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Abstract
In this paper, we discuss the pedagogically grounded and research-based design of a technology-enhanced learning tool, the Music Paint Machine. This interactive music system introduces a musical experience in which the musician creates a digital painting by playing an acoustic musical instrument and by moving the body on a coloured pressure mat. As a learning tool it aims at the development of musical creativity, at the stimulation of embodied understanding of music and at the development of an intimate relationship with the musical instrument.

First, the methodological approach is outlined and pedagogical and theoretical backgrounds are discussed. Then, we report on an experiment in which 51 amateur musicians participated. The experiment aimed at probing the application’s potential to induce a flow experience and to learn about how participants evaluate the didactic relevance of the Music Paint Machine. Results suggest that the Music Paint Machine has the potential to evoke a flow experience. Furthermore participants acknowledged its didactic relevance with regard to learning to improvise, to developing understanding of musical parameters and to stimulating creativity.

1. Introduction
In this paper, we describe a technology-enhanced music learning tool, called the Music Paint Machine, which provides musicians with visual feedback by monitoring their playing. The system allows a musician to draw a painting on a computer screen by playing a melodic acoustical music instrument (such as clarinet, flute, trumpet, violin, singing, ...), while moving on a coloured mat. An essential aspect of this learning tool is its embedment in a pedagogical framework that is inspired by recent developments in embodied music cognition.

There are several motivations behind the development of the Music Paint Machine. A first motivation is concerned with the question whether a technology-enhanced educational tool can be developed that facilitates learning to play a classical musical instrument. We believe that the Music Paint Machine is indeed a step towards such a learning tool, as it tries to stimulate the students’ musical creativity and playfulness with musical parameters. Flow, peak, or optimal, experiences have often been acknowledged as fundamental to the development of musical creativity (Csikszentmihalyi, 1990; Addessi & Pachet, 2005). By providing students with an immersive experience of playing with musical parameters, body movements and visualizations, the Music Paint Machine aims at inducing such optimal experiences with hopefully positive effects on musical creativity. In addition to the flow experience, playfulness with musical parameters has often been considered an important aspect of musical creativity as well (e.g. Deliége & Wiggins, 2006). The goal is here to stimulate students to explore and experiment with different musical parameters, using particular learning methods and learning tools. Learning to be playful with musical parameters,
using the Music Paint Machine, is thus linked with learning how to improvise. Improvisation can be considered as an essential component in the development of musical creativity (e.g. Van Regenmortel & Strobbe, 2010).

The second motivation is concerned with the question whether a technology-enhanced educational tool can cope with corporeal-based theories of musical meaning formation—as we believe that these theories have a great potential in the field of education. Musical experience, including music performance, is often seen as having a firm and indispensable corporeal ground (e.g. Bowman & Powell, 2007; Leman, 2007; Godey & Leman, 2010) and body movement is believed to provide students with a way to fluently access musicality (e.g. Dalcroze, 1980; Pierce, 2007). We believe that technology can stimulate an embodied understanding of musicality by invoking body movement as constitutive to the musical experience and by accommodating to the multi-modal nature of musical experience by means of real-time visual feedback. By using body movements to influence the way musical parameters are visually represented, the Music Paint Machine invites students to explore and experiment with the corporeal dimension of playing music. In this way, it provides them with an experiential basis that might contribute to the musical signification processes. In addition, musical experience is also said to be multi-modal (Leman, 2007). When performing music, the interaction with the performance context (musical instrument, music, audience, concert hall) involves the simultaneous perception of the different sensory modalities and a close interaction of sensory processing with motor production (Lappe, Herholz, Trainor, & Pantev, 2008). The Music Paint Machine aims at enhancing this multi-modal aspect by combining visual feedback with audio input and motion input.

