Somatic Sonification in Dance Performances. From the Artistic to the Perceptual and Back

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ABSTRACT

Since the end of the 1980s, interactive musical systems have played an increasingly relevant role in dance performances. More recently, the use of interactive auditory feedback for sensorimotor learning such as movement sonification has gained currency and scientific attention in a variety of fields ranging from rehabilitation to sport training, neuroscience and product design. This paper investigates the convergence between interactive music/dance systems and movement sonification in the field of dance. The main question we address is whether the emergence of the notion of sonification can foster new perspectives for practice-based artistic research. In this context, we highlight a fundamental shift of perspective from musical interactivity *per se* to the somatic knowledge provided by the real time sonification of movement, which can be considered as a major somatic-sonification turn.

CCS CONCEPTS

• **Applied computing → Performing arts**.

KEYWORDS

movement sonification, dance technology, dance/music interactive systems, somatic sonification

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1 INTRODUCTION

During the last three decades computer technologies have played an increasingly important role in the transformation of contemporary dance aesthetics. Within this context, the development of wearable sensors, computer-vision techniques and telematics technologies have marked a turning point in creative processes innovation by allowing artists and researchers to develop interactive systems for live performance, installations, virtual reality environments and net art [27]. Since the end of the 1980s, one of the most intriguing issues of interactive technologies is the real time generation and manipulation of digital media contents through movement capture. Over the years, particular attention has been carried to sound interaction [7]. Part of the reason for such an interest stems from the subversion of the usual relationship between music and dance. Interactive technologies allow performers to generate audio contents rather than follow a musical score, thereby enabling a new form of intertwining between movement and sound.

Over the years, interactive auditory feedback has also been extensively used in the fields of movement rehabilitation [68], sport training [48], neuroscience [30] and product design [11] in order to provide an effective alternative to data visualization. In this context, we usually refer to sound production as a *sonification* process therefore meaning that the sound is properly used as a means for objectively representing movement through the auditory channel. From this perspective, the goal of sonification is to provide a meaningful information about movement perception that can eventually enhance bodily awareness, control and knowledge.

This paper investigates the relationship between interactive music/dance systems and what we call somatic sonification, i.e. the use of sonification techniques and approaches in order to enhance movement perception, especially in dance practice. The central question that we address is whether real time sound interaction in dance performances can be considered as a proper form of sonification. The major difference between the two fields lies in the objectives of the sound outcome and in its relation with the movement being expressed. In data sonification auditory feedback is generated in order to provide information about movement while in artistic performance the sound is created and manipulated for expressive purposes. Similarly, the interactive systems design and the sound conception have been developed within the two fields with relatively diverse procedures, methodologies, tools and tasks. Not surprisingly, although data sonification represents a major area of research at least since the 1990's, the term "sonification" has been introduced into dance technology[1] only in the last few years. Therefore, we should ask whether the term has started to be used in dance research due to the popularization of sonification studies in recent years, or because dance technology has effectively adopted some core methodologies from data sonification, or, lastly, because

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[1]The term "dance technology" emerged during the 1990's and has been extensively used in North America in order to designate experimental practices merging digital media and dance. It should be noted that equivalent expressions have been used to define the same field of experimentation. Among those "digital dance" or "digital performance" (UK), "danse numérique" or "dance augmentée" (France), "scena digitale" (Italy), "tanz und technologie" (Germany).

a real epistemological shift is now occurring in the dance technology paradigm. In order to properly address this question, this paper aims at outlining the contemporary intertwinement between somatic knowledge, technological design and sound production at the crossroads of music/dance interactive systems and somatic sonification. To answer this, the first section of the paper presents a brief historical overview of dance technology with a particular emphasis on sound interaction. The following section introduces the relationship between auditory perception and sensorimotor learning and describes the emergent field of somatic sonification for dance practice. The last paragraph, in particular, tries to outline current issues in research-creation field. The final section provides a discussion upon the convergence between somatic sonification and music/dance interactive system fields, and reflects on how the development of a shared conceptual framework, can be beneficial for both theoretical approaches and practice-based research.

