Haptification of performer's control gestures in live electronic music performance

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ABSTRACT

In this paper, we introduce musical haptic wearables for audiences (MHWAs) which provide sensing and haptic stimulation technologies for networked musical interaction using wireless connectivity. We report on a concert experiment during which audience members could experience vibro-tactile feedback mapped to the control gestures of two electronic music performers. Preliminary results suggest that MHWAs may increase the audience's understanding of the musical expression and the presence of the performers when the tempo is slow while no significant effects were found at fast tempi. Participants' comments also indicate that vibro-tactile feedback related to musical attributes such as beat could enrich some aspects of the live music experience.

CCS CONCEPTS

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

KEYWORDS

Internet of Musical Things; musical haptics; audience

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1 INTRODUCTION

With digital musical instrument, many of the cues helping the audience to understand the gesture-sound relationships are lost due to the miniaturization of the control interfaces and potentially complex mappings [2]. In this work, we investigate whether haptic displays can increase the understanding of performers' musical actions (instrumental control gestures) and expressivity in the context of electronic music performance, and what are the effects of control-related haptifications on affective and hedonic aspects for listeners. To date, little work has been done on the haptification of control gestures to attempt to address the issue of transparency in digital musical instruments and improve the perception of performers' efforts by an audience.

Recently, we have proposed the "musical haptic wearables for performers" [5], a class of wearables delivering haptic cues devised to enhance creative communication between performers during live music practice. We position such wearables as part of a wider class of "Musical Things" following the Internet of Musical Things paradigm [6]. Here, we introduce the "musical haptic wearables for audiences" (MHWAs), which are wearable devices encompassing sensing, haptic stimulation and wireless connectivity, aimed at audience members of live music performances. We report on a concert experiment during which a duo of professional electronic music performers played for an audience wearing MHWA prototypes. We investigate how the use of MHWAs influences the audience's understanding of the instrumental control gestures of the performers and the sense of connection between the audience and performers.

2 EXPERIMENT

Setting and apparati

Ten MHWA prototypes were created to provide tactile stimuli on both arms. Their hardware components (see Fig. 1) consisted of a small fanny pack; two elastic armbands; the Bela board for low-latency audio processing; a Wi-Fi USB dongle compatible with the IEEE 802.11ac standard exploiting the 5Ghz band; four vibration motors, two for each armband (these particular motors were chosen for their capability of providing a wide range of dynamics given a maximum vibration amplitude of $7g$, and quick rise and decay time, 28 ms and 49 ms, respectively); a lightweight power supply. At software level, data processing and synthesis of the tactile stimuli were accomplished using Pure Data applications leveraging the Pulse Width Modulation technique. The same applications

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implemented data reception and forwarding through OSC messages over UDP. The motors embedded in each armband were connected to the Bela computing board using wires which were strapped to the participants' clothes using small clips (see Fig. 1). The performers used two laptops and four MIDI controllers.

All MHWAs and the laptops were connected using a router. The average latency and jitter of the local network (one way, not roundtrip) were 1.7 ms and 0.66 ms, respectively. Clock synchronization of the MHWAs and laptops over the wireless local network was achieved using the Ableton Link protocol. Each laptop ran four applications for live electronic music, which were developed using the Ableton Live digital audio workstation. These were composed by the performers who used different MIDI interfaces to control them (two drum pads and two keyboards). Each laptop also ran a Pure Data patch that mapped the MIDI messages controlling the Ableton Live applications into OSC messages wirelessly transmitted to all MHWAs. Some of the MIDI controller knobs, which generated MIDI control change messages, were mapped to the beat message of the Link protocol, to continuously control the tempo of the performed piece.

