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# When arts and science meet: Digital technology in artistic research

## ABSTRACT

*In recent decades, advancements in digital technologies have become a rich source of inspiration for artists, who seek to leave the trodden paths and find novel ways of expression. In addition, digital technologies are increasingly implemented in the development of artistic skills, providing new means to develop the artists' reflection on their own development. As such, they hold great potential to shape artistic research. Moreover, digital technologies offer possibilities to capture the learning process based on quantitative measurement, thereby becoming a potential interface between artistic and scientific approaches to investigating artistic growth. This contribution presents two artistic projects illustrating the potentialities of the art–science encounter. Embedded in the research paradigm of embodied music cognition, both projects explore the role of the body in music performance (interpretation and improvisation). The first project investigates the relation between gesture and interpretative intentions in a contemporary piano composition. The second project concerns the development of one's musical language through kinemusical improvisation. A mixed methodology and the use of technology as 'an augmented mirror' to monitor artistic practice were applied. Both projects illustrate how the*

## KEYWORDS

art–science  
technology  
embodiment  
artistic research  
music performance  
music improvisation

*implementation of digital technologies may boost the evolution in artistic research and facilitate novel approaches to music teaching and learning.*

## INTRODUCTION

What role can digital technology play in artistic research? This is an interesting question that emerges from the relentless possibilities new technologies offer.

The technological advancements and the potentials they introduce have led to a myriad of scientific studies in a diversity of fields (e.g. musicology, psychology, neuroscience or philosophy) and addressing a wide range of topics (communication between performers, between performer and audience, etc.). A great deal of these studies is driven by the paradigm of embodied cognition to study the corporeal engagement in music performance (Leman 2007, 2016; Lesaffre et al. 2017). However, the majority of such scientific studies are often conducted from a third person perspective, for example observing the interaction between musicians (e.g. Hospelhorn and Radinsky 2017; Bishop and Goebel 2018) or the different gestures of musicians (e.g. Bishop and Goebel 2016; Demos et al. 2018). In these empirical studies, musicians are mostly considered mere participants to experiments. Only in recent years, they started to involve in the analysis and interpretation of measurements and results, and therefore their role and voice have gained importance (e.g. Desmet et al. 2012; Coorevits et al. 2019). Although still a long road ahead, scientific and artistic research, often considered as fundamentally different, move towards an integrative approach and more and more research draws upon an artistic exploration of technological applications in music performance practise (Schacher, 2015; Coorevits et al. 2016; Dries 2017; Caruso 2018). However, such studies are still in their infancy and important questions remain:

- To what extent can a technology and a mixed method potentiate self-reflection in artistic research?
- How can musicians monitor performance practice by a creative use of technology?
- Can technology be used as an augmented 'mirror' to enhance music performance practice and induce body awareness?

As such, we believe it is necessary to further explore how digital tools can be implemented in artistic practice and research for better documentation and awareness of gestures in music performance. More specifically, this may involve exploring whether and how performers' expressive gestures, as results of subjective artistic experience (Godøy and Leman 2010), can be monitored and captured through the lens of digital technology. In our view, it is also of interest to do this in different contexts such as interpretation or improvisation.

These are the objectives pursued by the two projects presented in this article. The first project is a finished Ph.D. at University and Royal Conservatory of Ghent (Belgium), conducted by the first author and supervised by the second author. The main objective of this project was to investigate how self-reflection and body awareness in music performance practice can be stimulated through a technology-augmented mirror. The second project is an ongoing Ph.D. project conducted by the second author, the Royal Conservatoire of Antwerp (Belgium). The main objective of this project is to investigate how a musical language can be developed through technology-enhanced improvisation with

music and movement. Situated within the paradigm of embodied music interaction research, both artistic research projects are based on a mixed artistic research method that integrates qualitative and quantitative data, supported by state-of-the-art technologies, not only to look for new ways of artistic creation, but also to generate a deeper understanding of one's own artistic intentions and actions through a scientific approach. The combination of qualitative and quantitative data facilitates performers–researchers to investigate and validate their own intuitions and personal insights, and scientists to make sense of particular set of data related to the performers' personal decision-making. Aesthetic meanings and empirical observations become complementary and this complementarity contributes to creating a transdisciplinary artistic experience (Klein 2010). Considering how technology historically inspired musicians and researchers, our approach wants to launch a basis to complement traditional methods applied in artistic research on music performance (Borgdorff 2012; Coessens et al. 2009; Hubrich 2016) by exploring and designing new paths where art and science together can join forces.

### **THE ROLE OF TECHNOLOGY IN MUSIC PRACTICE AND BODY AWARENESS**

In recent decades, advancements in digital technologies have become a rich source of inspiration for artists, who seek to leave the trodden paths and find novel ways of expression. Indeed, since the creation of the computer, its possibilities have immensely expanded. Initially conceived as a calculator, the computer has evolved from a bulky machine into a multifunctional device (multimedia, communications, data analysis, etc.) that has completely infiltrated in our everyday life. Computational power has increased in such a way that data can be processed, transformed and visually presented at an ever-increasing speed and in real-time. This has led to a 'bewildering variety of computational techniques' (Wilson 1985: 13), available to artists. Computers are also becoming smaller and smaller. The traditional desktop computers are gradually replaced by mobile devices (e.g. tablet, smartphone and smart watch) and more and more embedded in other human artefacts (e.g. glasses, earrings and clothing).

