Smart Mandolin and Musical Haptic Gilet: effects of vibro-tactile stimuli during live music performance

Luca Turchet
University of Trento
Trento, IT, Italy
luca.turchet@unitn.it

Travis West
McGill University
Montreal, CA
travis.west@mail.mcgill.ca

Marcelo M. Wanderley
McGill University
Montreal, CA
marcelo.wanderley@mcgill.ca

ABSTRACT

In this paper we investigate the role of haptic stimuli in affecting the perception of live music. We designed a study where a smart mandolin performer played live for audience members wearing a gilet-based musical haptic wearable, which provided vibro-tactile sensations in response to the performed music. Six performances were conducted, each of which involved audiences of two people for a total of twelve participants. Results showed that the audio-haptic experience was not homogeneous across participants, who could be grouped as those appreciative of the vibrations and those less appreciative of them. The causes for a lack of appreciation of the haptic experience were mainly identified as the sensation of unpleasantness caused by the vibrations in certain parts of the body and the lack of the comprehension of the relation between what was felt and what was heard. Based on the reported results, we offer suggestions for practitioners interested in designing wearables for enriching the musical experience of audiences of live music via the sense of touch. Such suggestions point towards the need of mechanisms of personalization, systems able to minimize the latency between the sound and the vibrations, and a time of adaptation to the vibrations.

CCS CONCEPTS

• **Applied computing** → **Sound and music computing**; • **Hardware** → **Haptic devices**; • **Human-centered computing** → User studies.

KEYWORDS

Internet of Musical Things; smart musical instruments; musical haptics

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1 INTRODUCTION

Today, the latest Internet of Musical Things technologies allow composers to explore new avenues for artistic research in musical haptics [10]. The *Internet of Musical Things (IoMusT)* is an emerging research area that applies the Internet of Things paradigm to the musical domain [15]. Musical Things are the building-blocks of the IoMusT vision, and consists of computing devices capable of acquiring, processing, actuating, and exchanging data serving a musical purpose. Examples of Musical Things are *musical haptic wearables for the audience (MHWAs)* [14] and *smart musical instruments* [12]. MHWAs are devices that may comprise actuators and systems for capturing gestures, tracking physiological parameters, and enabling wireless connectivity. They were specifically devised to enrich an audience's musical experience of music performances by integrating haptic stimulations, as well as to provide new capabilities for creative participation thanks to embedded sensor interfaces. Smart musical instruments are characterized by a sensor interface, embedded computational intelligence, a sound processing and synthesis engine, wireless connectivity, an embedded sound delivery system, and an onboard system for feedback to the player. An example of this family of musical instruments is the smart mandolin [11]. An ecosystem connecting the smart mandolin with armband-based musical haptic wearables is reported in [13]. However, to date the evaluation of these kinds of IoMusT ecosystems in *live* scenarios has not yet been conducted. This is the matter of the present study.

In this paper we tackle the challenge of assessing the role of vibro-tactile stimuli in affecting the perception of live music. To investigate this we designed a study where a smart mandolin performer played live for an audience wearing a

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gilet-based musical haptic wearable, which provided vibro-tactile sensations in response to the music. The vibro-tactile stimuli were devised by a professional composer, according to *tactile composition* techniques [4]. The specific research questions we investigate are: i) to what extent do audience members appreciate live music with vibrations?; ii) is there a consensus by the audience about the way in which the vibrations influence the live music experience? To the best of our knowledge, this is the first study investigating the effects on human perception of the application of an IoMusT ecosystem encompassing smart musical instruments and musical haptic wearables in a live music setting.

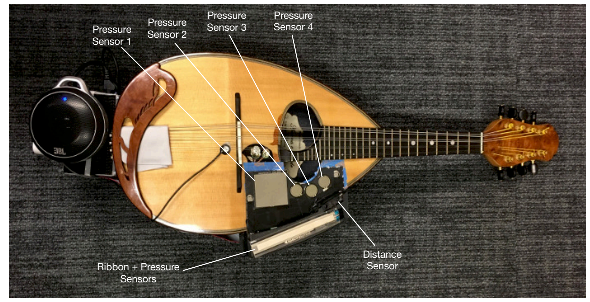

Figure 1: The smart mandolin with the indication of the sensors utilized during the experiments.