During the experiment the performers played on a small stage with the audience standing in front of them (see Fig. 1). As we wanted the audience members to be able to relate to the control gestures from both performers through haptic feedback, the MHWAs were set up so that each armband corresponded to one performer. Table 1 describes the mappings utilized to associate the MIDI and Link messages to the synthesized tactile stimuli triggered by the MHWAs. The tactile stimuli were designed based on "tactile music composition" procedures [3] and by consulting the two performers to find a relevant mapping with their control gestures. A pilot test was conducted with two participants (who did not take part in the subsequent concert experiment) to test the validity of the tactile stimuli. The haptification was based on the following MIDI messages: *MIDI Note on* messages triggered when keyboard keys and drum pads were pressed, *MIDI Control change* messages occurring once knobs were turned, and *MIDI pitch bend* messages produced when the pitch bend wheels of the keyboards were used. *MIDI program change* messages were not included as they did not directly trigger or modify a sound (hence their effect could be confusing). *After-touch* actions on pads and keys (and therefore the associated after-touch MIDI messages) were not used by performers. During tempo changes, a *beat change* message was produced through a designated knob on the keyboards to synchronize the tactile pulse on the performed beat. Since the perception of the tactile pulse is affected by the rise time of the motor and the skin sensitivity, the vibration was triggered 60 ms before the beat occurred (this anticipation was empirically tuned during a pilot study with 4 participants).

Table 1: Mapping between messages and tactile stimuli.

MIDI/Link	Tactile stimulus
Note on	Single pulse on left motor (duty cycle = 100%, duration = 150 ms)
Control change	Intermittent pulses on left motor (frequency = increase from 4 Hz to 20 Hz in 3000 ms and then stable for the rest of the duration of the action, duty cycle = 35%)
Pitch bend	Intermittent pulses on both motors (frequency = increase from 4 Hz to 20 Hz in 3000 ms and then stable for the rest of the duration of the action, duty cycle = 30%)
Beat change	Pulses on both motors (duty cycle = 100%, duration = 100 ms) triggered on each beat during a beat change and for 16 additional beats after the last change

When a new action was performed on the controller before the end of the tactile stimulus associated to a previous action, the current haptic stimulus was interrupted so that the most recent action could be haptified.

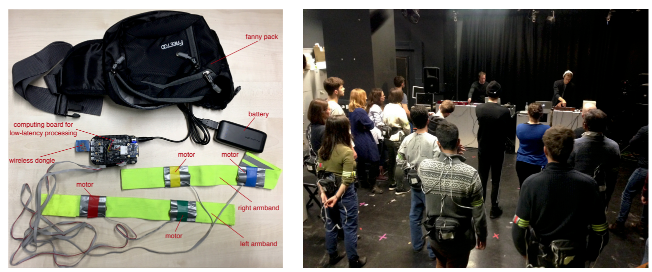

Figure 1: Prototype of musical haptic wearable for the audience used in the study and a picture of the concert.

Participants and procedure

Prior to the concert, the two performers were invited to prepare four pieces together, two with a fast tempo (130 BPM) and an exciting character, and two with a slow tempo (80 BPM) and a relaxing character.

The audience included 20 participants (8 females, 12 males, aged between 20 and 52, mean age = 32, SD = 7.5) which were divided into two groups of 10 members each. In each piece, one group used the MHWAs while the other didn't (control group). Participants were instructed that they would experience the performance using wearables producing haptic stimulations but they were not told how they functioned in relation to the performers. To assess whether the system was intuitive and self-explanatory, no familiarization stage was conducted. Each group experienced the fast and slow pieces with and without the MHWAs; the order of the sessions was as follows: Session 1 - Fast 1 (MHWA: Group 1); Session 2 - Slow 1 (MHWA: Group 2); Session 3 - Slow 2 (MHWA: Group 1); Session 4 - Fast 2 (MHWA: Group 2).

Each session lasted 10 minutes. This design enabled to investigate the effects of the tempo and haptic wearable factors on the experience of the participants. After each music piece, the participants were invited to complete a questionnaire using computers in a lecture room located next to the performance venue. The questionnaire was identical for both the MHWA and control groups and was composed of the following questions to be evaluated on 7-point Likert scale: **Arousal**: *"Please rate how calm or exciting you perceived the music to be".* [1=very calm, 7=very exciting]; **Valence**: *"Please rate how negative or positive you perceived the music to be."* [1=very negative, 7=very positive]; **Engagement**: *"Please rate your engagement level during the performance."* [1=not engaged at all, 7=very engaged]; **Enjoyment**: *"I liked the performance."* [1=strongly disagree, 7=strongly agree]; **Clarity**: *"The actions of the performers were clear to me."* [1=strongly disagree, 7=strongly agree]; **Understanding**: *"It was easy to understand the musical expression of the performers."* [1=strongly disagree, 7=strongly agree].

