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Improvising through the senses: a performance approach with the indirect use of technology

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ABSTRACT

This article explores and proposes new ways of performing in a technology-mediated environment. We present a case study that examines feedback loop relationships between a dancer and a pianist. Rather than using data from sensor technologies to directly control and affect musical parameters, we captured data from a dancer's arm movements and mapped them onto a bespoke device that stimulates the pianist's tactile sense through vibrations. The pianist identifies and interprets the tactile sensory experience, with his improvised performance responding to the changes in haptic information received. Our system presents a new way of technology-mediated performer interaction through tactile feedback channels, enabling the user to establish new creative pathways. We present a classification of vibrotactile interaction as means of communication, and we conclude how users experience multi-point vibrotactile feedback as one holistic experience rather than a collection of discrete feedback points.

KEYWORDS

Vibrotactile; interactive systems; dance; feedback loop; haptic; audiovisual

1. Introduction

In electronic music performances, sensor technology is often used to capture data from performers and, through different mapping and interaction design strategies, to control digital audio processing effects such as reverb, delay or filtering, for example. Such approaches are an inseparable part of how musicians and the broader performance art community may interact with electronic interfaces thus providing a blank canvas to composers for mapping performers' actions to the required sonic response (Birnbaum et al. 2007; Hunt, Wanderley, and Paradis 2003). The wide availability of controllers and sensor-enabled devices together with the implementation of different mappings arguably impel creativity. However, due to the broad possibilities of designing and interactions, performers often struggle to develop their musicality with electronic interfaces as they do with acoustic instruments. For instance, the gesture of extending the right hand above the head may control the wet/dry parameter of a reverb effect but could also control the audio playback of a pre-recorded audio file. As a result, the same gesture can produce very different sounding results, something that is inherently lacking in sound producing gestures in instrumental music. Consequently, performers often struggle to develop a connection with digital instruments in the same way as they do with acoustic instruments.

In this article, we present a system that enables performers, through vibrotactile

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feedback, to explore new ways to interact with one another. Through our case study, we explore novel ways for communication using haptic stimulation and examine the potential this has to elicit new creative possibilities of interpretation and improvization. Moving away from ‘traditional’ feedback modes of interaction such as visual and aural, we explore how tactile feedback can be used to facilitate the creative process. We discuss the development of a cross-disciplinary system and how this can enable new forms of creativity between different art forms.

Sigrist et al. (2013) suggest that vibrotactile feedback can become part of the external feedback mechanisms able to stimulate control and projection of movements. With that in mind, we hypothesize that vibrotactile feedback experience can also provide adequate sensory information to performers that can become part of a creative interplay and create new pathways that can influence the artistic outcome. Moreover, we present a bespoke wireless wearable system that stimulates the tactile feedback channel called Vibrotactile Armband (VARM). VARM is a wearable device that can receive different types of input signals from various software. Here, we use it as part of a more extensive system where multimodal interaction principles are applied between two performers. One performer (a dancer in our case) controls the vibrations through the Myo armband[1], a commercial device able to detect arm orientation and the activity of the forearm muscles. Movement data from the Myo are mapped to vibrational signals in the VARM unit that is placed on another performer’s body (pianist).

The use of haptics has been applied in a wide range of different disciplines including medical, gaming, automotive, arts and robotics to enable a closed feedback loop between two agents (Saddik et al. 2011). We believe that vibrotactile feedback has unique features for exploring digital creativity. Our approach of examining the creative relationship between a dancer and a pianist through vibrations is a result of the unique features of vibrotactile feedback enabling interaction.

In the following sections, we present the background information regarding the development of the VARM and the use of vibrotactile feedback as a method of communicating in technology-mediated performances. A discussion on the use of technologies in dance performances and audiovisual interactions enable us to identify common links between the relationships of vibrotactile feedback and its applications when interacting with technology. We then examine the development stage of the VARM followed by a description of the interaction design and hardware. Finally, in the case study we discuss our methods and analyse our findings from the three workshops that were conducted with the system.

2. Music and vibrotactile feedback

The expressiveness of a musical performance depends highly on our body’s sensory system mainly aural, tactile and visual. Performers receive sensory micro-nuances during a performance, which allows them to interact and react with their instruments and perform with others. They develop a unique relationship with their instrument through an ongoing process of exploration and creative development during long hours of practising (D’Ausilio et al. 2010). Other forms of live performances, where interactivity is a vital component, also require different levels of feedback information such as aural, visual and tactile as part of their creative and expressive interplay. While we understand the feedback modalities between instruments and instrumentalist, the use of technology often interferes and alters any already known and established music related feedback pathways that developed through years of practising. This is not to say that technology used in performances lacks any feedback channels but instead presents diminished sensory feedback information to the performer.