2 METHOD

Apparatus

The apparatus consisted of a smart mandolin, two haptic gilets, two laptops, and a wireless router.

Smart mandolin. The smart mandolin [11] (see Fig. 1) comprised a conventional acoustic mandolin enhanced with different types of sensors, a high quality contact microphone, a loudspeaker, wireless connectivity to both local networks and the Internet, embedded battery, and the Bela low-latency audio processing board. The audio engine was coded in the Pure Data real-time audio processing environment and comprised a variety of ad-hoc sound effects modulating the instrument's string sounds, a library of sound samples to be triggered, as well as mapping strategies to control the sound production from the data gathered from the sensors as well as from the real-time extraction of features from the audio signal captured by the microphone.

For the experiment the smart mandolin was configured with seven sensors: five pressure sensors, one ribbon sensor and one distance sensor. The ribbon sensor was attached, thanks to its adhesive film, on top of the strip pressure sensor in order to create a device capable of providing simultaneous information about finger position and pressure. Such sensors were mapped to parameters of audio effects and sound samples triggers as described in Table 1. In addition, we extracted the note onset from the audio signal captured by the microphone, by leveraging the Pure Data object *fiddle~*.

Wireless data reception and forwarding were achieved leveraging the Wi-Fi protocol and the Open Sound Control (OSC) messages over the User Datagram Protocol.

Haptic gilets. The haptic gilets [16] are musical haptic wearables that distribute thirty ERM vibration motors over the wearer's torso. Twelve motors are placed on the front of the torso and eighteen on the back. A schematic representation of the haptic gilet motors placement is illustrated in Fig. 2. Five driver boards are distributed on the garment which respond to OSC messages and generate PWM signals for six motors each. The driver boards connect to the Wi-Fi network using ESP8622 microcontrollers, specifically the ESP-12S modules. The PWM signals from the ESP-12S module are conditioned using the LM1930MC bidirectional motor driver integrated circuits. The involved motors (VPM2 from Solarbotics) were characterized by a maximum vibration amplitude of 1G, and a rise and decay time of respectively 15 ms and 400 ms [3]. Power supply was accomplished by five 3.7 V lipo batteries, one for each board.

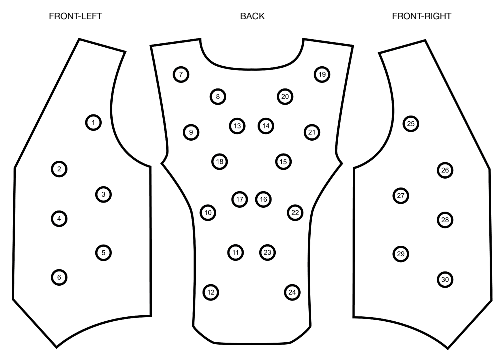

Figure 2: A diagram of the haptic gilet, in its front-left, back and front-right sides, and with the numbering of the 30 motors.

Laptops. A laptop controlled the gilet. A Max/MSP application was created, which received the OSC messages from the smart mandolin and mapped them into patterns of activations of the motors. The mappings are described in Table 1. A second laptop served the purpose of recording the OSC messages transmitted by the smart mandolin.

Router. The smart mandolin, the musical haptic gilets, and the laptops were connected to a local wireless network created by the router TP-Link TL-WR902AC, which was configured to support the IEEE 802.11.n Wi-Fi protocol over the 2.4 GHz bandwidth. The overall average latency between the smart mandolin and the musical haptic gilets was measured as 75 ms.