After the performances, participants had to complete a post-questionnaire comprising two parts. The first part consisted of Likert items selected and adapted from the mutual engagement questionnaire described in [1]. The second part consisted in reflective feedback using the Likert items listed in Table 3 and others about the vibratory sensations.

Results

Table 2 shows the number of occurrences of the different MIDI/Link messages involved in each session, which are also the numbers of haptic stimuli following the mappings reported in Table 1. All participants received the same stimuli and no packet loss occurred in the wireless transmission (as verified on the analysis of log files).

Figure 2 shows the results of the questionnaires provided at the end of each session for the MHWA and control groups. The participants' answers to Likert items were subjected to the Mann-Whitney-Wilcoxon nonparametric test to assess the effect of the Wearable between-subject factor. The analysis showed that in Session 2 (Slow 1) the perceived clarity of the performers' actions and the understanding of the musical expression of the performers were significantly higher for the group wearing the MHWAs compared to the group not wearing them (respectively U = 95.5, $p < 0.001$ and U = 75.5, $p < 0.05$). All other comparisons were non significant.

Regarding the first part of the post-performance questionnaire on mutual engagement, 14 out of 20 participants deemed that the best performances were produced when using the MHWAs, 5 without using them, and 1 did not express a preference; 11 participants reported that they felt more satisfied with the performances when wearing the MHWAs, 5 without wearing them, and 4 did not express a preference; 11 participants reported that they enjoyed themselves the most with the MHWAs, 6 without and 3 did not express a preference; 13 participants reported that they felt most involved with the performers when wearing the MHWAs, 3 without wearing them, and 4 did not express a preference. These results show that the majority of participants preferred the performances attended when using the MHWAs.

Table 3 reports the results of the reflective questionnaire. With the MHWAs, audience members felt slightly more connected to the performers (M=4.8, SD=0.38) and more engaged with the music (M=4.55, SD=0.46). Participants tended to enjoy the vibro-tactile feedback (M=4.4, SD=0.43) which was not found to be irritating (M=2.95, SD=0.35). They also expressed to be satisfied wearing armbands (M=4.85, SD=0.31). The additional questions related to the experience about the vibro-tactile feedback showed that 15 participants deemed the strength of the vibrations appropriate, 4 too soft and 1 too strong; 7 participants reported that the vibrations occurred an appropriate number of times, 7 too rarely, and 6 too frequently; 12 participants reported that each armband

Table 2: Number of occurrences of each MIDI/Link message for each session.

Stimulus	Session 1	Session 2	Session 3	Session 4
Note on	642	694	538	704
Control change	286	476	318	386
Pitch bend	5	15	8	8
Beat change	3	2	2	3

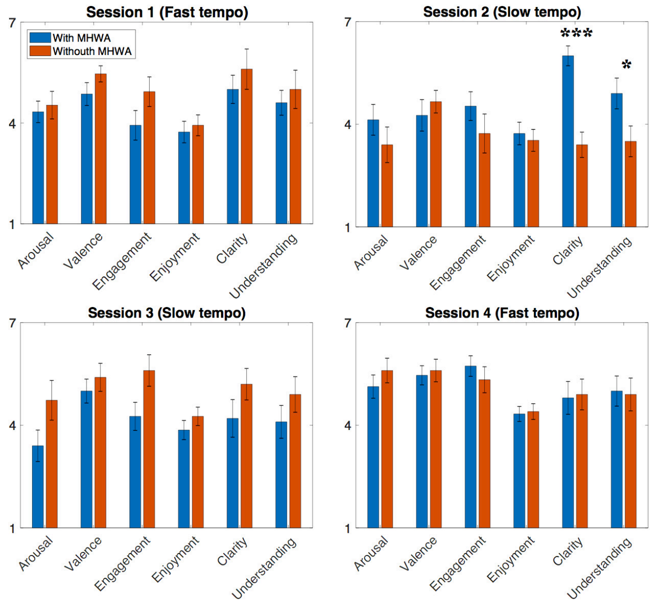

Figure 2: Results of the questionnaire provided at the end of each session. Legend: *** = $p < 0.001$, * = $p < 0.05$.