Instrumentalists build up a personal and unique perceptual understanding of how audio-tactile feedback is perceived; something that is akin to the way we experience latencies between action and the sound produced. The introduction of any 'unfamiliar' latency due to the use of technology impacts any prior learned kinaesthetic-acoustic mappings and disrupts the inner prediction of the instrument's responsiveness (Polydorou, Michailidis, and Bullock 2015). Technology is not only keen to the introduction of latencies related to audio but can also disturb known performance nuances that alter the behaviour of the instrument itself and requiring certain aspects to be relearned (Mäki-Patola 2005). The majority of Digital Musical Instruments (DMIs), custom-made controllers and augmented instruments are more likely to be performed by their creators since they are the most experienced regarding the interaction, software design and their sonic possibilities (Michailidis 2016).

In recent years, we have seen the development of haptic and vibrotactile feedback applications in electronic music performance. Vibrotactile feedback has been used by Michailidis and Berweck (2011) as a confirmation aid when using foot pedals to manipulate, trigger and control features of digital audio. Performers establish an excellent control of various digital audio processing elements through vibrotactile feedback which arguably contributes towards the performers' musicality (Hayes 2012; Michailidis and Bullock 2011).

Vibrations are sensed on the user's body through the skin. As a result, the process of experiencing the feedback is intimate to the user and may be applied to situations where aural and visual feedback are lacking or to non-traditional ensemble approaches. The 'natural' characteristics of vibrotactile feedback are different from aural and visual feedback, i.e., is not potentially masked by loudness nor does it require the performer to actively look. Instead, it can directly provide feedback to the performer and enhance closed feedback loop systems and applications. A noteworthy example is the research of Bouwer, Holland, and Dalgleish (2013) who applied vibrotactile feedback for learning rhythms and rhythmic patterns. Maté-Cid et al. (2012) demonstrated a significant improvement in learning relative pitch as well as its use to support the learning of violin bowing techniques (Grosshauser and Hermann 2009; van der Linden et al. 2011).

It is important to consider that the research detailed above pertains primarily to dynamic and straightforward binary information of the vibrotactile feedback. We should acknowledge that, due to its temporal limitations, such feedback might not be able to present more than the necessary semantic information. For example, experiencing the number four can be achieved with four short vibrations but understanding larger numbers, such as fifty, would require users to have a higher cognitive process to focus on the received vibrotactile feedback. Consequently, it would be unfair to expect performers to acknowledge a long list of combinations of complex vibrotactile stimuli in the heat of the performance. It is hypothetically possible, however, to devise or adopt a series of patterns, such as Morse code, to represent more complex semantic concepts but would require the performer to learn a new set of symbolic associations.

Research conducted by Frid et al. (2014) identifies vibrotactile intensity levels of the body with two motors placed at the back of the torso equally distanced from the spine. They concluded that the user could detect three levels of intensity with equal increment as noticeable changes in vibration. Khoo et al. (2013) suggests similar findings regarding the **AQ2** ability of arms to distinguish between three to four levels of vibrations. Moreover, Van Erp (2002) points out that four levels of intensity are optimal due to the comfort-pain threshold of the vibrotactile stimuli. Specifically, Van Erp suggests that any wearable technology should ensure comfort over extended periods of time; no heat generations on the body from the motors; comfortable stimuli above the threshold of detection; and using vibrotactile stimulation with caution to avoid irritating the user. The multi-localised approach, using three different vibrotactile stimulation approaches, single, nearest and funnelling, showed reduced reaction times in identifying the position of objects in space (Louison, Ferlay, and Mestre 2017). A multi-localised approach illustrates how a combination of motors in different places on the body could provide users with information regarding spatial awareness.

3. Dancing with technologies

The relationship and dynamic coexistence between dancers and new technologies on stage have been extensively analysed and discussed in various texts over the years (Anker 2008; Broadhurst and Machon 2009; Kozel 2007). There have been seminal works in identifying theoretical and methodological approaches about the role of dancers and how they are affected by technologies, as well as how audiences experience and perceive such new relationships. Since dancing is predominantly a visual experience from the audiences' perspective, the development of new technologies for image projection has seen greater exploration. Francksen's (2012) *Shift* sees the dancer interacting with her digital self, projected onto the floor rather than on a conventional screen. Whereas Gonzalez, Carroll, and Latulipe (2012) propose five design principles from making interactive dance through six case studies all of which include projected visuals.

For many dance practitioners, technology enables them to explore new methods and forms of dancing creating an adaptive system that feeds and grows according to its development. Dance practice informs the advancements for new technologies in the same way that new technologies influence the development of new forms of dance. Nonetheless, other technologies contributed towards new experiences for performers and audiences alike. For example, the development of interactive light design systems (Wiethoff and Blöckner 2010); interactive wearable sensor technologies by Birringer and Danjoux (2009); the use of augmented reality, motion capture systems and 3D vision (Clay et al. 2014; Johnston 2012); the use of artificial intelligence systems to recommend background images based on the dancing style (Wen et al. 2016); using Electroencephalography (EEG) and bio-signals from a participant on stage to inform other dancer's (Hieda 2017). New technologies can push dancers to new limits and allow us to explore new dance forms.