Stimuli

Two conditions were tested in the experiment: audio and audio-haptic. During the experiment a professional composer and smart mandolin player played the smart mandolin. During the audio-haptic condition participants experienced the music with concurrent haptic stimuli displayed by the gilet. The haptic stimuli were created according to tactile composition practices [4] and leveraging the pulse width modulation technique. They consisted of patterns of activations of the vibro-tactile motors that were inspired by the types of sounds that the smart mandolin could produce according to its configuration. They were devised with the goal of enriching the music experience. Specifically, the activation of the haptic patterns was associated to i) performer-sensor interactions, and ii) each note played when no sensor was concurrently active. Table 1 illustrates how each sensor and the extracted audio feature (i.e., the note onset) were mapped to both the electronically-generated sounds and the haptic stimuli.

Procedure

Twelve subjects (4 females, 8 males), aged between 21 and 43 (mean = 31.5, standard deviation = 6.52), took part in the experiment. All participants reported normal hearing.

The experiment comprised six experimental sessions. Each session consisted of three trials in which the player played the smart mandolin for an audience of two participants. Each trial consisted of an extemporaneous improvisation on a theme. The involved themes were "O sole mio" by composer Di Capua, a Swedish folk song, and a theme composed for this work. The order of the themes was randomized across participants. The performer tried to make the trials as similar as possible across participants (i.e., by using similar elements and adopting a similar playing style). Each trial lasted 6 minutes, during which the conditions with and without haptic feedback were automatically alternated every one minute by an application running on the first laptop. Therefore, in each trial participants underwent for 3 minutes both the conditions with and without haptic stimuli. The experimenter indicated to the performers when to start and stop. The order of alternation was randomized across trials. Therefore, the performer did not know when the audience would have received the haptic stimuli so his performance could not be affected by this information.

Participants were asked to wear the haptic gilet described in Section 2 and to sit on two chairs at 1.5 m distance from the performer. They were told that during each trial the gilets might have provided some vibrations. They were not provided with any information concerning the purpose of the experiment and did not undergo any phase of familiarization with the technology. Participants were asked to respond to between-sessions questionnaires and a post-experimental questionnaire, as detailed below.

Between-sessions questionnaire. At the end of each of the three trials participants were asked to evaluate on a visual analog scale (VAS) the following questions: **Irritating.** *I found the vibrations irritating while listening to the music*; **Enjoyed.** *I enjoyed the music with the vibrations*; **Distracting.** *I found the vibrations distracting from the music*; **Engage.** *I found the vibrations helped me engage with the music*; **Vib-music.** *I understood a correspondence between the vibrations and the music*; **Vib-actions.** *I understood a correspondence between the vibrations and the performer's actions*; **Enhanced.** *The vibrations enhanced my experience of the music.*

Post-experimental questionnaire. At the end of the experiment participants were asked to evaluate on a visual analog scale (VAS) the following questions: **Preferred.** *I preferred the performance with the vibrations compared to without*; **Satisfied.** *I was satisfied with wearing the gilet during the performance*; **Helped.** *The vibrations helped me to better understand the music*; **Enjoyed.** *I enjoyed myself the most when when I experienced the vibrations*; **Engaged.** *I felt more engaged with the music when I experienced the vibrations*; **Connected.** *I felt more connected to the performer when I experienced the vibrations*; **Enriched.** *The vibrations enriched my experience to listening to the music*; **Arousal.** *Please rate how calm or exciting you perceived the music to be with the vibrations*; **Valence.** *Please rate how negative or positive you perceived the music to be with the vibrations.*

In addition, we asked participants to answer to the following three questions: *How would you describe the experience with the vibrations compared to without?*; *Did you prefer the experience more with or without the vibrations? Why?*; *What would you change about the vibrations or the vest to improve the experience, if anything?* Finally, participants were given the possibility to leave an open comment.