2 A HISTORICAL SURVEY ON SOUND INTERACTION IN DANCE TECHNOLOGY

Merce Cunningham's *Variation V* (1965) is often mentioned as the first dance performance employing technologies (i.e. photoelectric antennas) in order to detect movement and produce a sonorous feedback [7]. Although interactivity isn't the central tenant of the piece, the relevance of the performance lies in the unprecedented collaboration between a choreographer (Cunningham), several intermedial artists (John Cage, Nam June Paik, David Tudor, Sten Van Der Beek, among others) and an electronic engineer, Billy Klüver who created the system that allowed Cage and Tudor to manipulate the signals produced by the passage of the dancers close to the antennas. Aside from Cunningham's seminal experimentation, the first known example of music/dance interactive system is Erkki Kurenniemi's *DIMI-O* (1971), a pioneering musical sequencer that employed rudimental computer vision techniques in order to play a precomposed musical score through movement. The Finnish composer, conceived such a system as a real time instrument for dance performance. Unfortunately, Kurenniemi's visionary invention did not receive much attention outside the DMI (Digital Music Instruments) community [54], and it was not further developed after its early prototype.

If the two examples mentioned above constitute important precursors of current music/dance interactive interfaces, David Rokeby's *Very Nervous System* undoubtedly represents a real milestone of dance technology. In 1986 the Canadian media artist presented the first version of its extensively celebrated work at Venice Biennale [71]. Even tough the work was primarily showed as an interactive installation in galleries and public spaces, the software has been used over the years in several dance performances by Todd Winkler's *Dark around the edges* (1997) to more recent works by the Ventura Dance Company's such as *Heliopolis* (2014)[76].

2.1 Evolution of digital interactive dance/music systems since the 1990s

Similar to Rokeby's VNS, some of the earliest interactive systems for sound control have been developed since the 1990s by independent artists with a DIY (do it yourself) approach. The most renowned examples probably are Frieder Weiss's *Eyecon* computer vision software [81](firstly used in Palindrome performances) and Mark Coniglio's *MIDIDancer* interactive costume [19](Troika Ranch). During the same years, several university research programs raised in the North America. The earliest is the Arizona State University's Intelligent Stage (1994-1999)[2], a reactive performance environment conceived as a permanent rehearsal/performance space embedding on-stage sensors (photoelectric and touch sensitive switches) and optical detection systems [50] [49]. Specific devices for dance performance and musical interaction have been developed, since the mid-1990's, also at the MIT Media Lab[3]. Among these, Joe Paradiso's interactive dance shoes, *Expressive Footwear* (1997-2000)[55], and Flavia Sparacino's computer-vision system, *DanceSpace* (1997-2000)[75], should have mentioned. Similar research programs have been carried out in Europe. Among the earliest projects, we should mention the *DIEM* wearable interactive system, which was developed within the Digital Dance Project (1996-1999)[72] and the STEIM's video-to-MIDI converter, *BigEye* (1995-2001)[58]. Towards the end of the decade, more long-lasting research programs arose. Among these, the University of Genoa's InfoMus Lab, is today with their *EyesWeb* platform [16], providing the most prolific software library for movement descriptors analysis and extraction for the performing arts. In France, Ircam's Sound Music Movement Interaction team have been developing interactive technologies for dance performances since 2004 becoming one of the main references in the field [5]. Since 2007, their research has focused on the development of gesture analysis and recognition tools based on machine learning techniques [6].

During the 1990s, the music industry also started to release commercial products allowing dancers to interact with digital media. Among those, the most interesting devices for movement-sound interaction were the Yamaha *Miburi* (1994)[78], a vest with embedded flex-sensors, two hand-grips, shoe inserts with pressure sensors, and a belt-worn signal distribution unit joined by a cable to a small synthesizer/MIDI converter, the *I-Cube* system (1995)[52], a hardware platform that enables the conversion of different analog signals (mainly contact, pressure, bend and proximity sensors) into MIDI data and the *Mandala System*, one of the early available softwares for Virtual Reality that allowed users to control several MIDI events [82].

