Haptic-Listening and the Classical Guitar

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ABSTRACT

This paper reports the development of a 'haptic-listening' system which presents the listener with a representation of the vibrotactile feedback perceived by a classical guitarist during performance through the use of haptic stimulation. The paper describes the design of the haptic-listening system which is in two prototypes: the "DIY Haptic Guitar" and a more robust trial prototype using a Reckhorn BS-200 shaker. Through two experiments, the perceptual significance and overall musical contribution of the addition of haptic stimulation in a listening context was evaluated. Subjects preferred listening to the classical guitar presentation with the addition of haptic stimulation and the addition of haptic stimulation contributed to listeners' engagement with a performance. The results of the experiments and their implications are discussed in this paper.

Author Keywords
Haptic, Shaker, Engagement.

1. INTRODUCTION

During instrumental performance, it is well-established that advanced instrumentalists rely heavily on the vibrotactile feedback that is relayed to them through the body of the instrument, to continuously reassess their technique and to inform musical and technical decisions [13]. This performer-instrument vibrotactile feedback relationship is vital for performer engagement with an instrument. For the purpose of this study, the term engagement was interpreted as the degree to which the listener feels actively involved in the presentation and the degree to which the performance holds the listener's attention.

Studies have shown that the addition of haptic stimulation in digital musical instruments (DMIs), which typically do not provide vibrotactile feedback to the performer, results in an increase in performer engagement with the instrument [4] [6] [12]. Through the use of vibration motors embedded in light-weight gloves, Lauren Hayes was able to establish a vibrotactile performer-instrument relationship for performers of her hybrid piano [4]. She concluded that the implementation of a feedback system allows performers to engage more closely with the instrument which has a major influence on the musical outcome. However, the emphasis of those researching the role of haptics in music has mainly been on the performer.

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Some research has been carried out on the role of haptics in the mediation of music and the potential for augmenting a listening presentation through the use of haptic stimulation. [3] coupled musical composition with tactile stimulation. Listeners wore a full-body vibrotactile stimulator during a one-hour concert of musical and tactile compositions. The study showed that the addition of tactile stimulation tended to result in stronger reactions to the compositions. In the present study, the research questions is: does the implementation of haptic stimulation in a listening context result in an increase in listener engagement with an instrumental performance?

There are a number of commercially available products which utilise haptic stimuli to enhance user experience. The "Basslet" is a haptic device designed by Berlin-based tech company, Lofelt, which is marketed as a "wearable subwoofer for your body" [10]. Using haptic technologies, the watch-sized device silently delivers a vibrotactile stimulus to the wrist which is designed to allow the listener "feel the music". Nintendo's 2017 video-game console, the Nintendo 'Switch', boasts a more nuanced haptic feedback system than any previous game console [2]. The increase in the number of commercially available haptic systems designed to enhance music listening, as well as the continued investment by video game companies in haptic technology, suggests that research into the role of haptics in music presentation is relevant to current trends in interactive media technologies.

In an address at the 2006 Connecting Media conference in Hamburg, Marc Leman defined mediation technologies as "technologies that connect the human mind with matter" [8]. He proposes that the future of mediation technologies lies in mediating interaction through a multimodal experience which reflects the embodied cognition understanding of musical meaning, a field of music cognition which suggests that our understanding of musical intentions emerges from our human motor-systems and body movements. This study explores the potential application of haptic technologies as a means of contributing to multimodal mediation of music through the medium of touch.

The design considerations in the development of a haptic-listening system are first discussed. This is followed by the results of two haptic-listening experiments: Experiment 1 and Experiment 2 which investigated the subjective responses of participants to the addition of haptic stimulation in music listening. Finally, the implications of these results are discussed.