However, not only the computer itself (hardware and software) undergoes substantial changes. Also the way we interact with the computer is constantly developing. Current developments (computational power, different sensors, etc.) enable the emergence of new ways to interact with the computer. A driving force in this development is the aspiration to optimize both the tangible and the social aspect of interacting with the computer (Dourish 2004). On the one hand, the aim is to connect all kinds of technologies with each other (e.g. from smartphone to blackboard), to accommodate everyday life objects with technology that allows to intervene in the environment and in activities (e.g. from running shoes to iPod), to decouple the human–computer interaction from the screen and enable a more intuitive interaction on the basis of tactile controllers (ranging from e.g. a pen to one's own body). On the other hand, the aim is to make the human–computer interaction more social by shaping the interaction as much as possible in accordance with the way people communicate with each other and by integrating social elements in the individual interaction. The strength of these developments lies in making the human–computer interaction more natural by aligning it to the way we function in daily life without a computer (Dourish 2004). In this way, fluidity of communication and reality is established.

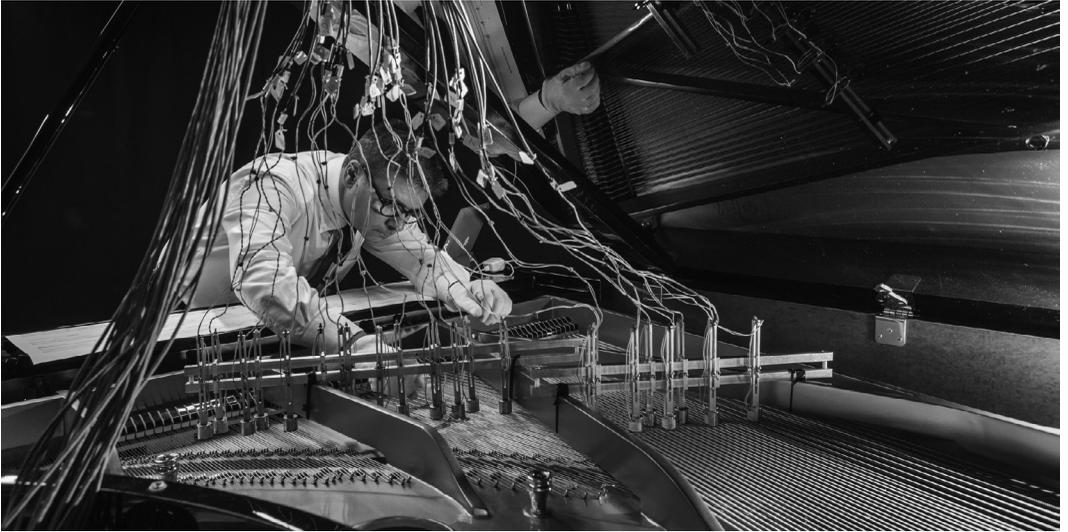
Since the beginning of the above-mentioned developments, artists have been spurred to explore the creative use of digital technologies. Examples include building electronic musical instruments, synthesizers, that generate audio signals by keyboards or are being controlled by sequencers, software or other instruments. The development of new interactive technologies has enabled manipulating the sound of acoustic instruments with midi controllers (e.g. 'Traiettoria ... deviata' by Stroppa [1982] 2010); body sensors such as Myo® bracelets (e.g. 'Suspension' by Tanaka 2010, see Figure 1); audio-video implementations (e.g. Piano Hero No. 1, Prins 2012); motion tracking system (e.g. Chemical Free by Sani 2015); living organic components cultured on a circuit board in interactive biocomputer music (e.g. Miranda 2015, see Figure 2) or touch keys system as in the Magnetic Resonator Piano Project (McPershon 2016).

However, artists not only deploy technology to create novel ways of expression. They also used technological means to support their practice and development of artistic skills. In the domain of music performance, different technological aids were designed already centuries ago. For example, as early as 1814, a new aid, patented as *chiroplast*, was devised by Johann Bernhard Logier (1777–1846). Designed for musicians, this technology allows practicing the keyboard with a correct position of hands and fingers. It consisted of a board on which the pianists placed their arms so that they could give the right position to their fingers (Rattalino 1982). This device was later improved by Kalkbrenner in 1830 and fittingly called *guide-mains* (see Figure 3).

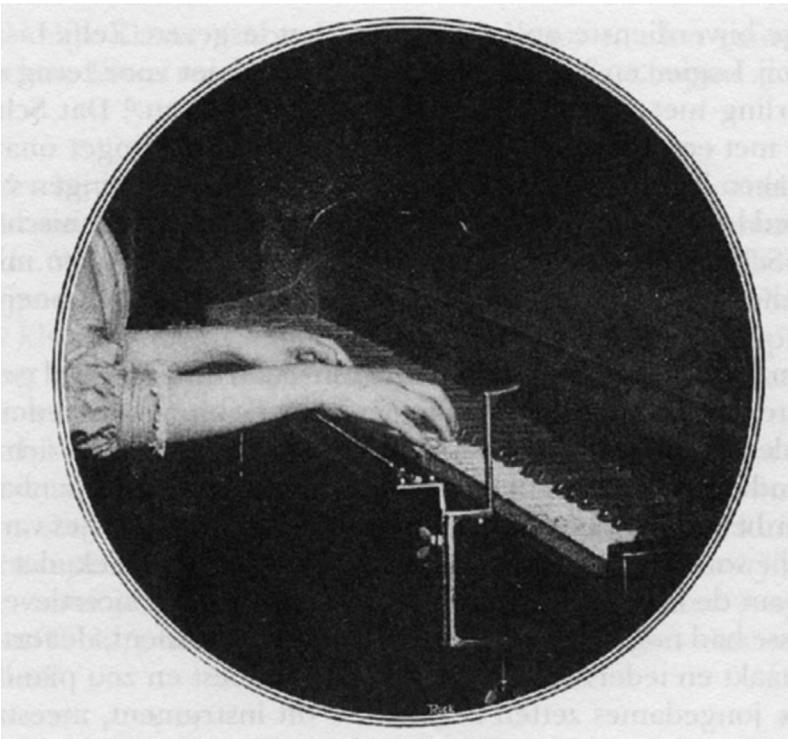
Another example is the device called *dactylion* (see Figure 4), invented by Henri Herz (1806–88). Interestingly, it is well known that Robert Schumann, in order to achieve more independence of his fourth finger, ruined his right hand with a similar device (Edler 1991).



