively enabled users to parse the stimuli and seamlessly self-synchronize.”
* Results:
  + Performance data captured in MIDI format, analyzed through DTW for errors
  + Examine difference in performance error between (A) and (C-2), for each condition.
  + Both conditions demonstrated reduced errors, with “Sync” condition reflecting larger reduction in overall errors.
  + Content-sensitive DTW recognized chords “fractionally”, which allowed for better analysis of correct song content, was developed to be more sensitive to learning differences.
* Takeaways:
  + Complex piano pieces may be taught passively across both hands at once (Sync condition). Thus – best to learn both hands together.

Items borrowed from Ian:

* 2 Xbee S1 modules (chip antenna)
* 2 XBee Sparkfun breakout boards unpopulated
* 1 XBee Sparkfun breakout board with male headers
* 1 XBee Explorer (USB)
* 1 XBee transmitter w/ large antenna (XBee + Explorer + case)
* 1 AVRISP mkII programmer

[1] C. Seim, T. Estes, and T. Starner, “Towards Passive Haptic Learning of piano songs,” *IEEE World Haptics Conf. WHC 2015*, pp. 445–450, 2015.