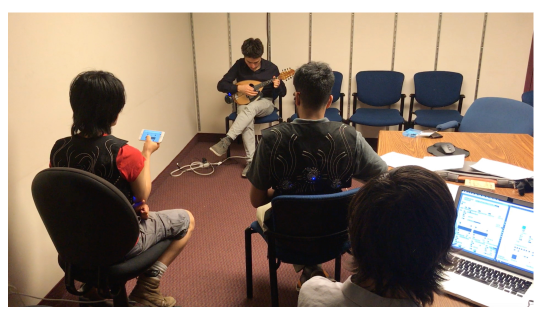

Figure 3: A picture taken during one of the experimental sessions showing, from the back to the front of the picture, the smart mandolin performer, the two participants wearing the haptic gilets, and the experimenter monitoring the data collection.

Table 1: Mappings between the OSC messages related to the smart mandolin sensors and extracted audio feature, the associated electronically-generated sounds, and the tactile stimuli delivered by the haptic gilets (for motors numbering see Fig. 2).

OSC message	Sound stimulus	Tactile stimulus
Pressure sensor 1	Pitch shifter at one octave lower, followed by a low-pass filter and a delay with feedback (delay time = 632 ms).	Amplitude ramp from 0 to maximum amplitude in 632 ms for motors 5, 6, 11, 12, while the amplitude of motors 23, 24, 29, 30 is controlled by a ramp from the maximum amplitude to 0 in 632 ms of motors (in both cases the duty cycle of the motors is set to 100%). This pattern aimed to create a fade-in of the motors on the body bottom left side, (front and back) which was simultaneous to the fade-out of the motors on the body bottom right side (front and back).
Pressure sensor 2	Pitch shifter at one octave higher, followed by a delay with feedback (delay time = 316 ms).	Circular activation of motors 2, 1, 7, 8, 19, 20, 25, 26 (back and forth, starting from motor 2). Each motor is activated for 79 ms, at duty cycle 100% and amplitude 0.79 of the maximum amplitude. The temporal distance between the activation of two sequential motors is 2 ms. This pattern aimed to create a sensation of fast horizontal movement along the body's top part (specifically the shoulders).
Pressure sensor 3	Pitch shifter at one octave lower, followed by a low-pass filter and a delay with feedback (delay time = 316 ms), with in series a pitch shifter at one fifth higher, followed by a delay with feedback (delay time = 158 ms).	Alternation between the simultaneous activations of all motors on the gilet's left and right sides. The time of alternation was 158 ms. For each motor in both sides the duration of activation was 79 ms, the duty cycle was 100% and the amplitude was 0.79 of the maximum amplitude. This pattern aimed to create a fast alternation between the front left and front right side of the body.
Pressure sensor 4	Triggering of a percussive sound sample.	Triggering of a short vibration (duration = 79 ms, duty cycle = 100%, amplitude = maximum amplitude) simultaneously on motors 3, 4, 9, 10, 15, 18, 2, 22, 27, 28. This short burst aimed to create an impulsive sensation on the central part of the body (both front and back).
Distance sensor	Triggering of a drone sound sample, whose volume is controlled by the distance of the hand from the sensor.	Simultaneous activation of all motors on the front-left and front-right side of the gilet. For each motor the amplitude was set to half of the maximum amplitude, while the duty cycle varied from 4.93 to 19.75 Hz and was controlled by the detected distance of the hand such that the closer the hand the higher the duty cycle. This pattern aimed to create a movement sensation on the whole front part of the body.
Ribbon sensor + pressure sensor	Continuous pitch shifting up to one octave higher followed by a delay with feedback (delay time = 316 ms). The finger position controls the amount of pitch shifting, the finger pressure controls the volume of the effects.	Sequential activation of the following motors, coupled by their vertical position: (7,19), (8, 20), (9, 21), (10, 22), (11, 24) and (12, 23). The finger position tracked by the ribbon sensor was mapped to the vertical position of such couples of motors such that the top motors were mapped to the right extremity of the ribbon sensor. This pattern aimed to create a sensation of vertical movement along the body's back.
Note onset	No mapping to sound effects or samples, only direct sound processed with a small reverberation.	Each note onset was mapped to the simultaneous triggering of a short vibration (duration = 79 ms, duty cycle = 100%, amplitude = maximum amplitude) on the motors 13, 14, 15, 16, 17, 18. This short burst aimed to create an impulsive sensation on the central part of the back of the body.