Figure 1: Tricia Dawn Williams, 'Suspension' (2010) by Atau Tanaka for piano and EMG sensors.



*Figure 2: Eduardo R. Miranda (2015), Biocomputer Music. Electromagnets set the strings into vibration and produce a distinctive timbre. The biocomputer interacts with the piano sound by generating musical responses in real-time.*



*Figure 3: Friedrich Kalkbrenner's guide-mains. This picture shows the rail on the front side of the piano on which the arms are placed.*



Figure 4: The dactylion by Henri Herz. It consisted of ten strings hanging above the keys, with a spring on top of it and rings on the bottom. The fingers would be inserted in the rings and, after striking the key, they were pulled up again by the simultaneously tightened spring.

These examples offer the reader an illustration of the early embracing of technology to support practice and the development of musical skills (e.g. expressive, technical and bodily skills). It is beyond the scope of this article to provide a full overview (see e.g. Taylor 2014 for an overview and discussion). These early devices addressed bodily engagement in performance from the perspective to enhance body awareness and technique in the perspective to improve the efficiency of a music performance.

Next to using technologies to create novel ways of expression, another aspect of artistic development is reflective practice. Since the emergence of recording devices, reflecting on one's own and other's performance has been facilitated by the possibility to bypass the volatile nature of a performance and re-listen to the performance as many times as wanted, as well as enabling the user to stop recordings and listen to fragments. An early example of a technology that allows a re-listening is the pianola, or reproducing piano, by Edwin Scott Votey in 1895. This was a sound-reproducing apparatus that to a certain extent preserved the intentions of musicians participating in the process of fixing and reproducing the performance of a musical work (Reynolds 1925; see Figure 5).

New technologies have introduced new ways to enhance musicians' reflective practice. An important development was the use of technologies that support and augment the visualization of performance, enabling to reflect on bodily aspects of performance. For example, the pianist and pedagogue Marie Trautmann Jaëll did a first study on gestures by using a sequence of photographs of her students' performing (Guichard 2004). The audio, video and computer technologies of today not only provide the opportunity to see and hear a complete performance after the execution but also process the recording in different ways, even in real-time. While the former enable the systematic observation and documentation of performances and practice sessions, the latter enables musicians to monitor their performance in real-time in ways that go far beyond what the naked eye (e.g. in mirror) and ear (e.g. listening to oneself while performing) may notice. Moreover, in addition to seeing and hearing oneself, new technologies (e.g. motion capture, muscle sensors and



Figure 5: *The Steinway Upright Pianola (1914), which plays back rolls recorded by pianists.*

infrared thermography) allow to measure, monitor and visualize the bodily engagement in performance, thereby complementing and intensifying the musicians own bodily awareness.

Recent works in the domain of embodied musicology show that performers use a set of different types of gestures, such as *sound-producing*, *sound-facilitating*, *interpretative* or *communicative* (Godoy and Leman 2010; Jensenius 2007). These different gestures are at the same time universal and idiosyncratic features (Buck et al. 2013): while *sound-producing* and *facilitating gestures* are determined by the postural and technical specificity of the musical instrument, *interpretative and communicative gestures* are based on intentions and expressive goals of each performer (Leman 2007). Beside this, performance gestures are induced by different sources of information, including the interpretation of musical structures (Wanderley et al. 2005), associated emotional states (e.g. Dahl and Friberg 2004) and expressive targets within the context of

a performance (Davidson 2005, 2007). Being aware of these different gestures means being aware of how and why each musician develops a specific performance model during their own artistic process related to their own creativity.

This is a fundamental step that is further explored in the two projects presented in this article through a mixed method that allows to elicit and support deliberate practice in artistic research.

### **PROJECT 1: TECHNOLOGY-ENHANCED MIRROR IN MUSIC PERFORMANCE PRACTICE**

In the framework of the theories on embodied music cognition and mediation technology (Leman 2007), this project proposes and develops a mixed method in artistic research based on a use of technology as an augmented ‘mirror’ to monitor performance practice and improve self-reflection, self-evaluation and body awareness. A technology-mediated approach supported the musician–researcher in developing strategies to analyse her own music performance. It led to an innovative paradigm of ‘technology-enhanced mirror’ (Caruso et al. 2021: 355) to support performance practice and artistic research. Such approach provides data-based mirroring to study one’s subjective gestural involvement from a more third-person perspective, allowing a detailed investigation and heightening of self-awareness concerning the relationship between interpretative decision-making on the score and expressive gestural involvement in performance. This study is the result of the Ph.D. research conducted by the first author at IPeM, University of Ghent (2015–18).

#### ***Looking into an ‘augmented mirror’***

A simple mirror can capture just a single moment of a performance which requires the performer’s personal evaluation within their artistic process. This assessment is part of a common practice for not only instrumentalists, but also singers, actors and dancers. They all have a common practice to study in front of a mirror in order to look at their posture, movements and articulation and to assess them. The artistic process concerns all artists’ subjective experiences and practices to create an artwork or a performance. In the case of classical music, instrumentalists are engaged in the challenge to turn a musical score into sound. This transformation involves specific learning strategies of established interpretative models (Chaffin and Imreh 2002). That is, the musician is called upon to ‘realize’ the music.