2. DEVELOPING THE HAPTIC-LISTENING SYSTEM

In order to create a haptic-listening presentation, a system was designed which presented the listener with a conventional stereo recording of a classical guitar performance with the addition of a haptic component. The system was designed to provide a representation rather than an accurate simulation of the player's experience. The technology required to create a convincing simulation of the performer's experience was not available to the researcher but this could be pursued in further research. There were two phases in the development of the haptic-listening system: (1) recording the physical vibrations of the guitar during an original performance; (2) reproducing the vibrations in the playback scenario. Recordings were made of the physical vibrations of a 2007 Dieter Hopf/Manuel Adalid "Artista Membrane" classical guitar during a performance by Alan Grundy, a renowned Irish performer and musicologist, in the Trinity College Dublin Music and Media Technologies (MMT) recording studio. The recorded vibration signal was then reproduced onto the body of the listener using haptic stimulation. While listening to an audio recording of the performance on headphones, the listener positioned a haptic actuator against his/her sternum which played back the recorded vibrations of the original performance. The system was designed to present the haptic stimulation in a manner that represents the conceptual metaphor of playing the guitar, i.e., the feedback is delivered to the sternum much like the guitar vibrations are felt against the sternum during performance.

2.1 Recording the Vibrations

The research of Marshall & Wanderley [12] and Askenfelt & Jansson [1] into the measurement of guitar vibrations indicates that a light-weight accelerometer is the ideal instrument for measuring instrument vibrations. A PCB Piezotronics ICP accelerometer, model 352C22 was used in [12] and a Brüel & Kjaer 4374, 0.6g accelerometer was used in [1]. The light-weight accelerometers used in these studies were highly sensitive sensors and the instruments were held in fixed positions when measuring the instrument vibrations. However, in the context of recording a guitar performance, such highly sensitive sensors would undoubtedly pick up extraneous sounds created by the bodily movements of the performer. For this reason, the present study made use of the less sensitive Schaller "Oyster" S/P piezo pickup to convert the vibratory motion of the instrument into an electrical signal. The pickup came with an adhesive wax which was used to attach the pickup to the guitar. The 'audio' component of the recording was achieved using an XY stereo array of Rode NT5 small-diaphragm cardioid condenser microphones. A Presonus Studio 192 audio interface was used for recording.

Alan performed four of his own original compositions, each varying in style and degree of technical complexity. During the recording session, four positions around the bridge of the guitar were investigated and eventually it was determined that positioning the pickup on the bridge of the guitar beside the bass strings (see Figure 1) yielded the most tonally balanced signal. Positions on the back plate and side plates were considered. However, the stiffness of the wood, as well as the proximity of the wood to the body of the performer, would mean that the ratio of guitar body vibrations to extraneous noise (both from performer as well as electrical interference) would be too small. The use of a multiple pickups to record the guitar was considered. Summing these recorded signals may have reflected the complexity of the guitar vibrations more accurately. However, this was not possible because the researchers did not have access to multiple pickups.

Figure 1: Pickup positioning during recording session. The black oval around the bridge is part of the "membrane" design of the guitar. This highly flexible membrane results in increased volume.

2.2 Reproducing the Vibrations

Two prototype acoustic 'shakers' were designed to reproduce the vibration of the guitar body on the listener. The first, called the "DIY Haptic Guitar", was a home-made prototype which was built so that it would be ready for Experiment 1 which was conducted in Dublin in Summer 2017. A more robust prototype was later built for Experiment 2.

Informed by Marshall & Wanderley's [11] findings, the "DIY Haptic Guitar" was realised using the voice-coil actuator of a disused 4-inch Panasonic speaker. The diaphragm of the speaker was removed and three metal washers from a cymbal stand were attach to the dust cap of the speaker using super

Figure 2: Exhibition prototype – Voice-coil actuator housed in a soft material and sewn shut.

glue. The washers acted as a 'foot' through which the vibrations would be channeled from the voice-coil to the listener's sternum. The speaker was then housed in a soft cushion-like material which was fashioned out of the strap of a camping bag. Soft padding from a pillow was inserted into the prototype behind the speaker to give it a teddy-like feeling. Two buttons were sewn onto the prototype to encourage people to engage with the device and to embrace it like a teddy (see Figure 2). The recorded vibration signal was amplified and channeled to the voice-coil using a Creek Audio Systems CAS4040 amplifier. After Experiment 1, a more robust playback prototype was built using a Reckhorn BS-200i shaker. It was felt that the DIY prototype was not robust and that the findings of a trial using the Reckhorn Body Shaker would be more robust and replicable.