Table 3: Questions and results (mean±standard error) of the post-session questionnaire (7-point Likert scale).

Likert item	Score
I felt more connected to the performers when I had the wearable	4.8±0.38
I felt more engaged with the music when I had the wearable	4.55±0.46
I found the wearable vibrations irritating while listening to the music	2.95±0.35
I enjoyed the wearable vibrations while listening to the music	4.4±0.43
The wearable vibrations distracted me from the music	3.4±0.40
The wearable enhanced my experience of the music	4.15±0.41
I was able to relate the wearable vibrations to the music produced by the performers	4.15±0.35
I was able to relate the wearable vibrations to the actions of the performers	4.3±0.39
The wearable helped me to better understand the music	3.3±0.39
The wearable helped me to better feel the music	4.1±0.46
I moved more when I had the wearable	3.75±0.42
I was satisfied with wearing armbands during the performance	4.85±0.31
I was satisfied with wearing a waist bag during the performance	4.3±0.36

produced vibrations related to the actions of a single performer, 4 that each armband produced vibrations related to the actions of both performers, 4 did not had an opinion on this matter. Most of the participants understood that each armband related to a specific performer, and that their vibrations related to the actions of the performers. On average, the vibrations were appreciated by participants and were found appropriate. However, participants had different preferences for the frequency of the vibrations. This indicates that it could be favorable to let users personalize the vibration frequency in the MHWA interface.

In the open comments, 9 participants commented that the vibrations should have been related to the music rather than to the performers' actions (e.g., *"There was not enough of a link between the music and the vibrations, they just related to the performers' actions."*). In particular, 3 participants suggested to synchronize the vibrations to the beat or rhythmic patterns (e.g., *"I think that vibrations would work best if more synced to the beat and the rhythm"*). Six participants also reported to be enthusiastic about the MHWAs.

3 DISCUSSION

Results showed that the MHWAs and produced vibro-tactile feedback did not significantly affect the emotional response, level of engagement and enjoyment of the audience. However, in one out of four sessions, Session 2 (Slow 1), the use of MHWAs significantly increased the clarity of the performers' actions and the understanding of their musical expression.

The positive feedback expressed about the MHWAs after the sessions (Table 3) contrasts with the lack of significant effects in-between sessions. This may be related to the rather small number of participants in each group (N=10) for the in-between Mann-Whitney-Wilcoxon tests which affects their power. Another aspect which may influence the results is that in the post-session questionnaire, participants' answers are made considering both the slow and fast pieces, providing a more general assessment than for the in-between session questionnaires, which are made only for specific pieces.

As shown in Table 3, although participants tended to be able to relate the wearable vibrations to the actions of the performers (M=4.3, SD=0.39), using them did not enhance the experience of the music in a clear way (M=4.15, SD=0.41). Since computer music gestures don't convey sensations of effort in listeners [4], the effects of their haptic mapping is inherently problematic to evaluate. This may be due to a lack of cause-and-effect between the haptic and audio domains impeding on the ability of listeners to connect the haptification of the gesture with the audible result. Indeed, with DMIs, the effects of control gestures can be highly non linear and not necessarily synchronous to the sound production. Even if the mapping from gesture to haptic can be understood, failing to interpret the mapping from haptic to sound may limit or jeopardize the benefit of MHWAs. Further research is needed to design musical haptic stimuli driven by control gestures, ensuring that meaningful interpretations can be made both for the gesture-to-haptic and haptic-to-sound domains. This is supported by the analyses of the open comments highlighting the desire by some participants to experience haptic stimuli related to the produced music (e.g., its rhythm) rather than to the performers' actions.

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