The digital developments offer nowadays video and audio recording devices that can support musicians in the observation and evaluation of their body posture and gesture while preparing a performance. Furthermore, sophisticated software and systems for motion and audio tracking provide quantitative data on gesture and sound that can amplify the possibilities to analyse a music performance (Goebel 2014). Respect to a simple video recording, the motion capture technology, for instance, augments the visualization of a performer’s body projected in an avatar-like representation in 3D. Beside this, it provides quantitative movement data, like the displacement, acceleration and velocity. The 3D perspective in combination with these motion data offer musicians with the exclusive advantage to look at and analyse their body image by jumping from a first-person perspective, as actors of their lived performance, to a third-person perspective, as external observers of the same performance (Himonides 2012; Pitozzi 2014).

How can these technologies be integrated in a mixed method to monitor performance practice and stimulate and support self-reflection?

This project envisages a multimodal approach to align performer's reflections on their artistic process by using motion capture technology to potentiate the perspective provided by a traditional mirror or simple devices for audio–video recordings. The aims are to: (1) find methods to systematically monitor performance practice; (2) augment its efficiency; and (3) cope with the subjective component in evaluating a music performance through recalled lived experiences.

### ***Performer-based analysis method***

According to Sutil (2015), the representation of human motion can be mediated by a written record (i.e., notation), a visual record (i.e., animation) and a computational record (i.e., motion capture). In this way, the three types of representation (notation, animation and motion capture) were used in a performative experiment by applying a mixed method that combines subjective descriptions (i.e., qualitative approach) from the performer's artistic perspective and objective data (i.e., quantitative approach) from video, audio and motion capture recordings. Both approaches, qualitative and quantitative, converged in a *performer-based analysis method* (Caruso et al. 2016) that considers quantitative measurements as an alternative way to verbal description in the process of documenting, observing and evaluating artistic experience, score interpretation and gestural involvement. Therefore, quantitative data on gesture and sound are used as an external feedback to nourish music performance practice from the gestural and sound perspectives. Obviously, the feedback is re-injected in the artistic process that defines and shapes the expressive intention of the performer. The mirroring technology thus becomes a tool in a reinforcement dynamic within the artistic process. This method enables performers to proceed from an intuitive analytical observation to a deliberate acquisition of knowledge (concrete level) and to a final systematic evaluation mediated by the technologically augmented mirror (meta-level).

### ***Performative experiment and procedure***

To explore the efficiency of technological integration in music performance practice and artistic research, the performative experiment was set up including audio, video and motion capturing of a piano performance and a musician's explanation of her performance practice and artistic process. In this study the researcher is also the participant: a concert pianist trained in classical music, now more oriented in the performance of contemporary music repertory (post-master in contemporary music at the Royal Conservatory of Ghent, Belgium). In this performative experiment, the pianist chose to investigate gestures in contemporary music repertory by performing the eighth cycle from the *72 Etudes Karnatiques pour piano* (1957–84) by the French composer Jacques Charpentier (1933–2017). This piece is a contemporary western piano work based on the South Indian 72 Karnatic modes (*Melakarta Ragas*) and on an elaboration of rhythmical patterns from the 120 Hindustani *decitalas* (Carsuo 2019). The performer was quite new to Indian music tradition, therefore she decided to have brainstorming, discussions, interviews, collaborative practice with the composer and Indian music experts. She conducted her artistic practice as a research study to investigate the development of her artistic process, in particular the evolution of her interpretation of the score related

to her execution, i.e. the relation between intentional gesture (Jenseniuss 2007; Godøy and Leman 2010) and sound results.

To ensure the ecological validity of the performance space/situation (Doğantan-Dack 2015; Goffman 1974), the performative experiment was conducted in a concert hall using a grand piano Steinway. The performer's movements were recorded with the OptiTrack Motion Capture System (<http://www.optitrack.com/>). The pianist had to previously elaborate the experiment set-up (i.e. cameras position around the piano and markers configuration). She had to learn how to work with the software and perform camera setting and calibration. This stage included studying and exploring the morphology of her body to decide where to put the markers and to define the motion capture configuration of 'rigid bodies', i.e. the joints reproduced in augmented reality to calculate the rotation, displacement, acceleration and velocity of the movements. This preliminary work brought to position six infrared cameras in a hexagonal configuration on a fixed bridge and to setup a three-dimensional positional readout of eighteen infrared reflective markers, at a sampling rate of 100 Hz, on the pianist's upper body (three on the head, three on each hand, three on the back and three on each elbow), and four on the boundaries of the keyboard to have its reference in the visualization of the motion capture recording (see Figure 6).



*Figure 6: The markers positioned on the performer's body and on the piano.*

The performative experiment was recorded with two video cameras (lateral and top view) and a microphone to document the experiment and to also provoke spontaneous playing, suggesting the natural feeling of a concert, even if there was no audience in presence as in usual public performance condition (a reportage is available on <https://www.youtube.com/watch?v=tOmF4YeBgvY>). The experiment was structured as follows:

1. Performative Section 1: Concert-like performance of the entire piece.
2. Fragment Sections 1–3: Performance and performer-based analysis of three fragments extracted from the piece using a retrospective thinking-aloud procedure to show a possible different gestural approach related to different intentions.
3. Performative Section 2: Concert-like performance of the entire piece.

The retrospective *thinking-aloud procedure* (Van den Haak and De Jong 2003) allowed the performer to render her artistic reflections explicit and systematic. The two concert-like performances (Performative Sections 1 and 2) were used to provoke a spontaneous performance of some fragments of the piece. They were also used as a point of reference in order to detect possible biases during the *thinking-aloud* procedure, i.e. whether the supposed causal sequence of stimuli and expressive responses influence the natural performance.

The data obtained from the experiment consist of both the performer's subjective reflections retrieved during the *thinking-aloud procedure* and motion data retrieved from the gestural recording and video and audio data. The motion capture recording provided raw data in the form of Euclidean positions of the markers in the performance space and, most important for musicians, the visualization of the avatar as her 'mirrored' image (see Figure 7).