By the early 2000s, a dramatic democratization of interactive technologies occurred. Wearable technologies became smaller and cheaper, the development of easily-programmable micro-controllers (e.g. *Arduino*) enhanced DIY approaches to physical computing, while the commercialization of video-game motion-based interfaces, such as the *Wiimote* (2006) and the *Kinect* depth sensor (2010), significantly promoted the accessibility of interactive sound media for the performing arts. Moreover, an increasing number of gestural controllers have been released during the recent years, thus reflecting the growing demand of interactivity in musical interfaces, video-game and consumer technologies markets. Last but

[2]According to Lovell and Mitchell (1995), early researches on movement sensing have been conducted at Arizona State University since the mid-1980's even though first significant advances in the real time sound manipulation were provided at the beginning of the 1990's with the implementation of Max multimedia programming software.

[3]It should be noted that similar researches have been developed in the field of augmented theater and music performances since the end of the 1980's : e.g. the *Hyperinstruments* and the *Brain Opera* projects.

not least, several libraries for motion analysis and real time sound interaction have been implemented in the last fifteen years, especially for the *Max/Msp* environment. Among these, we should mention Jean-Marc Pelletier's *cv.jit* library (2004)[56], a collection of jitter externals based on computer vision techniques, Ircam's *Mubu* library (2008)[69], a toolbox for multimodal analysis of motion and sound, and for real time gesture following, Federico Visi and Luke Dahl's *Modosc* (2018), a movement descriptors library for professional MoCap systems (i.e. Qualisys)[22].

2.2 Rise and fall of dance technology

Despite the raising interest in interactive music/dance systems over the past decades, it should be noted that most historical relevant conferences, manifestations, comprehensive publications, and artistic productions, on dance technology took place between mid-1990's and 2007. Among those we should mention the *International Dance and Technology Conference* (IDAT) that was held at different locations in North America between 1992 and 1999. The last edition, organized by John Mitchell at the Arizona State University, can be considered as a turning point between the first and second wave of the dance technology movement. In 1999 the first European conference about dance technologies - *Danza e nuove tecnologie* - took place in Bolzano (Italy), the following year a similar conference - *Nouvelles Interfaces pour la Danse* - was held in Paris [59]. From 2001 to 2007 the "Digital Dance Section" of the *Monaco Dance Forum* became the most important event in the field since the IDAT (2002 and 2006 editions were specially involved with interactive technologies)[18]. In 2005, the first edition of the digital arts international Biennale, *Bains Numériques*, focused on contemporary dance and new technologies. During the second half of the 1990's, the first website, *Dance and Technology Zone*, also appeared [24]. The website, initiated by Scott DeLahunta in 1996, was active until 2003 and it represented an undeniable reference for practitioners and scholars in the world.

Since the mid-2000s a decrease of interest can be observed. A similar trend characterizes scientific literature. Between 1999 and 2004, renowned dance francophone journal *Nouvelles de danse* released two special issues on dance technology, both directed by Florence Corin [20][21]. Moreover, three important collective publications on performance and technology (one in French and two in English) were directed by Emanuele Quinz between 2000 and 2003 [61][59][60]. During the same period, several monographic publications appeared. Among these we should mention the Italian *La scena digitale* (2001)[51], directed by Armando Menicacci and Emanuele Quinz, the German *Tanz und Technologie/Dance and Technology* (2002)[26] and the French *Danse et Nouvelles technologies* (2007)[40]. Other important publications in the field of digital performance, released during the first decade of 2000s, include either specific chapters on dance technology history [27][65] or remarkable contributions from scholars and practitioners in this field [13][44][8]. It should be noted that none of these publications directly addressed the question of sound and corporeality in dance research. Comprehensive contributions in dance technology have become rarer in recent years. Important exceptions include recent publications by Stamatia Portanova [57] and Maaike Bleeker [9].

Notwithstanding the huge amount of projects and technological innovations, the academic and artistic interest in dance and interactivity has decreased over the last fifteen years. This is supported by the fact that several pedagogical and research programs ended over the years[4]. It is no coincidence that permanent curricula on media, art and performance are extremely rare outside North America and UK universities. In general, we can affirm that dance technology no more exists as a proper and autonomous field of artistic and scientific research. This can be explained both as a consequence of the increasing interdisciplinarity of arts since digital and technical innovations did not represent an artistic stake *per se*, as it was for the first and second wave of dance technology (1986-2007).