3 RESULTS

Results of the between-sessions evaluations

Fig. 4 (left) shows the results for the evaluations of all participants in terms of mean and standard error. However, these aggregated scores hide the presence of different subgroups within the participants. An in-depth analysis at the subject level revealed that there were two groups, those more positive towards the vibrations (7 subjects), and those more negative towards them (5 subjects). In the reminder of the paper we refer to those groups as "positive group" and "negative group". The mean and standard error of the evaluations of the two groups is shown in Fig. 4 (right). An analysis conducted using the Mann-Whitney-Wilcoxon test, showed that the positive group evaluated the level of irritation caused by the vibrations as significantly lower compared to the negative group (U = 297, $p < 0.001$); the evaluations of the level of enjoyment caused by the vibrations was significantly higher for the positive group compared to the negative group (U = 61, $p < 0.01$); along the same lines, the positive groups rated the enhancement of the music experience caused by the vibrations as significantly higher than that reported by the negative group (U = 80.5, $p < 0.05$).

Furthermore, to assess the effect of stimuli repetitions across the time we checked for differences between the trials considering all subjects. The mean and standard error of the participants' evaluations after each trial are illustrated in Fig. 5. A statistical analysis conducted between the ratings of the first and last trials for each questionnaire item, using the Mann-Whitney-Wilcoxon test, showed that the level of engagement of participants induced by the vibrations was significantly higher for the last trial compared to the first (U = 31.5, $p < 0.05$). All other comparisons were not significant. A tendency towards significance was found for the level of distraction caused by the vibrations (U = 31.5, $p = 0.08$), which was higher for the first trial compared to the last.

Results of the post-experiment evaluations

Results for the post-experimental questionnaire for all subjects are illustrated in Fig. 6 (left). Again the mean from all participants blurs the evidence: an in-depth analysis at subject level revealed that the same subjects identified as belonging to the positive and negative groups in the between-sessions evaluations, could be also grouped for the post-experimental evaluations. Results for the evaluations of the two groups of subjects are shown in Fig. 6 (right). Using the Mann-Whitney-Wilcoxon test, significantly greater evaluations of the positive group compared to the negative one were found for preference for, enjoyment of, and engagement with the music with the vibrations (respectively U = 0.5, $p < 0.01$; U = 6, $p < 0.001$; and U = 4, $p < 0.05$). Moreover, the positive group rated that the vibrations enriched the music experience with significantly greater evaluations compared to the negative group (U = 0.5, $p < 0.01$). As far as the valence is concerned, the positive group rated it as significantly higher than the negative one (U = 3, $p < 0.05$).

Thematic analysis. We analyzed participants' answers to the open-ended questions using an inductive thematic analysis. The analysis was conducted by generating codes, which were further organized into themes that reflected patterns, as described below.

Attention. According to two participants the vibrations enhanced the attention to the music as they stimulated them to search for the relationship between what was heard with what was felt (e.g., *"The vibrations made me pay attention to the music to try to match it with the vibrations"* or *"Vibrations added a new level and I found myself searching for relationships between music and vibrations"*). Conversely, two participants reported that in some cases the vibrations distracted them from the music. This happened for instance in presence of uncomfortable sensations caused by the vibrations in certain locations (e.g., *"It was too distracting from the music when vibrating below the stomach as it was an unpleasant sensation"*) or when a connection between the music and the vibrations was searched and not found (e.g., *"I could not make a connection between vibrations and music, so it was mentally distracting"*).