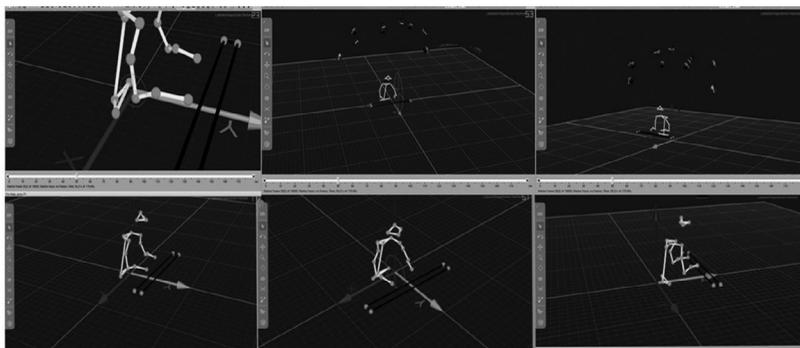
### **Data analysis and results**

These data were analysed by the performer through ELAN, an easy-to-use software for video annotation (Wittenburg et al. 2006) in which motion capture and video recordings were combined with sound and subjective annotations (see Figure 8). This layout provided the performer with a technology-enhanced mirror that:

1. enables an intuitive and graspable way to empirically analyse music performance by focusing on the video analysis;
2. offers the possibility to visualize the avatar on different angulations by rotating the figure;
3. allows zooming in and out on particular body joints in order to better understand, for example, the displacement and amplitude of gestures.

Body awareness was achieved by scrutinizing the performance through a combination of qualitative reflections and quantitative feedback to see how the body reacts and accomplishes specific musical patterns. The interpretation of the score was used as a point of reference for understanding the development of the artistic process. In this way, the performer proceeded from an intuitive analytical observation to a deliberate acquisition of knowledge (concrete level) and to a final systematic evaluation mediated by the technologically augmented mirror (meta-level) (De Baets and Nijs 2015). In this approach, the performer-based analysis is supported by technology as a

1) visualisation

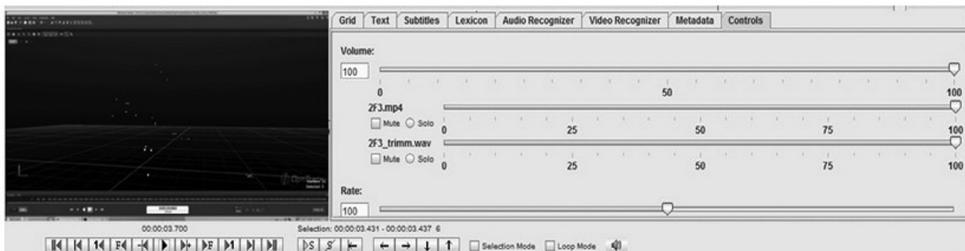


2) objective data

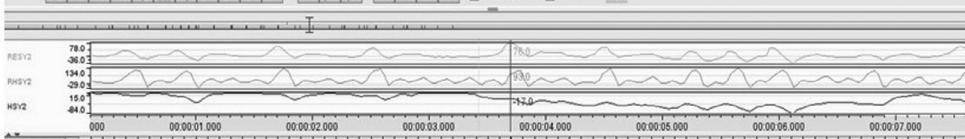
Frame#	TIME[S]	RHF1 VELOCITY	RHF1 TIMING AVERAGE	RHF1 ACCELERATION	RHF2 VELOCITY	RHF2 TIMING AVERAGE	RHF2 ACCELERATION
2	2839	94.6666667	0	0	94.6666667	1	0
3	2840	94.7	0	94.6833333	94.7	0	-30
4	2841	94.7333333	0	94.7166667	94.7333333	2	60
5	2842	94.7666667	-2	94.75	94.7666667	2	0
6	2843	94.8	-1	94.7833333	94.8	3	90
7	2844	94.8333333	-5	94.8166667	94.8333333	5	120
8	2845	94.8666667	-7	94.85	94.8666667	15	180
9	2846	94.9	-6	94.8833333	94.9	18	90
10	2847	94.9333333	-9	94.9166667	94.9333333	25	210
11	2848	94.9666667	-7	94.95	94.9666667	34	270
12	2849	95	-5	94.9833333	95	35	30
13	2850	95.0333333	-2	95.0166667	95.0333333	1	-1020
14	2851	95.0666667	-1	95.05	95.0666667	-9	-300
15	2852	95.1	-5	95.0833333	95.1	-1	240
16	2853	95.1333333	-6	95.1166667	95.1333333	6	210
17	2854	95.1666667	-10	95.15	95.1666667	12	180
18	2855	95.2	-13	95.1833333	95.2	12	0
19	2856	95.2333333	-9	95.2166667	95.2333333	8	-120
20	2857	95.2666667	-4	95.25	95.2666667	-2	-300
21	2858	95.3	-5	95.2833333	95.3	3	60
22	2859	95.3333333	-7	95.3166667	95.3333333	14	420
23	2860	95.3666667	-9	95.35	95.3666667	28	420
24	2861	95.4	-10	95.3833333	95.4	30	30

Figure 7: Examples of the avatar visualization and data retrieved from the MoCap system.

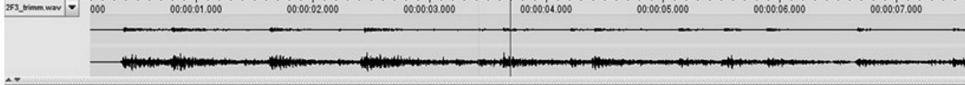
1)



2)



3)



4)

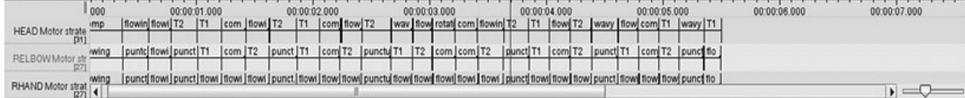


Figure 8: This screen shot, taken from one of the Elan projects, shows the parallel configuration, displayed from up downward, of quantitative measurements: (1) the video; (2) the motion tracks of head, right hand and right elbow; (3) the audio waveforms – and qualitative descriptions; and (4) the performer’s annotation (Caruso 2018: 87).