3 FROM MOVEMENT SONIFICATION TO DANCE PRACTICE

In the last few years, researchers increasingly refer to gesture-sound interaction in dance performance as a sonification process. Since the concept was formally introduced in the first half of the 1990's [45], sonification can be namely defined as a sub-type of auditory displays that use non-speech audio to convey information [79], or, alternatively as a technical process of transforming data relations, whatever the nature of data, into perceptible relations through an acoustic signal for the purpose of facilitating communication, analysis or interpretation. From this perspective, sonification has been developed, as an alternative or a complement of data visualization across a variety of different scientific domains. A wide range of techniques have been formalized over the years [29]:

- *audification*, the direct translation of data streams into sound waves.
- *auditory icons*, short environmental sounds associated to discrete events.
- *earcons*, synthetic short sounds with no ecological meaning (in term of affordances) and they function as an alarm or a signal.
- *parameter mapping sonification*, the mapping of the data values to specific attributes of sounds such as volume, pitch, panning, timbre or a combination of these attributes.
- *model based sonification*, dynamic systems that provide adaptive synthesis model which behavior evolve in time following a set of predefined principles.

3.1 Towards interaction and sonification

As we outlined in the introduction, one of the main questions addressed in this paper is whether, and to what extent, gesture-sound interaction in dance performances can be described, technically speaking, as a form of sonification. If we look at the different sonification techniques, interactive music/dance systems can be classified as a special kind of parameter mapping sonification: since the development of the first gesture-sound interfaces, media artists and performers often adopted direct mapping techniques in order to arbitrarily associate specific sound parameters to several gestural

[4] A striking example is the *Médiadanse* research group and laboratory (Université Paris 8) which offered the first curricular courses in Europe in dance and technology. Started between 2000 and 2002 by Armando Menicacci, Emanuele Quinz and Andrea Davidson, the laboratory ended its activity around 2008.

inputs [64][39][80]. However, one main difference between interactive music/dance systems and sonification techniques is that the former use motion-based data for generate sound content in real-time while the latter often involve auditory displays of prerecorded data for diverse purposes not necessarily related to real time gesture-to-sound transformation. Moreover, despite the great number of artistic practices that recently used sonification techniques to make audible real-time data [74], many scholars insist on straightforwardly distinguishing data-driven sonification for scientific purposes from artistic and musical applications on the basis of specific goals [67].

Some important studies have been made over the years in order to establish a possible convergence between the two fields. In a seminal paper, Hunt and Hermann [38] first argued the importance of interaction in sonification processes highlighting how the «quality of the interaction» can enhance perceptual skills in performing activities or in accomplishing simple sensorimotor tasks. This text marks a turning point in real time sound interaction because it provides a conceptual bridge between data sonification and interaction sound design for new musical interfaces and DMI. Furthermore, the paper posits the centrality of gestural interaction as a means for experimenting high-dimensional data-space sonification. In so doing, the authors implicitly suggest to merge the methodological background of sonification with the know-how developed over the years in designing interactive music systems. In a similar vein, Salter et al. [66] observe that, although the vast majority of literature on sonification emphasizes non-musical applications to scientific purposes, sonification frameworks can provide conceptual insights for composing effective, and aesthetically meaningful, interactions for the performing arts. Furthermore, Diniz et al. [25] claim that music-based interactive systems and embodied music cognition framework can stimulate the development of user-centered interactive sonification.

In the last few years, interaction has effectively become a crucial issue, if not a trend topic, in sonification field [12][23][83]. At the same time, the use of auditory displays as a means for improving movement perception has definitively been incorporated in recent HCI research [35]. Nevertheless, some differences remain between data-driven sonification and "classic" approaches to interactive music/dance systems. The crux of the matter is that the goal of data sonification is to aid in understanding, exploring, interpreting, communicating, and reasoning phenomena, an experiment, or a model, whereas in artistic performance, the goal of sound feedback is (mostly) to create an aesthetic experience. From this perspective, the choice of the sounds in artistic performances, even though expressively meaningful, is ultimately based on a subjective artistic point of view while in data-driven sonification the sound feedback is expected to reflect objective properties or relations of the data.