3.1. Audiovisual interaction

According to Goodale and Milner (2013), there is a distinction between how we perceive the world around us and how we process visual information related to actions. Vision for perception is aimed at 'identifying objects in the visual world and attaching meaning and significance to them' whereas the vision for action 'permits the execution of skilled actions directed at those objects' (Goodale and Milner 2013, 64). Interestingly, our 'vision for action' can be stimulated through observation. Expert ballet dancers, for example, showed brain activity of pre-learned moments during observation. Visual input can trigger specific motor skills of the observer as discussed by Calvo-Merino et al. (2005). This phenomenon is not just limited to visual stimuli. Dancers can accumulate vibrotactile feedback as an extrinsic feedback mechanism that can stimulate control and projection of movements (Sigrist et al. 2013). A study by Haueisen and Knösche (2001) showed how expert pianists when listening to a familiar piano performance they exhibit involuntary finger movement. Furthermore, a functional magnetic resonance imaging (fMRI) study demonstrates that professional musicians exhibited higher audio-motor associations than amateur musicians (Lotze et al. 2003). The research continues to suggest that motor functions and auditory areas of the brain are linked, and one can be stimulated by the each other. Such mirror-like mechanism can evoke the same motor functions for both, listening to musical excerpts or through observations of movement (Volpe et al. 2016).

The language used to describe sound frequently incorporates metaphors drawing upon movement and visual such as flow, high, low, soft, hard. These relationships act like image-schematic metaphors generating physical-to-abstract mappings, drawing on image-schemas 'subconscious and embodied mental representations of basic sensorimotor experiences in the world' (Hurtienne and Meschke 2016, 324). Applying these types of relationship in the context of audio software and user interface design Wilkie, Holland, and Mulholland (2009) indicate how extending the application of image-schemas through conceptual metaphor makes them a flexible and powerful construct.

These relationships appear intuitively cogent and coherent and suggest that applying conceptual metaphors to audiovisual art can provide fruitful results. The objectivity of conceptual metaphors begins to disintegrate when we examine specific relationships between sound and visual elements. For example, questions such as, what is the visual correspondent of a low pass filter on white noise, or what is the sonic equivalent of a slowly pulsating blue square are ones that can generate a multiplicity of possible outcomes. Audiovisual works repeatedly encounter this problem as artists frequently re-examine it. In section 5.3 we examine these types of relationships and the problems we identify with objectively mapping sound to visuals to explore further any similarities with vibrotactile feedback, as well as the relationship of mapping movement to vibrotactile feedback and vice versa. Since the integration of haptics as a means of communicating between spatially separated performers is not usual performance practice, we wanted to examine if there are any similarities or differences with visual feedback that could help us to understand better the role of vibrotactile stimulation. This is not to say that vibrotactile and visual stimulation bare similar attributes but rather how performers might have similar methods of decoding visual stimulus with vibrotactile feedback.

4. Varm: a vibrotactile ARMband

VARM is a vibrotactile wearable system able to provide vibrating feedback on the user's body to stimulate the tactile sensory channel. In our case study, VARM is embedded within a bigger system utilized in our workshops for the improvizational performance between two performers. The first performer, acting as the *leader*, gathers movement data from the upper body through Inertial Measurement Unit (IMU) and Electromyography (EMG) sensors. The second performer, the *follower*, wears the VARM and receives movement data in the form of vibrations created by motors embedded in the VARM wearable. Considering bidirectional complementarity concepts by Tanaka and Knapp (2017), we combined IMU and EMG data that could establish a strong movement to sound relationships.

4.1. Architecture and implementation

4.1.1. Hardware

The design of the VARM system was developed through an iterative process with the dancers. Our initial requirements of the system were centred on wireless communication so that movement would not be restricted. We then considered the weight of the device and the efficacy of the vibrating motors bearing in mind the different thresholds of vibrations on the body. After initial tests, it was clear that an armband design was optimal as it could support four motors without compromising its usability. To reduce the weight on the armband, we used a separate box to host the battery and microcontroller that is wired to the armband.

The VARM device consists of a central unit placed on the performer's torso and houses the X-OSC device, a wireless IMU prototyping board with up to sixteen Pulse Width Modulation (PWM) outputs. The PWM outputs, which are responsible for driving the motors, are capable of 16-bit resolution ranging from 5 Hz to 250 kHz[2]. PWM outputs are controlled via Wi-Fi connection through Open Sound Control (OSC) messages. VARM is powered using a 3.7v lithium battery 2000mAh enclosed in the central unit with dimensions $80 \times 96 \times 32$ mm and weighs 175 grams. A female RJ11 Breakout Board (telephone socket) that is used to connect the cable for the vibrating motors allowing us to use coiled patch lead for flexibility of movement. There are six enclosed vibrating motors in total with dimensions of 25 mm and 8.7 mm, and vibrating amplitude up to 7G[3]. The central unit hosts two of the motors, and the remaining four can be attached to a wearable armband.