'mirror' that provides top-down and bottom-up enhanced feedback about the performance. Obviously, feedback from technology concurred to shape the artistic process and define the expressive intention of the performer. In this way, mirroring technology thus becomes a tool in a reinforcement dynamic within the artistic process.

The rationale behind this approach is to support performers in explicating and evaluating their artistic practice and process by quantitative information that can help to reinforce decision-making on the score interpretation related to musical gestures and sound results.

## **KIMUPE: A JOURNEY OF ARTISTIC EXPLORATION IN KINEMUSICAL PERFORMANCE**

The KiMuPe project originates in the educational research of the artist-researcher, the second author, and is still ongoing. KiMuPe is an acronym for 'kinemusical performance', which is a music performance that integrates movement improvisation. Based on his work on the musician-instrument relationship (Nijs 2017; Nijs et al. 2013), in which it is argued that an optimal relationship between musician and instrument involves the incorporation of the instrument as a natural extension of the musician, he develops a *kinemusical* approach to instrumental music learning and teaching. This approach brings the body to the heart of the instrumental music learning process by promoting a bodily engagement at the intersection of personal style, instrumental gestures and bodily responses to the music, through the deliberate use of expressive movement (Nijs 2019).

Throughout the years of educational work, it became increasingly clear that the educational work needed a more profound artistic foundation. Despite many years of experience in teaching (clarinet, saxophone, ensemble and creative ateliers) and music performance, the researcher had no 'kinemusical' artistic practice. As such, the KiMuPe project addresses the author's personal artistic need. Through this project, the artist-researcher seeks to deconstruct his performing self as trained within the conservatoire tradition and starts 'from scratch' to develop his own musical language. The starting point for the (de)construction of his performing self is Merleau-Ponty's (1945) idea that the body is the primary sphere in which meaning is initially engendered. Indeed, our bodily existence with its embodied skills, experience and knowledge functions as the background of our interaction with the world. This very idea is reflected in the research paradigm of embodied music cognition that investigates the role of the body and body movement in musical meaning formation, and therefore in musical creativity, expressiveness and communication.

### ***Developing a musical language***

The primary goal of this artistic research process is to explore how improvisation with music and movement can support the development of a personal musical language that enables to express the artist's personal 'voice'. According to Wooley, building a musical language creates 'a living body of learning, shaped by the process of an individual engaging with the sort of imperfection that comes through physical limitation, testing their own ideas against generally agreed-upon musical aesthetics and embracing radical moments of alterity' (2020: 45).

The development of a musical language can be seen from two perspectives. A first perspective concerns *how the language is built*, involving its phonology, morphology and syntax (Wooley 2020). In the same way as language learning involves discovering patterns built of certain building blocks (e.g. phonemes and syllables) by segmenting perceived speech into patterns, improvising music involves the segmenting of musical material and combining such segments into meaningful patterns (Norgaard 2012). Such patterns can constitute the 'language' of an improviser. For example, based on 250 transcriptions of improvised solos by Charlie Parker, it was found that the famous jazz saxophonist had an entire system of musical patterns and pattern relations that he used in various forms throughout his solos (Owens 1974). Interestingly, both in language and music, the emergence of patterns can be linked to the body (Norgaard 2014). The body may facilitate both the segmenting of patterns and the emergence of higher order patterns (Leman 2016).

A second perspective concerns the *expressive use* of the language. This is related to the use of, for example, timing, prosody and intonation to build phrases. It is all about manipulating the acoustic properties such as articulation (relations of tone offsets to successive tone onsets such as staccato/legato), timbre and intensity (dynamics) without changing the categorical information (e.g. musical pitches) (Palmer and Hutchins 2006). Such manipulation can be linked to the basic mechanism of the enactment process, namely alignment (the matching of physical actions to what happens in the music), entrainment (the process of being pulled towards synchronization with the music) and prediction (anticipating how the music is unfolding) (Leman 2016).

### **Approach**

The root of the adopted artistic approach is twofold. First, it is rooted in the theory of embodied music cognition (Leman 2016; Lesaffre et al. 2017), including a specific 'embodied' view on the musician instrument relationship (Nijs et al. 2013; Nijs 2017). The basic idea of embodied music cognition is that we make sense of music by a process of 'enactment', which involves the transformation of sound into music on the basis of the association of patterns in the sounds (e.g. chord sequence or melody) with movement patterns (e.g. shape, direction and energy) and thereby with the intentional states (e.g. an emotion) that underlie these patterns (Leman 2016). Nijs (2017) argues that the instrument can interfere with this process and therefore ideally becomes incorporated as a natural extension of the musician. The usual way to optimize the relationship between musician and instrument is years of deliberate practice. In this case, it is supposed that the body is gradually constrained and directed to perform in particular ways. By training the body's relation to the instrument, these constraints are ideally naturalized by accommodating the body and the instrument to each other. Alternatively, instead of counting on years of deliberate practice to fit instrumental technique to a particular body-in-performance and thus develop bodily freedom in performance, motility or bodily freedom may be deliberately addressed from the very beginning of learning how to play an instrument. The latter is the rationale of a kinemusical approach to instrumental music education, in which learners are given opportunities to explore and experiment with music-movement associations to autonomously develop creative and expressive behaviour in instrumental music performance (Nijs 2019).