3.2 Sonification and sensorimotor learning

Although interactive music/dance systems and data-driven movement sonification both use movement interaction in order to generate sound contents, theirs goals are usually different. Broadly speaking, in the former approach the interaction deals with *sound-oriented tasks*, while the latter focus more on *movement-oriented tasks* [4]. In the first case, users pay attention to the sound outcome: movement is thereby functional to sound production. In the latter, the attention of the user is focused on the movement itself: sound is thereby functional to movement achievement. In this context, we use to refer to sound as an *auditory augmented feedback*. This expression highlights the fact that sound is considered as an artificial extension of movement that can be employed to enhance sensorimotor learning. Sigrist et al. [73] present a conceptual framework in rehabilitation and sport activities.

From a neurophysiological point of view, the use of the auditory channel as a means of transmitting sensory feedback on movement presents several advantages in terms of efficiency of the corporeal involvement. For instance, auditory information processing time is remarkably shorter compared to visual stimuli [1]. Even in terms of fine time-based pattern discrimination, auditory channel can provide a more accurate analysis [84]. Johanna Robertson et al. [63] also note that hearing has very high response rates to amplitude and frequency modulations. Moreover, our perceptive organization in the temporal domain is based on the close relationship between auditory, vestibular and motor systems [3]. For this reason, motor-auditory coupling can also enhance a variety of multimodal integration processes involving temporal coincidence and spatial proximity [34]. In fact, auditory feedback can be also used in order to provide accurate spatial informations such as the body's position in the space or the distance from an external source.

From this perspective, sonification has been proven to be a valuable assistance to the perception of movements, and more specifically to the perception of one's own body motion, i.e. kinesthesia. In this context, the auditory feedback can be used used either as i) a reward system or; ii) as an informational channel for experiencing a new modality of perceptual organization and corporeal creativity. In the former, feedback functions as *knowledge of result*, in the latter as *knowledge of performance* (for an accurate definition see [70]). The first typology of feedback provides information about the accomplishment of a motor task. It has been used, for instance, to reward simple motor tasks, such as reaching a target [43], to signal the successful achievement of a learned gesture [10], or to sonify functional gripping movements in order to promote hand motor recovery after stroke [33]. The second typology is used to provide qualitative or quantitative information about the movement during its execution. It has been used, for instance, to improve gait coordination through rhythmic audio cues in patients with multiple sclerosis [1], to stimulate motor creativity in people with different abilities through highly involving musical environments [2], to accompany upper limbs stroke rehabilitation with motion energy sonification of continuous movements [68]. In all these cases, the augmented feedback allows for an increase in knowledge about the body and especially the knowledge of several subtle movements which normally remain below the level of perceptual awareness. In other terms, we can say that sonification helps to make audible several phenomena that are usually invisible or that are perceptible just in a subjective and individual way (e.g. proprioception). From a phenomenological perspective, the transformation of mainly interoceptive or proprioceptive sensations into exteroceptive stimuli (i.e. augmented "auditory" feedback), allows the user not only to become aware of his own body but, due to this new sensorial feedback, he/her also becomes capable of experimenting new modalities of movement execution. Especially for dance practitioners, such a sensorial re-organization allows the performer to go beyond what Hubert Godard often calls a «choreographic fixation» [*névrose chorégraphique*] that is the repetition of the same dance patterns stemming from dancer's cultural, emotional and choreographic habitus [46].