Music-vibration connection. Six participants reported that the vibrations did not fully correspond to the music heard. While in some cases they were able to find a clear connection, in other cases they did not perceived coherence between what they were hearing and what they were feeling. In general, this was reported to have affected negatively the audio-haptic experience (e.g., *"I preferred the experience without vibrations because I didn't see much correspondence between music and vibrations"* or *"I preferred when the vibrations corresponded strongly with an effect or to the strumming. If there wasn't a clear connection between music and vibration it was distracting"*). Two of these participants commented to have enjoyed the experience the most when a correspondence was clear to them (e.g., *"I didn't understand the correlation between the music and the vibrations for most part, but when I did perceive them to go well together I enjoyed it"*). All of them suggested to design the vibrations in such a way to have a more intuitive audio-haptic correspondence (e.g., *"The relation between the sound and haptic feedback needs to be more understandable"*, *"I'd make the music correspond to the vibrations more precisely"* or *"Ideally, the vibrations should be modulated by the intensity of the music, which I felt was not the case always"*). One participant commented to have perceived a latency between the music and the vibrations (e.g., *"Sometimes it felt like if the haptic feedback was not at the same time as the music, like if there was a delay"*).

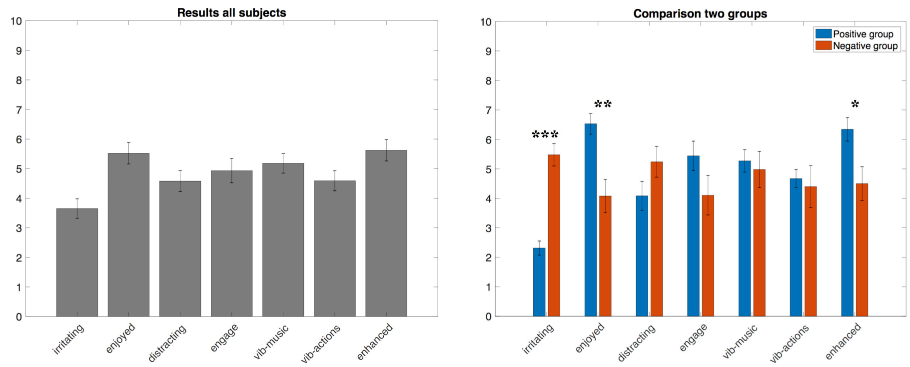

Figure 4: Mean and standard error of the between-session evaluations for all subjects (left) and for the two identified groups (right). Legend: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

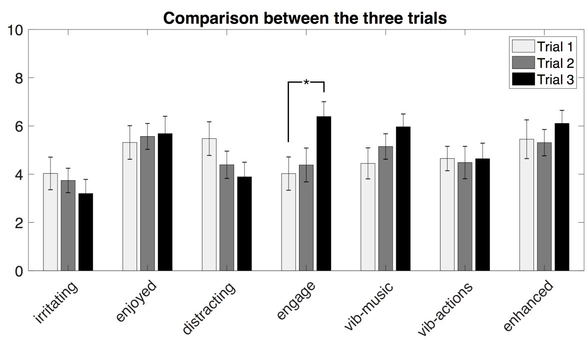

Figure 5: Mean and standard error for the evaluations after each trial, for all subjects. Legend: * = $p < 0.05$.

Adaptation time. Two of the participants commented that the very first impact with the vibrations was not pleasant and a time of adaptation was necessary to them to get used to the vibrations and enjoy the experience (e.g., *"The stimuli were at first distracting but then I slowly got used to them. I mostly enjoyed the experience of the vibrations towards the end"* or *"At first I preferred the musical experience without the vibrations but then I liked it because of the challenge to make a connection with the sound"*).

Arousal. Two participants reported that the vibrations induced them to feel more excited (e.g., *"With the vibrations the experience is more exciting"*). One of these participants also reported that vibrations were enhancing the arousal of the more exciting musical parts (*"When there was a very exciting passage the vibrations enhanced the music, I even felt the need to dance"*). Conversely, one participant reported that vibrations induced a state of relaxation, especially when the music had a calm mood (*"The vibration helped me to relax while the music was more calm"*).