Figure 3: Trial prototype – The Reckhorn Body Shaker inside its homemade pouch.

The shaker was housed in a pouch made from a thick plastic bag. The remaining space in the pouch was stuffed with soft padding from a pillow to give it a more comfortable feeling. Again, buttons were sewn onto the prototype to encourage people to engage with the device (see Figure 3). The device could also be attached to a strap with which listeners could mount the device against their chests. A Creek Audio Systems CAS4040 amplifier was used to amplify the haptic signal.

3. RESULTS

This section describes the results of two experiments designed to evaluate the effects of the addition of haptic stimuli on the overall listener experience of a classical guitar recording presentation. Participants were asked to respond to questionnaires in each experiment. Experiment 1 was a preliminary trial carried out during the MMT Exhibition and Experiment 2 was a more formal listening test carried out after the Exhibition.

In both experiments, listeners were asked to indicate whether they preferred the presentation with or without the addition of haptic stimulation. The participants were also asked to rate the degree to which the addition of haptic stimuli contributed to their level of engagement with the performance. In Experiment 1 participants were asked to identify what emotional feeling the haptic stimulation encouraged. The options presented to participants were based on informal feedback received during the development of the haptic-listening system. In Experiment 2, participants were asked to rate the degree to which the addition of haptic stimuli contributed to the perceived expressivity of the performance. For this study, the term expressivity was interpreted as the degree to which the emotion of the performance is communicated. Responses were based on three-point or five-point scales. A three-point scale was judged to be sufficient for a preference test while a five-point scale was used for the engagement and expressivity tests to allow for finer resolution.

As the responses to the listening experiments were likely to be different depending on whether a participant was an experienced guitarist or a non-guitarist, participants with varying degrees of familiarity with the guitar were included in both experiment samples. The participants were categorised into three groups: (1) experienced guitarists; (2) novice guitarists; (3) participants who have almost never played the guitar.

Figure 4: MMT student interacting with the haptic-listening installation.

3.1 Experiment 1: Exhibition Responses

3.1.1 Methodology

Experiment 1 was carried out at the MMT Exhibition of students' projects and was attended by the students, family and friends of the students, MMT staff, and members of the public. Attendees were invited to interact with the various projects. The haptic-listening installation was titled the "DIY Haptic Guitar" and comprised the haptic-listening system as well as a simple Max/MSP patch that allowed users to choose between the four Alan Grundy compositions and to adjust the volume of the haptic and the audio signals. The reason that participants had the ability to adjust the volume of the haptic and the audio signals was to give the researchers an insight into the level at which users liked to feel the haptic signal relative to the audio signal. However, the level adjustments made by the participants were not recorded by the researchers. The test would have been more scientific if the same levels were used for all participants. A toggle was included in the patch which muted/un-muted the haptic signal. When attendees chose to interact with the "DIY Haptic Guitar", they were invited to complete a questionnaire afterwards.

Participants were instructed to hold the device against their sternum with both hands "like a teddy" (see Figure 4). This meant that the vibrations were felt against the sternum and in the hands. Before interacting with the installation, participants were given a brief demonstration on how to use the "DIY Haptic Guitar" and how to use the Max/MSP interface. Participants were invited to listen to as many of the four compositions as they wished. Participants were instructed to toggle between having the haptic signal muted and un-muted in order to get an impression of what the presentation felt like without haptic stimulation. In more ideal circumstances, participants would have been instructed to listen to the compositions for a fixed length of time, with and without haptic stimuli, to allow for more consistent treatment conditions. However, due to the informal nature of the exhibition, the length of time spent interacting with the "DIY Haptic Guitar" varied with each participant and, as such, the experiment was designed to be completable within a few minutes.