3.3 Somatic sonification for dance training and movement analysis

Although the interest in sensorimotor learning with movement sonification has dramatically increased over the last ten years, the vast majority of neuroscience, medical and sport experiments still employ very basic interactive systems, often based on simple pitch or volume control of pure tones and electronic noises with a little concern for sound design (for an extensive review see the excellent work of Dubus and Bresin [29]). Conversely, sensorimotor learning has been rarely studied explicitly in the design of interactive music/dance systems. According to Bevilacqua et al. [4], a methodological convergence would be desirable and would present enormous advantages for both fields in order to design efficient applications using movement-based sonification. Some efforts have already been made in such direction and several experimental studies at the crossroads of sonification and dance technology have been carried out. These studies can be described as somatic sonification practices because of their attempts to enhance corporeal awareness by means of interactive sound feedback. One of the earliest relevant experiments in somatic sonification has been reported by Menicacci and Quinz [62]. In this study, the real time sonification of a physical quantity (i.e. performer's lower limb extension captured by flex sensors) is experimented in order to successfully support dancer's postural reorientation. Note that the term "sonification" is not employed in the text, even though the goal and the theoretical hypothesis of the experiment can be clearly interpreted in terms of somatic sonification.

To our knowledge, the first study that used explicitly the term "sonification" for sensorimotor learning in dance was carried out by Jensenius and Berkstrand [42]. The authors explore the sonification of micromovements in professional dancers (i.e movements that occur at the scale of milliseconds) with a Qualisys marker-based motion capture system. According to the main author [41], the study was originally conceived as a preliminary experimentation for a music/dance performance. In particular the study focused on how to sonify some involuntary movements (e.g. chest tiny movements induced by heartbeats or breathing) or micromovements during standstill. Other studies focused more particularly on the way in which sound feedback can provide meaningful information to the dance training. Grosshauser et al. [36] developed a wearable sensor-based system (including an IMU module, a goniometer and a pair of FSR) in order to sonify classical ballet jumps typologies (i.e. *Italian changement* and *Sauté*) in dance classes of different ages and level. The study shows that the sonification of both knee bending and foot pressure, provides a valuable teaching tool for students and teachers during the learning of choreographic sequences. In terms of sonification, these two studies mainly use simple additive synthesis with pure tones (or white noise).

Other recent studies investigated how interactive sonification can enhance understanding, learning and transmissibility of a movement quality in dance practice. Françoise et al. [32], for instance, report the results of an experimental workshop in which the authors propose an interactive sonification of effort categories issued from Laban Movement Analysis [47]. A relevant aspect of the sonification is the use of "vocalization" in order to support movement learning. Several examples of movement qualities, and related vocalizations have been performed by two Certified Laban Movement Analysts (the study focused especially on Time and Weight Effort Factors). Both movement patterns and vocalizations are recorded and then synchronized via a multimodal machine learning system based on HMM (Hidden Markov Models). Multimodal capture included voice audio analysis, electromyography and accelerometers (sensors were attached to one of the performer's forearm). Workshop participants are invited to execute certain movement patterns according to a specified effort quality. The system analyzes the movement and answers with a peculiar vocalization according with the movement qualities. According to the authors, such an interactive sonification, has proven to be effective since it helps the practitioners to recover a certain movement quality by recognizing vocal-gesture patterns' idiosyncrasies.

Other relevant researches on movement qualities sonification have been conducted by InfoMus Lab team. In a recent study [14], they propose an interactive sonification of movement dynamic symmetry in dance performance. This study describes, in particular, the implementation of an EyesWeb algorithm based on *dynamic symmetry analysis*. This mid-level motion feature[5] is obtained from the combination of two different low-level features: *jerkiness* and *kinetic energy*. Both features are computed from raw acceleration. Accelerometers were placed on the right and left wrist of a dancer. The auditory feedback produced is conceived in order to provide a reward system for a student who tries to reproduce dynamic symmetry (not from the point of view of the exact trajectories, but rather in terms of similarity/symmetry of jerkiness) in a movement previously executed by a teacher. In terms of sonification, two different techniques, such as spectral stretching and dynamic stochastic synthesis, are proposed in order to convey symmetry in the auditory channel. According to the authors, the sonification system should convey information about the level of coordination, symmetry, and synchronization achieved by the student with the arms. From this perspective, the system enhances the learning of a certain quality of movement rather than encouraging the mimicking of the teacher from the point of view of the exact movement trajectory. In a following study conducted by the same research-team [53], the sonification of other mid-level features, i.e. *lightness* and *fragility*, is explored. The first quality is derived from LMA while the second is directly issued from Virgilio Sieni's choreographic vocabulary. Such qualities are extracted from the computation of a full-body analysis while the real-time sonification is based on IMU-Marg sensors values. Sensors are placed on the dancer's wrists and ankles. This paper, describes detailed mathematical functions the authors use to calculate such features. Moreover, they introduce an interesting model-based sonification in which a specific sound synthesis model is devised for each movement quality. Technically