The development of the device was realized by adopting a user-centered design (UCD) methodology informed by the collaboration of two professional dancers. We chose to work with dancers due to their greater sense of body awareness compared with other performing arts and artist, thus making them potentially more likely to engage with the expressive possibilities of the vibrotactile experience. The development process had a duration of nine months with eight sessions in total and an average duration of five hours per session. Through our UCD approach, we gave dancers the opportunity to explore and familiarize themselves with the system over an extended period which provided constructive feedback. During the sessions, we observed how the dancers interacted with each other through the VARM and its ability to facilitate the desired interaction. We provide them with simple tasks testing the capabilities and limits of the system. As a result, we have developed and tested several iterations of the VARM system. An informal evaluation (discussed in section 4.2) identifies possible relationships between the gestural data and vibrotactile feedback. Moreover, through the three workshops, we examined these relationships using the system in improvised performances between two performers, a dancer as the leader and a pianist as the follower.

4.1.2. Software

We developed software to support the communication and interaction between devices and the performers. For the leader's Myo armband we used the Myo Mapper software (Di Donato, Bullock, and Tanaka 2018). Myo Mapper receives raw IMU and EMG data from the Myo armband and converts those into scaled values that can then be sent as OSC messages to an OSC client on the same network. Myo data were first pre-processed, using an application developed using Max[4], and consecutively mapped into parameters to control the VARM. The data mapping was performed using Wekinator software's Multi-Layer Perceptron algorithm (MLP) (Fiebrink and Cook 2010). Wekinator is an open source interactive machine learning software designed for artistic applications.

4.2. VARM informal evaluation

During the development period, we observed the dancer's behaviours with the system through a series of tasks and informal interviews and discussion system. Tasks include identifying different dance gestures through vibrations, recognizing different locations of the motors and different vibrating intensities, navigate in space and so on. This qualitative approach aimed to evaluate the system as well as the experience and the interactions between movement and vibration. Furthermore, to establish a relationship between movement and vibration, the follower initially observed the leader's movement while experiencing the vibrotactile feedback in real time. The follower registers and associates visual gestures of the leader with felt vibrations on the body. From very early on, both dancers acknowledge the significance of experiencing vibrations in the form of rhythmic patterns and how it contributed towards an understanding of movement. It was paramount to establish new paradigms of feedback association to address the significant meaning and user's understanding of the vibrotactile experience. During the development and evaluation, we use four motors attached to the armband as shown in Figure 1. Explicitly, for the evaluation process, we linked the EMG data to the intensity of the vibration of the motors and the IMU sensor to the position of the motors.

We propose a classification of vibrotactile interactions that enables us to interpret and better understand the relationships between vibrational experience and upper body movements: gestures, directionality and intensity. *Gestures* examine how the follower recognizes hand gestures through vibrations. Different arm movements provide different vibrational sensations to the follower established through the Myo-to-VARM mapping functions. For example, a cyclic movement of the right hand of the leader will result in activating in a circular motion the motors attached on the VARM. We consider this as an *active multi-point* mapping relationship where particular gestures trigger different motors.

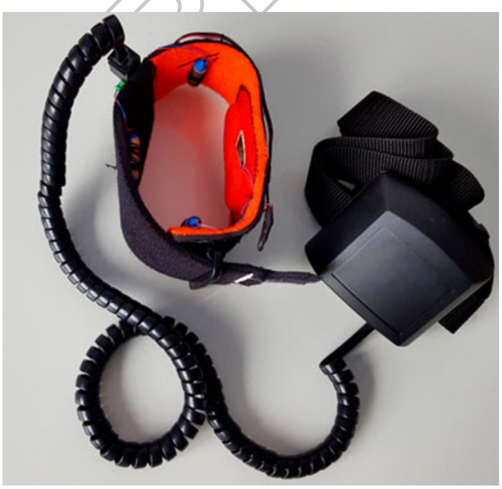

Figure 1. The VARM system: module box (on the right), coiled cabling and the Velcro strap with four motors attached.

Directionality, focus on how the notion of movement in space can be understood through vibrations. During the evaluation process, both the leader and the follower explored in what ways direction and intention of movement can be recognized through vibrations, i.e., the ability to navigate and give directions to another performer through vibrations. For example, feeling the vibration on the top of the arm signifies forward movement where vibrations on the left and right side assume left and right movement. This approach has a *static single-point* mapping relationship between movement and vibration.

Moreover, *intensity* examines the follower's ability to acknowledge changes of intensity of the vibrating motors. Our ability to perceive differences in intensity of the vibrotactile feedback is vital in further creating a complex vibrotactile experience. We carried out a test to examine the performers' ability to recognize the intensity of vibration during movement. We asked the dancers to acknowledge any changes in the intensity of the vibrational motors, while randomly triggered. Both dancers commented that they could promptly identify differences between three levels of insensitivity during the activation of one motor. We conclude that the following three levels of intensity of the PWM duty cycle where optimal: 0.25, 0.65, 1[5]. However, dancers reported during discussions that it was difficult and most of the times incapable to distinguish between the three proposed levels of intensity when operating all four motors. We believe that the proximity of the motors on the armband is masking their ability to identify the intensity levels. We also noticed an overall reduction of the vibrotactile stimuli experienced during hand movements. This observation suggests that tactile feedback can be masked by hand movements, reducing the ability to focus and accumulate feedback from the motors.