The questionnaire was completed by forty-one participants, of which thirty were members of the public, ten were MMT students, and one was a lecturer at MMT. Thirty-two participants were male (78%) and nine participants were female (22%). Thirteen participants identified as "advanced guitarists" (31.7%), fifteen identified as "novice guitarists" (36.5%), and thirteen said that they had "almost never played the guitar" (31.7%). Regarding participants' level of experience with instruments other than the guitar, seventeen participants (41.5%) identified as "advanced instrumentalists", thirteen (31.7%) identified as "novice instrumentalists", and eleven said that they had "almost never played any other instrument". Participants were not asked to state their age.

Table 1 - Experiment 1: Effect of haptic stimulation

	No.
Preference for haptic stimulation	
Preferred with haptic technology	39
Preferred without haptic technology	1
No preference	1
Total respondents	**41**
Effect of haptic stimulation on engagement	
Very distracting	0
Slightly distracting	0
No effect	1
Slightly engaging	11
Very engaging	29
Total respondents	**41**
Feelings encouraged by haptic stimulation	
I thought it was:	
Funny/silly	1
Calming/relaxing	31
Uncomfortable/weird	1
Pensive/reflective/sad	8
No effect	0
Total respondents	**41**

3.1.2 Outcomes

Table 1 summarises the responses following Experiment 1. Almost all participants preferred the presentation with haptic stimuli (95%). Almost all respondents found the haptic stimulation contributed to their engagement with the presentation (97.5%). In addition, when asked "which of the following feelings did the addition of haptic stimulation encourage?", a large majority of respondents found the haptic stimulation calming/relaxing (75%). However, the responses to this question may have been influenced by the compositional style of the recorded music. At the end of the questionnaire, respondents were asked to "provide any additional thoughts or comments". The twenty-two comments show that respondents generally enjoyed the experience of the haptic stimulation technology. Many respondents seemed to find the experience relaxing and suggested that a haptic-listening presentation could be useful in music therapy: "I think it's very promising for music therapy/treatment for autism etc.", "Definite scope for music therapy". Many respondents felt that the haptic component added an extra dimension to the experience: "Haptic feedback added another element to the song", "After [the haptic component was removed], the music felt empty and dry as if a richness had gone", "It felt a bit like getting the performer's perspective rather than the audience's." These comments are representative of the general comments from participants. As respondents were not a random sample, the possibility of bias in their responses is acknowledged. A comparison of the responses of non-guitarists, novice guitarists, and advanced guitarists showed that responses were not dependent on the respondents' level of experience with the guitar, although the small sample size precluded statistical analysis of the differences in responses by level of experience.

3.2 Experiment 2: Controlled Experiment

3.2.1 Methodology

Like Experiment 1, Experiment 2 involved interacting with the system and responding to a questionnaire. However, a number of changes were made to the presentation and the questionnaire to achieve a more robust and controlled result. The strategies used in creating the experiment were informed by [9]. Rather than giving participants control over the playback volume, the audio and haptic components were played back at a fixed volume for all participants. The more robust Reckhorn BS-200 shaker haptic-listening prototype was used. This prototype was strapped onto the participants so that the device would be firmly positioned against the listener's sternum. This meant that the contact, pressure, and positioning of the device would be relatively consistent throughout the experiment across each participant. It also meant that the vibration signal would not be felt through the hands. Participants were presented with three short excerpts from the recording session with Alan. The order of presentation of the trials were randomised. Excerpt A ('Without Words') and B ('Millennium Mirror') were stylistically contrasting and were both heard four times, twice with haptic stimuli and twice without. Excerpt C ('Karma'), was also heard four times: twice with a haptic signal that was congruent with the audio signal; twice with a haptic signal taken from a separate recoding and, therefore, incongruent with the audio signal. The composition used for the incongruent haptic signal was another of Alan's compositions called 'Waltz Louise'.