[5]For an accurate classification of the different motion features see [17]

speaking, the sonification is realized by combining both lightness and fragility amounts, and other low-level features, such as *weight Index*, *motion index* and *Leg Release*. The system has been evaluated during an experimental study. The authors demonstrate how the participants (both expert and non-expert dancers) were able to distinguish the two movement qualities from the perception of the auditory feedback. It should be noted that interactive sonification was experimented by the participants during a physical training. As it has been clearly demonstrated by the authors, the use of interactive sonification clearly improved the recognition process (at least in the case of Fragility).

In another study, Françoise et al. [31] directly address kinesthetic awareness via interactive sonification. The authors combine conceptual frameworks issued from somatic practices (e.g. Feldenkrais method, somaesthetics approach) to user-centered HCI. The study describes a somatic experimentation in which participants (both skilled dancers and non-dancers) wear a pair of MYO armbands, placed on the lower legs, to sense neuromuscular activity (EMG) of the calves and shins. An adaptive mapping system is implemented in order to scale the sensitivity of the EMG dynamically over time. This means that the system can react to very different ranges of actions, from jumping to micro-movements (e.g. involuntary muscular contractions occurring when the person standing still). In terms of sonification, the authors propose a corpus-based concatenative synthesis in order to generate sound grains from ambient field recording (i.e. water and urban sounds). During the experimentation, participants are invited to freely explore the installation space. In a second phase, exploration is facilitated by the experimenters that lead participants to focus on their micro-movements while performing simple actions (i.e. walking, standing still). An explication interview methodology [77] is used by the authors in order to evaluate the experience. Broadly, both sonification methods and user-centered strategies (e.g. adaptive system; neuromuscular sensing), combined with somatic approaches to experimentation, seem to provide a rich playground for accessing bodily awareness and especially the dynamic relation between proprioception and movement.

3.4 Somatic sonification in artistic practice

After a period of stagnancy, some important artistic creations involving dance and real time sound interaction have appeared in recent years thanks to the collaboration between artists and research centers. These collaborations have been supported, among other things, by the development of new international networks promoting the bodily movement computation, analysis and classification (e.g. MoCo conference annual conference), the interdisciplinary study of movement from a political, social and philosophical point of view (see European founded Metabody forum) and the development of new pedagogical processes for teaching, learning and creating dance movements (e.g. WhoLoDancE research and education project). These projects try to explore new directions in dance technology by focusing on somatic sonification. Among those, Isabelle Van Grimde's *Le Gestes* (2013) based on the collaboration with the CIRMMT (McGill University, Montréal). The research team developed innovative prosthetic instruments (PI), in order to create a visceral relation between dance and music [37]. The PI are musical instruments explicitly conceived and manufactured for dance interactive performances. Each instrument, embeds a 9DoF IMU and touch capacitive sensors. However, each of them presents a specific design in order to provide a peculiar bodily extension (an extended spine, a visor and a rib prosthesis). A special attention was paid, during the creative process, to the effectiveness of the musical device from the point of view of the the sensorimotor learning: the instruments were designed in a close collaboration with dancers who suggested several modifications in order to integrate the prosthetic musical devices into their proprioceptive organization. Therefore, dancers and choreographer's somatic point of view represented a crucial element during the design process. Final prototypes are therefore designed as a physical and sonorous extension stemming from dancers' corporeal knowledge. The performance *Les Gestes*, can be seen as a dance-music quartet involving two dancers and two musicians. The PI allow dancers to modify and to spatialize the sound produced by the cellist and violinist in real time, thereby creating a profound intertwining between sound and movement.