Second, the artistic approach is rooted in non-linear pedagogy, which adopts a constraints-led approach. By manipulating the *organismic* (characteristics of an individual), *task* (goals and materials of a task, feedback on a task) and *environmental* (physical factors surrounding an individual, shaping certain or limiting behaviour) constraints, the learning process is shaped and scaffolded towards the realization of its goals (Newell 2003; Bremmer and Nijs 2020). In this project, organismic constraints are introduced by combining movement with playing the clarinet. In this way, the movement is, in addition to the instrument, a factor that constrains the bodily engagement with the improvised music (see also Nijs 2017, 2019). Task constraints are introduced based on different movement approaches, such as Dalcroze or Laban, leading to specific locomotor and non-locomotor movement tasks. Environmental constraints are introduced in two ways. First, by improvising in specific locations (Urbex) that, due to their acoustic properties, invite to explore and experiment with these acoustic properties. Second, by sonifying the feet and clarinet movement, based on the quantitative measurement of these movements, using in-house design foot-sensors and the Sabre® sensor (see Figure 9). In this way, the kinemusical improvisations will be embedded in a sounding environment that is dynamically shaped by the improvisations themselves.

### ***A mixed method: Combining first and third perspectives on the artistic process***

According to Wooley, building a musical language is a slow and accretive process, encompassing an ‘organic and often insular and intuitive practice that defies an exact explanation’ (2020: 45). This project seeks to make the process of developing one’s own musical language visible, trying to go beyond the ‘insular and intuitive’ and ‘explain’ the artistic change or growth over time. To do so, it focuses on both the process (practice sessions) and the product (concerts and recordings), combining a first- and third-person perspective.

The first-person perspective involves qualitative methods such as *think aloud procedure* (commenting on the process of kinemusical improvisation



Figure 9: In-house designed foot sole with five pressure sensors (left) and Sabre® sensor (right).

during practice session), *video stimulated recall* (looking back at the video footage of practice sessions and concerts and commenting on it) and a *diary* (post hoc description of the lived experience during practice sessions and concerts).

The third-person perspective involves the quantitative measurement of music and movement over time. Movement is measured using on body motion sensors (Noitom Perception Neuron; <https://neuronmocap.com/>), visualized in Neuron Axis software and analysed in R. Music is recorded with an AKG WMS 420 clip-on microphone and analysed using SonicVisualiser and R. The idea is to capture the self-organizing processes unfolding through the interaction between movement and music improvisation. This will be done by investigating emergent properties in music and movement, looking at how patterns in movement and music jointly co-evolve over time, allowing to learn about the emergence of a musical language based on discerning recurring musical patterns (cf. Norgaard 2014; Demos et al. 2018).

In addition, the quantitative data is used to create an ‘augmented mirror’ (see project 1). The movement during improvisation will be visualized (e.g. using Neuron Axis) using a skeleton-based avatar and visually annotated (e.g. using different colours, showing clusters) on the basis of an analysis of the movement data (see Figure 10). Furthermore, the quantitative data allows creating time series of music and movement that can be triangulated with the data generated by the first-person perspective (see Desmet et al. 2012).

## DISCUSSION

Considering that mediation technology is nowadays a territory of creative experimentation, documentation and knowledge archiving and transmission (Di Bernardi 2018; Bleeker 2017), this article proposes an innovative implementation of digital interaction in artistic research, not only in the perspective of artistic creation but also in the perspective of enhancing music learning,

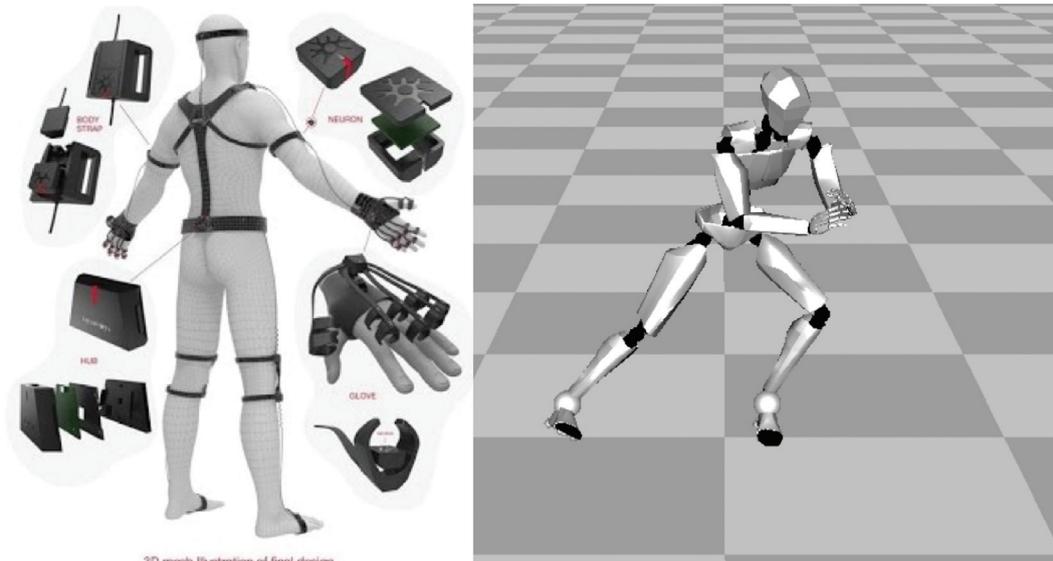


Figure 10: A skeleton-based avatar is retrieved from the movement data, captured with the Perception Neuron MOCAP and visualized in Axis Neuron.

performing and researching. We presented two projects that, situated within the paradigm of embodied music interaction research, explore the role of technology in monitoring performance practice, improving music performance and reach body awareness.

The first project concerns the use of technology to monitor the corporeal engagement in the performance of a contemporary piano piece; the second project explores the role of body movement in developing one's musical language through kinemusical improvisation.