Through the informal evaluation process, we observed that both dancers were able to identify vibrotactile feedback under the proposed classifications and interpreted the received vibrations. Both dancers had the opportunity to take the leader and follower roles. Our evaluation showed that vibrotactile feedback could provide adequate information to identify specific gestures[6], recognize the intensity of vibrations as well as understand the concept of navigation and directions in space as shown in Figure 2.

5. Case study

The case study aimed to recognize and identify any creative interplay that existed between movement and vibrotactile feedback during three workshops. The three workshops focused on an improvizational performance between a dancer acting as a leader and a pianist acting as a follower. In particular, we explored how upper body movement from a dancer can create a 'vibrotactile score' for the pianist. Both performers had no prior experience with the devices used, and each workshop had a duration of two and a half hours.

Movement data from the dancer are utilized to control the vibrating motors worn by the pianist, whose improvization responds to the changes in vibration felt. The dancer then listens to the improvised music that influences choreographic decisions, thus closing the loop. In addition to auditory feedback, in workshop three we used the audio produced by playing the piano to generate visual content projected on a screen. In doing so, we aimed to reflect on how visual might influence the dancer and if there are any similarities between visual and vibrotactile feedback as discussed in section *3.1 Audiovisual Interaction*. As the pianist improvises in response to the dancer's movements, musical motifs served to produce visualizations that would further stimulate the dancer's response[7]. Examples of the projection of the generated visual are shown in Figures 3–5. AQ4

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Figure 2. The two dancers during the evaluation process. Dancer at the back is the leader and provides directions to the dancer at the front acting as the follower through vibrations.

5.1. Workshop one

The pianist wears the VARM's armband on the right bicep, the same hand as the dancer wearing the Myo armband. Both performers were first informed about the system and allowed 20 minutes to practice and familiarize themselves with it. For this workshop, we used the VARM v1 where the pianist received vibrotactile feedback through three motors (left, front and right) rather than four as described in the informal evaluation process. EMG data from the Myo was not used in this system, so as to understand the relationship between the IMU sensors and vibrations better. Having only three motors enabled us to establish a baseline of the pianist's ability to detect and respond to

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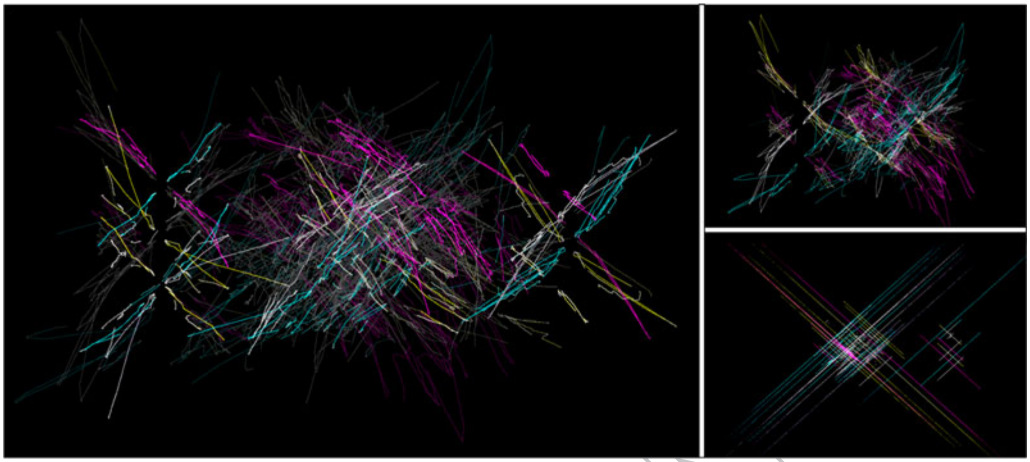

Figure 3. Generated visuals from the sound of the piano. Amplitude and frequency control the length, colour and position of the lines.

the vibrotactile experience and improvise. Also, the interaction design and the movement data mapping were different from the one described in the informal evaluation section *4.2. VARM Informal Evaluation* as we wanted to represent the dancer-pianist relationship better. Precisely, the vertical movement of the dancer's arm controls the intensity of the vibrational motors on the pianist, maintaining a relationship low arm/low vibrational intensity and high arm/high vibrational intensity. The horizontal movement of the arm was responsible for activating and deactivating the three motors by increasing and decreasing the intensity of the motor. The left, front and right motors were respectively activated when the arm was oriented left, front and right and associated with low, middle and high register on the keyboard. The intensity of the motors suggests the use of dynamics so that high-intensity imply to play *fortissimo* and low-intensity *pianissimo*.