Another significant performance merging sonification and dance technology is Marco Donnarumma and Margherita Pevere's *Eingeweide* (2018). The piece is part of the 7 Configurations cycle (2014-2019) and it was created in partnership with the Neurorobotics Research Laboratory, Beuth Hochschule (Berlin). The performance presents a drastic form of bodily experimentation at the crossroad between body art, *tanztheater*, sound art and media art. Two bodies interact with each other embodying non-human corporealities and postures. Their encounter is mediated by an autonomous prosthetic limb mounted on the head of one of the performers. Prosthesis' movements are controlled by an Artificial Intelligence (AI) system which interprets performers' actions and reacts to them thereby representing a third machine-organic partner of the performance. The same AI system generates the soundscape of the performance as well. Control signals are produced by the direct audification of the performers' muscular activity detected by a couple of Mechanomyograms (MMG)[6]. By analyzing salient features of the muscle signals, some relevant body's actions, such as abruptness, intensity and pace, are then sonified. An immersive soundscape made of electronic granular textures are thereby generated as a response to performers' internal physiological behavior. Both AI algorithm and performers actions are dependent from each other. By making audible the reciprocal sensorimotor learning process, the sound generation functions as a medium enabling a visceral relationship between human and machine partners.

In Muriel Romero and Jean-Marc Matos's *Two Pandoras* (2018-2019), sonification techniques are employed to investigate to what extent dancers' kinesthetic body awareness can be enriched through the use of these interactive movement analysis systems. The piece stems from the collaboration between K-Danse and Istituto Stocos companies, and the InfoMus Lab research team (Università di Genova). This collaboration has been developed in the framework of the European WhoLoDancE project (H2020 program) merging scientific research issues (e.g. movement qualities computation, movement learnability) and artistic creation [15]. In *Two Pandoras*, the relationship between two dancers (Muriel Romero and Marianne Masson) stems from the improvisation with sound and light entities that

[6]Performers worn a Xth Sense device designed by Donnarumma[28]

are generated in real time following the behavior of both dancers. Different technologies are specially designed to capture dancers' movement: a couple of pressure sensitive shoes, several IMU modules placed on dancers' joints and some interactive lasers placed on the dancers' wrists, projecting and extending their movement in the space. Several movement qualities are extracted by using Eyesweb algorithms for real time movement analysis. Movement sonification is provided by sound synthesis generative algorithms designed by Pablo Palacio. Both movement analysis and sonification techniques were originally developed as methods for studying movement and improving sensorimotor learning. Such a methodological convergence between scientific purposes and artistic approaches suggests new possible insights for developing research-creation frameworks.

4 CONCLUSION

Since the earliest experimentations in dance and technology, the interaction between gesture and sound has proven to be the subject of ongoing interdisciplinary research. In recent years, sonification techniques and methodologies have been introduced among artistic creative process by suggesting new ways for experiencing the relation between movement and sound. In this research, the sound is primarily conceived as a way to provide kinesthetic awareness to dancers, to support dance training or to phenomenalize, by means of sound (i.e. to make audible), dynamic or expressive qualities of movement. Therefore, sound interaction becomes a means of understanding and reorganizing movement rather than a mere interactive control. As we analyzed, the auditory augmented feedback can be used to activate sensorimotor learning processes in order to attain a variety of choreographic goals such as: to highlight a certain part of movement, to trace dancer's movement, to communicate dynamics, to report the duration of a gesture, to indicate upcoming changes in a phrase, to underline temporal aspects of movement. From this perspective, the role of technology in performance seems to have changed over the years. In first and the second wave of digital performance or dance technology the discourse mainly focused on capture and technological innovation, whereas recent research on somatic sonification seems to highlight the role of technology plays in corporeal knowledge transmission. In this framework, new insights can be fostered between the use of sonification for scientific purposes and artistic creative development of interactive systems for digital performance. From a historical point of view, the research on movement and sound interaction has shifted from earlier artistic and technical issues to question perceptual entwinement between auditory and sensorimotor knowledge. Such a perspective seems to suggest a fundamental shift in the contemporary artistic scene perspective not only by transforming traditional choreographic dispositives but also by redefining the understanding of the dancer's corporeality. In this context, sound interaction offers the performer a new sensory horizon that allows him/her to renew his/her perceptive organization and to enhance what we could call a sonorous knowledge of the body.

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