After the participants responded to the questions relating to each excerpt, they were asked to respond on their overall impression of the haptic playback system. This comprised two sections. The first section asked participants whether they preferred listening to the music in general with or without haptic stimulation. The participants were then given the opportunity to submit their thoughts or comments on the system. The second section presented the participants with selected comments from the responses to Experiment 1 and asked them on a five-point scale to state the degree to which they agreed or disagreed with each comment. These comments were judged to be representative of the general comments from Experiment 1. The Experiment 2 questionnaire was completed by nineteen participants, of which fourteen were friends of the researcher and five were MMT students. Fifteen participants were male (78.9%) and four participants were female (21.1%). All participants were between twenty-two and twenty-six years old. The average age of participants was 23.47 (std. dev. 0.993).

3.2.2 Results

Table 2 summarises the responses to Experiment 2. Participants preferred the music with haptic stimulation (89%). More participants preferred the addition of haptic stimulation with Excerpt A (89%) than with Excerpt B (73.6%). With Excerpt C, participants preferred the version with congruent haptic stimulation (89%). Participants found the addition of haptic stimulation made them feel more engaged with the performances (89%). Most participants found Excerpt A more expressive with the addition of haptic stimulation (73.6%). Participants were evenly split on whether Excerpt B was more expressive with or without haptic stimulation. Participants found Excerpt C was more expressive with congruent haptic stimulation (89%).

Participants' responses in Experiment 2 to the Experiment 1 comments showed that participants tended to agree with most of the Experiment 1 comments. Participants were almost unanimously in agreement with the following comments: "It felt a bit like getting the performer's perspective rather than the audiences'"; "Definite scope for music therapy"; "Helps to make the [music] more immediate and live".

As in Experiment 1, participants were asked to provide additional comments. The eighteen comments show that many participants experienced an increased sense of engagement when haptic stimulation was included: "Preferred with haptic feedback, the vibrations put you more 'in the moment' with the music as if you were playing the guitar yourself," "I think as someone who is not familiar with guitar music (as in classical guitar), I found the haptic feedback helped me engage more with a genre I am novice to. It made me pay more attention to the chord progression or subtle shifts in the playing. In short it forced me to take notice of a type of music I would not normally listen to." Some participants said that the haptic stimulation enhanced the excerpt only if the participant liked the audio component of the excerpt: "The haptic component definitely adds to the listening experience, however, it doesn't necessarily improve it. It doesn't really suit some music types."

A comparison of the responses of non-guitarists, novice guitarists, and advanced guitarists showed that responses were not dependent on the respondents' level of experience with the guitar, with the exception of Excerpt A. Most non-guitarists found Excerpt A more expressive without haptic stimulation while all novice and advanced guitarists found it more expressive with haptic stimulation. Because only two pieces with congruent haptic feedback were presented in the experiment, it was not possible to determine why non-guitarists found Excerpt A more expressive without haptic feedback while all novice and advanced guitarists found it more expressive with haptic feedback. A study which presented a larger number of performances could clarify why responses might vary depending on the composition.

Table 2 - Experiment 2: Effect of haptic stimulation technology

Overall preference for haptic stimulation			**No.**
Preferred with haptic stimuli			17
Preferred without haptic stimuli			0
No preference			2
Total respondents			**19**

Preference for haptic stimulation			
Excerpt	A	B	C
Preferred with (congruent) haptic stimuli	17	14	17
Preferred without (with incongruent) haptic stimuli	2	4	2
No preference	0	1	0
Total respondents			**19**