Richer experience. Five participants reported to have enjoyed the experience of the vibrations as they led to a novel, interesting, or richer experience (e.g., *"I liked a lot the experience with the jacket and the vibrations"*, *"The experience of the music with the vibrations is more engaging. It creates a sense of being more involved"*, or *"I prefer the experience with the vibrations. My experience was more intimate, as if someone was interacting with me"*).

Unpleasantness. Three participants deemed parts of the haptic experience unpleasant. This was due to the fact that in some cases the vibrations were perceived as uncomfortable since they stimulated parts of the body where participants were more sensitive. In particular two of those participants suggested to not use the vibrations in the region of the stomach (e.g., *"Avoid the vibrations on the whole part of the abdomen, they are sometimes painful if you are a woman"* or *"Sometimes the feeling is uncomfortable. Don't provide vibrations in the region below the stomach"*).

4 DISCUSSION

The results of both the between-session and post-experiment evaluations consistently revealed the presence of two groups within participants, which could be categorized on the basis of their positive or negative appreciation of the provided vibrations. The thematic analysis carried out on the open-ended questions revealed various causes that led the participants of the negative group to generally prefer the experience of the music without the vibrations, as well as some of the participants of the positive group to rate with not very high values the evaluation scales assessing the vibrations appreciation. Some of those participants addressed the lack of appreciation of the haptic experience to the sensation of unpleasantness in some parts of the body where they were particularly sensitive, while others to the lack of full comprehension of the relation between the music and the vibrations (revealing to have appreciated mostly the audio-haptic experience when such a relation could be found). These aspects were reported to have distracted participants from the music.

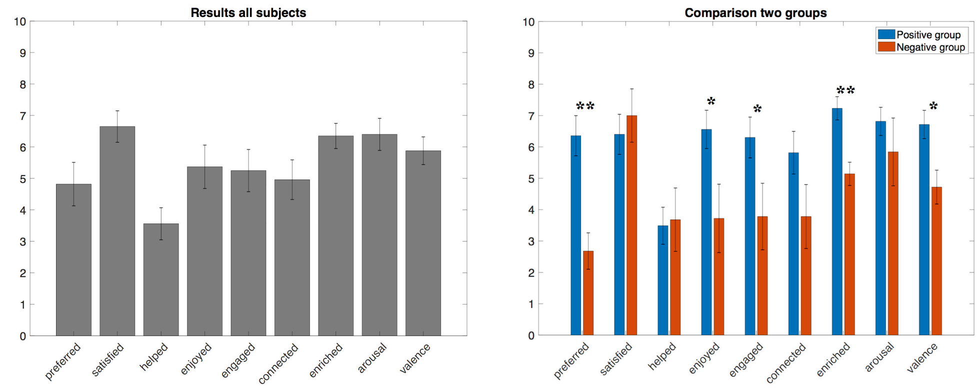

Figure 6: Mean and standard error of the post-experiment evaluations for all subjects (left) and for the two identified groups (right). Legend: * = $p < 0.05$, ** = $p < 0.01$.

On the other hand, some participants deemed that the vibrations actually enriched the live music experience (their average evaluation on such a scale was 7.2 out of 10) and reported to have enjoyed the experience of the music in presence of the vibrations. The causes that led to such enjoyment were different as participants addressed the enhancement of the music experience to the capability of the vibrations to induce either a state of excitement or of relaxation. Similar considerations on the affective interactions between the two compositional media were provided by the participants of the Gunther and O'Modhrain's study [4]. The increased excitement experienced by some of the participants in presence of the vibrations parallels the findings of Mazzoni and Brian-Kinns on the influence of vibrations on arousal in mood music of movies [7]. Interestingly, some participants reported that the provided vibration patterns spurred them to a higher level of attention to the music in order to find the relationship between what was listened and what was felt.