The third motivation is concerned with the question whether a technology-enhanced educational tool can contribute to the establishment of an optimal relationship between the musician and the musical instrument. This question is related to the idea that the unity of musician and musical instrument, or at least the intimate interaction between musician and musical instrument, is an important aspect of musicianship. In an optimal relationship with the musical instrument, the musician is not hindered by the technicalities of handling the instrument so it becomes possible to focus on musical goals and to immerse in the musical world that is being created throughout the playing (Leman, 2007; Nijs, Lesaffre, & Leman, 2009). The Music Paint Machine aims at offering a learning environment in which the relationship between musician and musical instrument can be fully deployed and monitored, through the visual feedback on the screen. This optimal relationship with the musical instrument is assumed to rely on the fine-grained control over the instrument, and for that reason, parameters such as intonation and dynamics can be enhanced and explored. We believe that the study of the effect of technology-enhanced feedback of fine-grained control parameters is educationally appealing in the sense that it may contribute to an efficient learning of advanced musical skills.

The goal of the present paper is to introduce the Music Paint Machine by describing the design of this technology-enhanced learning tool in relation to the educational, cognitive theoretical, and experimental framework. Our approach aims at optimizing the didactic potential of the Music Paint Machine through a ‘spiral collaboration’ (Addessi & Pachet, 2005) between three partners, namely, the designers of the system (who work on the concept, the software and the hardware of the tool), the pedagogical experts (who work on learning and education), and the users (who work with the tool, such as teachers and students). The ultimate purpose of our research is to evaluate if the Music Paint Machine can be effectively used to learn to play music. However, this is a long term goal and this paper, therefore, is limited to a description of the design, the underlying principles, and the results of a first experiment that aimed at probing the Music Paint Machine’s potential for inducing a flow experience while playing. Given the user-oriented development approach, we also report briefly on the participants’ perception of the didactic potential of the application.

This paper is structured as follows: in a first part, we describe the relationship between the Music Paint Machine and monitoring in music education (Section 2). In the second part, we explain the methodological approach behind the design of this learning tool (Section 3). Next, we outline the background that constitutes its conceptual design (Section 4), which is followed by a description of its implementation in hardware and software (Section 5). The next part (Section 6) describes the setup of a first experiment that was conducted with 51 amateur musicians, followed by a report (Section 7) and discussion (Section 8) of the results of this experiment. Finally, we present the general discussion (Section 9) and a conclusion (Section 10).

2. The Music Paint Machine and monitoring

Technology-enhanced learning tools aim at providing solutions to certain problems in education. One of the central issues is concerned with the feeling that education is often a slow process and that the use of tools may perhaps facilitate and speed up the learning process, so that learning becomes more efficient in terms of produced quality in a shorter time span. This idea clearly applies to music education, where learning to play a musical instrument is known to be a time-consuming and
pedagogically intensive process. Does there exist a technology-enhanced learning tool that can make music education more efficient?

A good starting point to tackle this question is to consider the monitoring of a musical performance, in particular monitoring one’s own performance, as this may be a crucial aspect of learning to play a musical instrument. Indeed, self-monitoring implies an awareness and evaluation of the quality of one’s own playing, which forms a basis for error correction and further improvement of one’s playing skills (Goolsby, 1995; Palmer & Drake, 1997; Woody, 2001; Altenmüller & Gruß, 2002). However, this awareness and evaluation can interfere with the performance in such a way that it affects concentration, focus, and eventually the musicality of the playing. The question is whether a monitoring tool can help develop this sense of self-monitoring.

In traditional music education, self-monitoring is primarily acquired through a master–apprentice model. In this model, a ‘master’ or music teacher helps the ‘apprentice’ or student to develop the necessary monitoring skills by giving verbal and gestural feedback on different aspects of their playing (e.g. posture, technique, interpretation) (Ericsson, 1997; Lehmann, 1997; Hoppe, Sadakata, & Desain, 2006). By receiving repeated feedback from the teacher, the student gradually develops the self-awareness that is necessary to evaluate their own performance quality.