Initially, we hypothesized that the pianist would be able to distinguish different positions, intensities and patterns and be able to perceive the nuances of vibrotactile feedback in the same manner as earlier findings, thus being able to improvise based on the new sensory modality. On the contrary, the pianist found it very difficult to differentiate the feedback received from each motor. Even though it was possible to pinpoint the location of the motors in a static position, the pianist needed to shift his focus on the vibrotactile feedback to decode the information sent by the dancer during the performance. The pianist mentioned that he could easily recognize the vibrations when placed on opposite sides (left and right) but found it harder to decode motors that are next to each other. The pianist also mentioned that at instances there was an overload of information which limited his ability to improvise and perform.

In contrast to the evaluation process carried out with the two dancers, we were unaware of the ability to communicate within a common artistic framework between dancer and pianist. During the evaluation process, the two dancers demonstrated ease of understanding about the way movement and vibrations are linked. However, the relationship between the pianist and the dancers was very different. While we acknowledge that there might be differences as performers, we also consider that a dancer-dancer relationship already had an established and developed language regarding dance movements and practices over the years. Dancers

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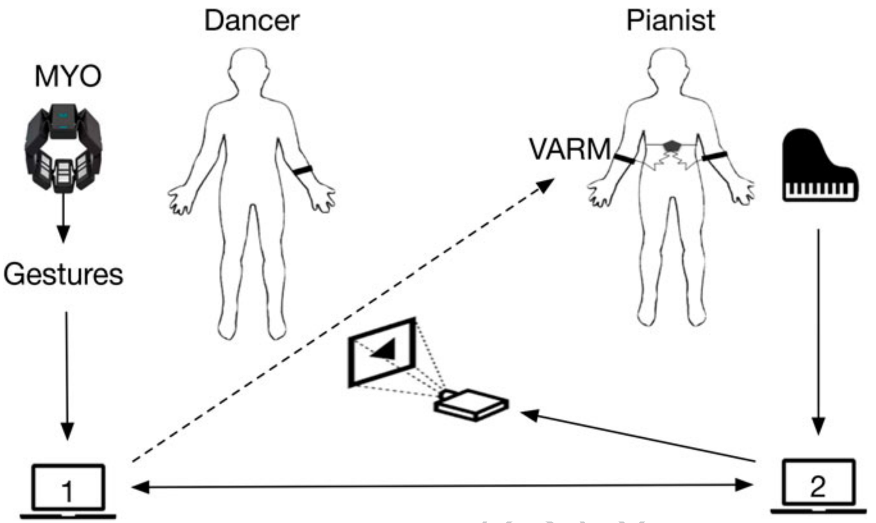

Figure 4. Shows how the leader (dancer) and follower (pianist) are connected through the VARM device during workshops two and three. Gestures from the leader are filtered through various software and then sent out to the VARM device as vibrations for the follower to experience on the left and right hand. The second laptop makes use of the leader's data to control the projected visuals.

communicated intuitively through shared experiences and non-verbal interactions. On the contrary, due to their different artistic backgrounds, the communication between the dancer and pianist resulted in a diminished communication between the two.

Colour online, B/W in print

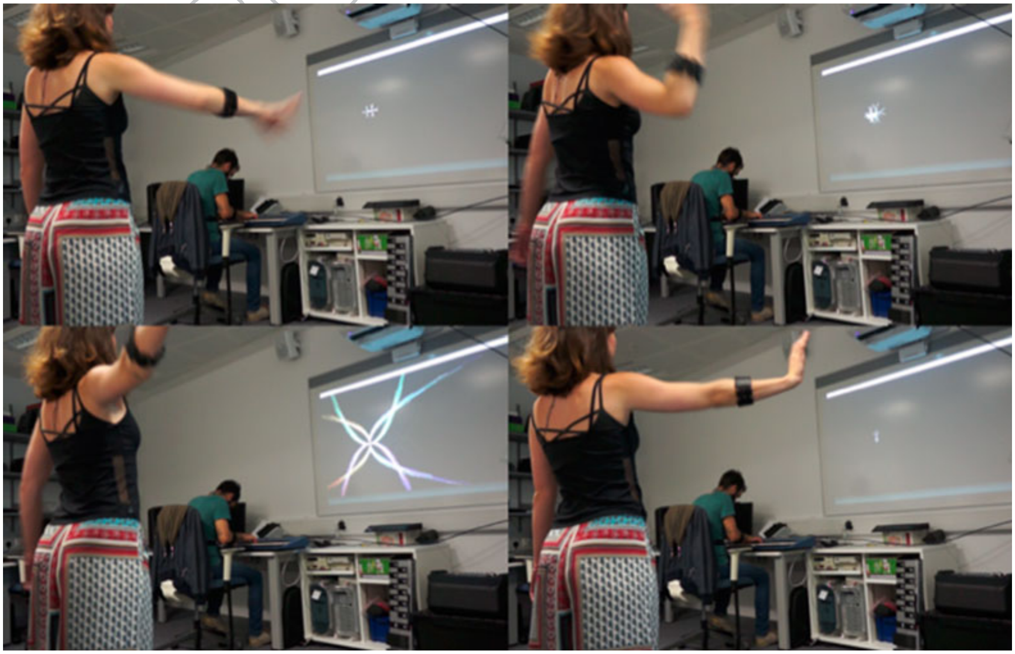

Figure 5. Shows a series of pictures of dancer and pianist during workshop three that took place in the lab.