Effect of haptic stimulation on engagement			
Excerpt	A	B	C
More engaging with (congruent) haptic stimuli	17	17	15
More engaging without (with incongruent) haptic stimuli	1	1	3
No preference	1	1	1
Total respondents			**19**

Effect of haptic stimulation on perceived expressivity			
Excerpt	A	B	C
More expressive with (congruent) haptic stimuli	14	9	17
More expressive without (with incongruent) haptic stimuli	5	9	1
No preference	0	1	1
Total respondents			**19**

4. DISCUSSION

The objectives of this study were to present the listener with a representation of the vibrotactile feedback perceived by the classical guitarist during performance through the use of haptic technology, and to evaluate the perceptual significance and overall musical contribution of the addition of haptic stimulation in a listening context. Preference for the addition of a haptic component, increased engagement with the performance, and increased perceived expressivity were the parameters by which the musical contribution of haptic stimulation was evaluated. Original compositions by Alan were successfully recorded and presented via haptic-listening prototypes at the MMT Exhibition and at a subsequent formal trial. In two experiments, subjective responses to the MMT Exhibition presentation and the formal trial were obtained through two questionnaires.

The Experiment 1 questionnaire responses showed that almost all participants preferred the listening experience with the addition of haptic stimulation. The questionnaire also showed that almost all participants felt more engaged with haptic stimulation. An attempt was made to establish what type of emotional contribution might come from the introduction of haptic stimulation. While the majority of participants said that the haptic stimulation made them feel “calm/relaxed”, it is likely that the responses to this question were influenced by the mood of the compositions. The free-flow comments suggest that participants were enthusiastic about the system and felt that it had relaxing and therapeutic effects.

The investigation carried out by Marshall & Wanderley [12] showed that the introduction of haptic stimulation in a digital slide guitar resulted in a marginally significant increase in performer engagement. The research by Hayes [4] [5] also suggested that the addition of haptic stimulation in DMIs could result in an increase in performer engagement with the instrument. The results of this experiment support the argument that, in the same way that haptic stimulation can result in a performer feeling a greater sense of engagement with an instrument, haptic stimulation can be used in a listening context to enhance the listener’s engagement with the performance.

Experiment 1 was not a highly controlled experiment and the results are not as robust as the more formal Experiment 2. However, Experiment 2 supported the results of Experiment 1 in that almost all participants preferred the listening experience with the addition of haptic stimulation. Participants also felt more engaged with the addition of haptic stimulation. Participants found Excerpt A more expressive with the addition of haptic stimulation. The sample was split down the middle on whether Excerpt B was more expressive with or without the addition of haptic stimulation. Participants preferred the version of Excerpt C with congruent haptic stimulation and found it to be more engaging and expressive than the version with incongruent haptic stimulation.

Some of the comments of participants in Experiment 1 were supported by participants in Experiment 2 which reinforced those of Experiment 1. Experiment 2 shows that participants agree that a haptic-listening presentation could be implemented in a music therapy context. The role of haptic stimulation in music therapy may be a subject for future study. In Experiment 1 the listener held the device in by hand against the chest while in Experiment 2 the listener could position the device against the sternum using a belt. The results of the experiment did not show a clear difference between the two approaches but this could be pursued in further research.

Preference for the addition of haptic technology and increased engagement with the performance suggests that haptic stimulation could be used to improve instrumental listening. As participants in the experiments suggested, haptic stimulation could be used in a wide number of listening contexts such as art installations, therapeutic and health settings, mental health settings, and as a sleeping aid. The technology may have particular application for hard of hearing/ deaf children and adults. The findings support the recent investment by companies like Lofelt into haptic stimulation in listening contexts.

This study implements the ideas suggested by Marc Leman [8] relating to the multimodal mediation of music. The results of the experiments and the enthusiasm of participants supports continued research into multimodal mediation of music. From our results, it is clear that there could be a demand for haptic-listening technology which can improve our music listening experience. The results of this study suggest that the multimodal mediation of music could be a viable next step in improving listener experience.

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