However, recent pedagogical developments propose a constructivist model of education, which is different from the traditional educational model. This constructivist model is based on a learner-centred approach in which decision-making, autonomous self-monitoring and self-regulation are considered to be essential (e.g. Elliott, 1995, 2005). In this approach, exploration and experimentation are promoted as an experiential basis for students’ self-learning and development of self-monitoring skills. Consequently, the feedback is less teacher-imposed, and more learner-controlled than the traditional educational model. Educators believe that feedback should include the following characteristics (Bos, 2001):

- be intrinsic and embedded in the students’ performing experience;
- be direct and highly responsive and immediate;
- maintain engagement and motivation;
- present the student with the opportunity to reflect on it.

It is important to develop a proper monitoring tool that helps to realize these feedback characteristics. Therefore, what is needed is the development of a proper technology-enhanced learning tool that is fully embedded within the educational context, and that is well grounded in a theory of human–machine interaction. Such a tool should be developed in a context that allows the testing of its effectiveness in music education, so that it is possible to tell whether the tool makes any difference in learning or not.

With the development of the Music Paint Machine and the integration of a monitoring and feedback system we want to complement educational approaches with a technology-enhanced learning tool that (1) makes it possible to monitor different aspects of playing a musical instrument, such as breathing, sound characteristics, posture, bow speed/pressure, using state-of-the-art sensing technologies, (2) stimulates intrinsic feedback mechanisms by providing an immersive experience that engages its users in an interactive feedback loop and stimulates intrinsic motivation, and (3) provides off-line feedback (in the form of paintings and other types of data logs) as pedagogical documentation that can be used for further study and reflection. Accordingly, the application is intended to introduce new ways of monitoring the students’ playing that can potentially enhance learning and teaching (Nijs, Coussement, Müller, Lesaffre, & Leman, 2010).

The idea that technology-enhanced systems can contribute to monitoring and thus to more effective music education is not entirely new. Reference can be made to previous systems, such as the augmented mirror (Ng et al., 2007b) or the ‘seeing sound’ system of Ferguson, Moere, and Cabrera (2005). The augmented mirror allows the tracking of the bow of the violin and the system can provide an analysis of the playing characteristics, including recommendations for improvement. Ferguson and colleagues developed a system that provides real-time feedback on sound characteristics. The main difference with the augmented mirror is that our approach can be applied to a large range of acoustical musical instruments, and that the processing of audio, motion, and visual information is based on concepts that are rooted in child education, embodied music cognition theory, and conceptions about music mediation. The main difference with the ‘seeing sound’ system of Ferguson et al. lies in the kind of visual feedback that is provided. The development of the Music Paint Machine is strongly user-driven and based on a close interaction with students and teachers.

3. Methodological approach

The design and development of the Music Paint Machine is directed at an optimal embedment of this learning tool within a pedagogical framework and context. This pedagogical embedding is a major concern in ongoing research concerning technology-enhanced music learning (e.g. Webster, 2002, 2007; Adessi & Pachet, 2005; Adessi, Ferrari, Carlotti, & Pachet, 2006; Bresler, 2007). In line with current developments within the field
of embodied music cognition (Leman, Lesaffre, Nijs, & Deweppe, 2010) and in music education research (for an overview see e.g. Colwell & Richardson, 2002; Bresler, 2007), we adopt a methodological design approach that copes with three recent developments, namely, (1) a shift of focus from a subject who participates in an experiment to a user of tools, (2) a shift of focus from laboratory research to research in an ecological setting and (3) a shift from a mere qualitative approach to a combination of qualitative and quantitative research methods.

3.1 Embedding the Music Paint Machine in a pedagogical context

The pedagogical embedment of the Music Paint Machine implies the participation of active subjects whose actions contribute to relevant output that forms part of our study. Therefore, the active involvement while using specific technology-enhanced learning tools as well as the way this involvement is experienced become objects of the study (Leman et al., 2010). This means that our approach is practice-based and user-oriented in order to ensure the application’s relevance within the field of music instrument education. The purpose is to develop didactic practices with the Music Paint Machine, which are based on common findings of students and teachers who used the application. Qualitative methods are here used to analyse the users’ experience and the ideas that emerged from this experience (e.g. questionnaires), and as a means to exchange the experiential knowledge (e.g. focus groups). Furthermore, findings from the qualitative approach provide a solid basis for guiding the development of hardware (e.g. a coloured mat that allows the selection of colours for visual feedback) and software (e.g. the mapping of high and low pitch to high and low positions on the visual feedback). The goal is that throughout different developmental and experimental phases, a continual iteration between theory and practice and between research and user feedback is established. This can make sure that the conceptual design and its implementation into the necessary soft- and hardware are continuously informed by pedagogical reasoning. This process will lead to the design of good practices that will be tested empirically. Results will be compared to the theory behind it.