5.2. Workshop two

A second iteration of the VARM system aimed to overcome issues and limitations encountered during the first workshop such as an overload of vibrating information on the hand wearing the armband and unable to locate motors due to proximity. In VARM v2 the motors are split across two armbands, left and right. The motors were placed at the back and front in each armband equally distant from each other. This second iteration of the VARM enabled the pianist to have a better distinction between left hand (low register) and right hand (high register) when vibrating.

Along with the hardware modifications on the VARM we also include the use of the electromyogram signal (EMG) from the Myo armband worn by the dancer (leader). EMG data were linearly mapped into the two motors placed in the central unit. To improve the pianist-dancer communication, we proposed the interpretation of movement and gestures into rhythmical vibrotactile patterns. As rhythm is a fundamental component in both dancing and musical performance, we hypothesized that exploring rhythmic patterns could be a creative link in the 'dialogue' between dancers and musicians. From here, the interpretation of vibrating feedback information would be through the objectivity of rhythm and how it may enable further the understanding of conceptual metaphors (e.g., raising the hand high, signals the pianist to play higher pitched material). As a result, we used short vibrating pulses as feedback, rather than continuous vibrations. The ability to use a combination of vibrating pulses expands our possibilities concerning the information received by the pianist. For the VARM v2 iteration, when the leader extends the hand forward, at chest level, activates the back motors on both hands of the follower. Any hand movement left or right activates the front motors on left and right hand. Through the proposed classifications of *gestures* and *directionality*, the dancer generates a 'score' in real time for the pianist indicating in which register he should be playing (low, middle or high). The central unit was responsible for providing different vibration intensities through EMG data as described through the *intensity* classification. For example, right-hand movements by the dancer 'direct' the pianist to improvise on the high register where the intensity of the vibrations on the chest provides the dynamics of the improvization.

VARM v2 significantly improved the performers' experience and the communication between each other. The pianist commented to have been able to distinguish easily between the vibrations sensed with the left and right arm. He recognized vibrating rhythmic patterns as well as the intensity levels on the torso. However, one noticeable limitation of the VARM v2 was the rapid changes in the rhythmic patterns that distracted the pianist resulting in non-synchronised events between the two. The dancer could alternate between gestures and change the speed of movement faster than the pianist's ability to decode the feedback.

5.3. Workshop three

In the last workshop, we investigated further the relationship between musical tempo and the dancer's movement. In VARM v3 we changed the functionality of the central unit to provide a reference tempo through pulsed vibrotactile feedback. In this third iteration, the intensity of the motors was fixed and set to maximum with a vibrating metronome of 75 Beats Per Minute (BPM). We developed an algorithm that enabled the dancer to control the tempo through movement. Any constant movement of the dancer for a duration between 12 and 24 seconds increases the tempo once by 10 bpm. Any movements below 12 seconds have no impact on the tempo. Constant movements for more than 24 seconds the value of the tempo is re-initialised to its original value (BPM). These thresholds were discussed and agreed with the dancer as she felt confident enough to control the system. Overall, the dancer can trigger tempo increments up to six times up to a maximum tempo of 135 bpm. All movements were tracked through the IMU sensors embedded in the Myo armband.

By providing a constant rhythm to follow, the vibrating metronome improves the overall experience of the pianist enabling him to engage with the dancer better than earlier workshops. During the workshop, we noticed at times that the pianist was not able to follow the exact tempo but instead grasp the 'feel' of the vibrations. He commented, 'I could feel waves of vibrations. I could not recognize what was happening—I could not pinpoint all the time what was left, right and centre, but I could feel something repeating itself'. The pianist's awareness increased, and as such he was able to respond to the vibrational patterns with greater confidence. The vibrating metronome acted as a reference point that can be relied upon and allowed the pianist to identify emerging vibrating patterns better than before.

Furthermore, we introduced two scenarios to examine if the generated visuals from the piano influenced dancer's improvization which potentially influences the pianist. Visual projections were realized through an oscilloscope-based visualization software that directly maps the sound's pitch and amplitude to the generated visual patterns. The dancer had no previous experience of being stimulated through screen-based visual feedback. In the first scenario, the dancer performed without any visual feedback and was facing away from the pianist. Her improvization was influenced by aural feedback alone. The dancer could follow the sound of the piano and improvise accordingly with relative ease. In the second scenario, the dancer experienced the generated visuals (Figures 3 and 5) as well as the sound of the piano. She mentioned that the visuals were harder to interpret compared with audio and she felt distracted and overwhelmed by the process. Her movements were not as fluent, and continuity of movement was absent. This lack of fluency was also communicated to the pianist through the VARM: the pianist felt the absence of continuity on the vibrations, thus reducing the level of engagement between them. We suspect that it was harder and more challenging to cognitively process a combination of audio and visual feedback on the spot considering the overload of feedback information and the dancer's unfamiliarity with visual feedback[8].