In both projects, the artist-researchers apply a mixed methodology by applying technology as an 'augmented mirror' to reflect on their own artistic practice and to study how their own gestural approach on their instrument, i.e. how they evolves and changes, affected by the progresses of their own artistic intentions. In doing so, the artist-researchers aimed at: (1) defining new technological applications in achieving body awareness in music performance practice and creation, in particular the understanding of one's own artistic intentions and actions in relation to performance gestures; (2) developing a new performer-based analysis method that can integrate qualitative and quantitative data in artistic practice; and (3) encouraging the dialogue between art and science in artistic research.

### ***Body awareness***

The presented projects focus on making explicit the development of the embodied involvement in music performance through the observation of their performing body as the visible factor of the enactment processes, i.e. the transformation of intended expressions into musical sound patterns and through systematic and technology-enhanced reflection on this process (Leman 2016). In both projects, corporeal articulation is seen as an interface between the performer's artistic process and intended expression. In the first project, the observation of the body is related to the interpretation of the score, used as a point of reference to understand the connection between gesture and musical interpretative intentions; in the second project, the monitoring of the body in musical improvisation allows to understand the connection between gesture and the creation of a personal musical language. In both cases, body awareness is achieved by scrutinizing the performance using different digital technologies such as motion capture or dedicated software for the visualization and analysis of video, sound and movement data, to understand how the body reacts and accomplishes specific musical patterns, interpreted and improvised. Such self-monitoring is situated at three levels: the technology supports the understanding of the sensorimotor information that, by mediation of the 'body schema' (repertory of pre-reflective and not intentional actions), serves to reach the awareness of the conscious image or representation of gesture, 'body image' (Gallagher 1986; Nijs 2017), not in a context of determined experimental studies but in the context of spontaneous and personal artistic experience, practice and research.

### ***A performer-based analysis method: The integration of qualitative and quantitative approach***

The underlying rationale of both projects is that technology-enhanced self-monitoring gives performers an outsider perspective on their own bodily involvement in performance, making their own musical intentionality and

their own artistic growth explicit in ways that are complementary to the common ways of self-monitoring (e.g. mirror, memory and video or audio recording). Indeed, the inclusion of quantitative measurement and computational analysis gives performers a possibility to complement verbalizations with the systematic documentation and observation of the different steps of their artistic process and to reveal the tacit dimension (Polanyi 1966) of their performance practice and artistic intentions. After all, the visualization and analysis of quantitative data provide detailed information that cannot be seen by the 'naked' eye in the elusive moment of a live performance, or even in the qualitative observation of a video recording. While a qualitative analysis can reveal lots of information on, for example, categories of movement, it is more difficult to see significant recurrent patterns over longer periods of time. As such, the quantitative measurement of sound and gesture produced during a performance constitute complementary information that induces and potentiates the performers' artistic reflections. In other words, if quantitative data constitute a way to speak about music performance in terms of numbers and measurements on gesture and sound, this information is related to each performer's artistic perspectives to be correctly interpreted.

### **Art and science**

Both projects are an example of how art and science can meet in the perspective of enhancing practice and research through technology. The conjunction of the artistic and the scientific worlds is a specific characteristic for the dual role of artist-researchers who are at the same time performers and observers, evaluators and analysts of their own actions and work. The mixed methodology applied in the described projects may lead to deeper insight by combining first-person descriptions/reflections (qualitative approach) and third-person measurements of performative gesture (quantitative approach). Indeed, monitoring gestural and musical expression via technology allows performers to jump from a subjective, first-person perspective to a third-person perspective to obtain a fine-grained analysis of once performance and artistic growth over time. At the same time, the first-person-perspective is needed to align quantitative observations and analyses with one proper artistic intention. In line with the paradigm of technology-enhanced learning (Bransford et al. 1999; Duval et al. 2017; Waddell and Williamon 2019), the feedback gathered from technology affects the artistic process in the sense that it assists self-reflection and self-evaluation to reach a better performance.

The introduction of self-monitoring technological approaches to music performance and practice offers a mutual reinforcement model in both domains: the scientific domain, concerning the analysis of quantitative data, affects the artistic domain, concerning the creation of a performance, and vice versa.

### **CONCLUSION**

The domain of artistic research is fast evolving. By focusing on the possibilities of digital technologies to enhance musician's self-monitoring and, as such, to shape the process of artistic development, this article wants to contribute to this evolution. We believe it offers a perspective and method for the exploration and the design of new paths within the field of artistic research. To illustrate our stance, we described two Ph.D. artistic projects that, each in its own way, explores the role of the body and body movement in performance.

The main goal of both Ph.D. projects is to investigate whether and how technology can be used as a tool that facilitates and mediates music performance practice and, therefore, encourages the rapprochement of the arts and the sciences. In our view this is an important and necessary possibility that, when increasingly finding its way to the conservatoire, its broader implementation may contribute to promote student-oriented, student-active and student-centred learning in conservatoires and music departments. Indeed, the use of digital technologies to support performance practice enables moving from a top down model (the teachers monitors, analyses and evaluates) to a bottom up approach (enhanced self-monitoring by the student). Without reducing the important role of excellent and inspiring teachers, such enhanced-self monitoring arguably may contribute to, for example, the students' self-regulation skills, self-efficacy and autonomy. As such the student-teacher interaction may be fuelled with a stronger student voice. Investigating these aspects is in our view an interesting and even important avenue for future research, allowing to gain deeper insights in the role of technology in artistic growth.

Finally, we believe that the scientific and artistic conjunction has an important impact in generating new insights concerning our ways of experimenting, performing and disseminating music practice as a research. By removing the boundaries between art and science, the digital revolution is boosting innovations across our contemporary culture contributing to the social transformation and leading towards a new way of thinking and placing the artistic practice.

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