However, even for the positive group the vibrations were not effective in drastically enhancing the music listening experience of participants. This result is only in part in line with the findings available in the literature of musical haptics involving recorded music. The studies reported by Merchel and Altinsoy [9] and those by McDowell and Furlong [8] showed that vibrations were generally effective in improving the listeners' music experience. Nevertheless, those studies involved recorded music, which is devoid of the vibrations that can be naturally perceived by the body during a live music concert. The vibrations provided in those experiments aimed to recreate the haptic sensations that could be experienced during a live music setting, which showed to have a positive effect in the perceived quality of the heard music. On the other hand, those studies used wearables very different than the one used here. Such devices were based on vibration speakers and the haptic stimuli were tightly synchronized with the music participants were listening to. In our experiment, participants experienced vibrations that superimposed onto the ones already perceived by the body through the live performance setting. Moreover, the provided vibrations were not tightly synchronized with the music. Although the vibrations had a high degree of temporal relation with the music played (e.g., the delay time of the delay effects was coherent with the temporal distance between the vibrations), there was a high latency in the wireless transmission and generation of such vibrations (75 ms). It is plausible that such delay between the heard music and the experienced sensations had an effect on participants' perceptions. The comments of one of the participants about the perceived latency supports this hypothesis.

Notably, some participants reported the need of some time to get used to the vibrations and, as a consequence of this, enjoy the experience. The results of the analysis of the participants' evaluations after each trial support these comments. From Fig. 5 a general trend emerges where the evaluations about the irritation and distraction caused by the vibrations decreased from the first to the last trial, while the evaluations about the level of the engagement induced by the vibrations significantly increased from the first to the last trial. It is also worth noticing that the results of the questions on engagement and enhancement/enrichment of the post-experimental questionnaire were on average slightly greater than the corresponding ones of the between-session questionnaire (see Fig. 4 and Fig. 6). These results are in agreement with the findings of Gunther and O'Modhrain [4], who used a wearable device with spatially distributed vibration speakers (although involving pre-recorded music delivered via headphones). Some participants of their study commented that at first it was difficult for them to make sense of the perceived vibrations, but that their ability to understand and appreciate the played tactile compositions improved with the time.

The study reported here mostly focused on artistic and expressive applications of haptics technology, which is in line with the endeavors of composers adopting tactile composition techniques to augment the audience's music experience (see e.g., [1, 4, 5]). The vibrations were designed according to the composer's aesthetic choices, which were however aiming to create at haptic level a coherent representation of the played music. Notably, aesthetics is a topic that has been largely overlooked in haptic design research [2, 6] and has recently been encouraged by haptic designers such as Hayes and Rajko [6]. This study also aimed to contribute towards a discussion on aesthetics in musical haptic practice.

Design considerations

Based on the results mentioned above we delineate the following design considerations that may benefit designers of musical haptic wearables focusing on enriching the musical experience of audiences of live music.

Co-design. The issues of lack of comprehension of the connection between the music and the vibrations call for a better design of the haptic stimuli in relation to the music. One possible strategy to cope with this issue is that of involving audience members into the design process.

Personalization. To avoid unpleasant sensations that some people may experience in certain parts of the body it is important to empower the audience members with the possibility of personalize their musical haptic wearable. Such personalizations may account for the selection of which parts of the body one wants to experience the vibrations on (this might imply the deactivation of certain motors impacting certain regions of the body), the regulation of the maximum amplitude of the vibrations, or the choice of specific vibrotactile patterns among a set.

Latency reduction. The synchronization between the music delivered by a musical instrument and the related vibration delivered by a musical haptic wearable seems to play a relevant role in the audio-haptic experience. Therefore, it is crucial to minimize the latency between the two media. This may be achieved by leveraging wireless communication protocols faster than the one used in the present experiment. Latency may also be reduced by involving vibration speakers, which have a minimal rise time (differently from ERMs).

Familiarization phase. When designing a live music performance it is important to reserve some time before its beginning to make the audience members experience the vibrations. Especially for some participants a certain time for adapting to the sensations caused by the vibrations is needed in order to understand and appreciate the played tactile compositions.

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