6. Conclusion

In this paper, we presented novel ways in which performers may indirectly engage with the technology by stimulating the performers' senses through vibrotactile feedback. We developed the VARM system that enables us to explore how vibrotactile feedback establishes new relationships between two performers and enhances the artistic expression.

We propose three classifications for interpreting vibrotactile feedback between the leader and the follower. *Gestures* enables the follower to recognize specific movements through vibrations; *directionality* looks at how vibrations can assist navigation and direction in space, and *intensity* acknowledges changes of intensity of the vibrating motors. These proposed classifications enable us to understand the relationships between movement and vibrations in a performance environment and further acknowledge a creative interplay between two performers.

We presented a case study consisting of three workshops where we further explored creative ways using the three classifications. The vibrotactile feedback is applied as part of an improvizational environment between a dancer and a pianist. In each workshop, we provided an iteration of the VARM system changing the way data and vibrations were used. Throughout the three workshops, we noticed a change in the way the pianist interpreted the feedback. In the first workshop, the piano sound was more melodic with fixed tempo and fewer changes in dynamics, wherein the second and third workshop, where the vibrating tempo is applied, there was an increased use of rhythmic motives with alternating tempos and changes in dynamics. Even though these observations took place in a relatively short period, we believe there are further creative advantages to be explored through vibrotactile feedback. We noticed a stronger synchronization between the dancer and the pianist when we introduce the vibrating tempo in VARM v3. Having a semi-fixed vibrating tempo enabled the pianist to focus on other vibrating feedback information that had a knock-on effect on the performance and thus on the dancer. Furthermore, we included two scenarios where we introduced visual feedback for the dancer in an attempt to explore any similarities with vibrating feedback and visuals. We were unable to come to any meaningful relationships and conclusions due to the dancer being overloaded with visual feedback and unable to cope with the high amount of multimodal stimulation.

The pianist mentioned that the synchronization between the two would have been harder to achieve without the use of vibrotactile feedback. Though the pianist noted at first that vibrations appeared alien and outside the typical pianistic experience, through practice, they became integrated into the creative process. Throughout our various iterations and changes during the workshops we were able to balance the level of vibrational stimulation to minimize invasiveness, yet meaningfully contribute to the creative process. The performer said that the dynamic nature of the vibrations, controlled by the dancer, provided a useful form of communication and interaction between them. Examining workshops one and three, there are clear indications about the role and use of vibrotactile feedback within the process. Even though the setting was improvizational without a concrete structure, there is clear evidence about the effect and impact of vibrotactile feedback.

Moreover, there are also limitations and potentially negative effects when vibrotactile feedback is overused; this is also true for other forms of feedback. For example, having a screen with an overload of visual information might have an adverse effect on the user. Similarly, trying to listen to a person speaking while being in a noisy environment is difficult due to the overwhelming amount of audio information. When vibrotactile feedback is applied, we should consider a design approach based on the needs and requirements of the situation to produce an effective level of feedback to the user.

A significant observation is how users may experience complex vibrating rhythmic patterns as clusters rather than individual vibrating points. When many vibrating sources activate at the same time, in our case we used a maximum of six, users cannot accumulate the felt experience of individual vibrations. As a result, multi-point vibrations are perceived as events over time thus forming a holistic experience. The relationship is perhaps similar to the way we experience music and our ability to group rhythmic patterns and melodic lines as events rather than individual notes. The pianist found the use of vibrotactile feedback more meaningful when experiencing rhythmic patterns from the whole system rather than sensing individual motors. This observation suggests that we consider a broader view and application when we employ a large number of vibrating points at the same time as there is a difference in how we experience single point vibrational feedback.

Our approach and case study show encouraging evidence how vibrotactile feedback can become an innovative tool for interaction and digital creativity.

Notes

1. https://www.myo.com.
2. http://x-io.co.uk.
3. Vibrating amplitude (G) refers to the intensity of the vibration of motors.
4. https://cycling74.com.
5. Similar results are also proposed in the work of Frid et al. (2014).

6. Excerpts from two sessions with the dancers as well as part of the evaluation process can be viewed online https://youtu.be/n1×0fVHA2iw.
7. The visual content realized using the GEM library for Pure Data were generated through mapping the piano sound's acoustic properties mainly the amplitude and frequency of the piano control the length, colour and position of the lines.
8. Excerpts from the case study between the dance and the pianist can be viewed online https://youtu.be/oxxiF0y7hFY.

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Disclosure statement

No potential conflict of interest was reported by the AQ5 authors.

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