By adopting this design methodology, it is also possible to take into account the particular situation of the so-called part-time music education system, which is a specific form of non-compulsory educational system that is organized in music academies. This education system can be seen as an addition to the regular school education system (Tchernoff, 2007). Children and adults can follow it.

A characteristic aspect of this educational system, when seen in relation to the development of a technology-enhanced learning tool, is the existence of a wide gap between the practically oriented educational goals and the academic world. According to Woody (2001), this gap can be attributed to several misconceptions about academic research that exist among music teachers. For example, it happens that teachers are cautious and even reluctant towards academic research and the use of technology-enhanced learning tools in their proper educational environment. However, we believe that by involving teachers more closely in the design process of a technology-enhanced music-learning tool, it is possible to establish a close collaboration between researchers and teachers. Such an approach is adopted here, as we believe that a user-based development cycle may increase the relevance (ecological validity and impact; see also Welch, 2009) of the Music Paint Machine for music instrument education.

3.2 Bringing research into the field of practice

Our design method is largely determined by a gradual shift in focus from a laboratory setting to an educational setting (see also: Addessi & Young, 2009; Ilari & Gluschankof, 2009). An ecological approach of observing users in their habitual environment emphasizes the importance of understanding teachers’ and students’ concerns about technology-enhanced learning systems. At this early stage of development, a first trial with the use of the Music Paint Machine in an educational context has been conducted in music academies (73% of the tested population), under the guidance from the experimenter, as well as in the laboratory (27% of the tested population). Although this deployment of the Music Paint Machine in music academies is perhaps not yet fully ecological, we believe that the confrontation with context-dependent practical requirements has lead to results that contributed to the further development of the application in terms of its usability.

3.3 Combining qualitative and quantitative research methods

The methodological approach is furthermore characterized by a combination of qualitative and quantitative research methods. Traditionally, the effect of music education has been reflected in descriptions based on assessments that involve subjective interpretation. In addition to that approach, the new generation of technology-enhanced learning tools offers means to monitor the students’ performance using sensing technologies that provide them with more objective data on, for example, movement and sound. The data are objective in the sense that algorithms can extract higher-level features from the data. These features can provide both teacher and student with useful information when compared with other data (e.g. other students, of the student’s learning progress). New technologies
thus complement subjective measurement methods (e.g. questionnaires, video annotation, narrative analysis) with objective measurements (e.g. sound and movement analysis) that form part of the technology-enhanced learning tool.

However, to further ensure the relevance and the possible impact of the Music Paint Machine as a usable didactic tool in the field of instrumental music education, we believe that the research method can initially be qualitative. It means that, prior to the quantification of the learning process, it is important to gather and analyse qualitative data on the user experience of students and teachers. Specifically, we believe that answers to open questions in the questionnaire and information retrieved from the focus group can provide us with the necessary information that is needed to optimize soft- and hardware modules of the technological tool. By adopting qualitative methods in a user-oriented approach which is fully embedded in an educational setting, we believe that it is possible to ensure the application’s relevance for the naturalistic context and to design didactic practices that are acknowledged as useful for the daily practice of teaching and learning to play an instrument. Therefore, based on the findings that result from the qualitative approach, decisions will be made to refine the quantitative approach and make sure it leads to findings that are considered relevant for teaching practice.

Given the three characterizations that we described above with regard to our methodology, and how they fit with recent shifts in research attention, it is now possible to present an overview of the design methodology in Figure 1. The first module and starting point of the methodology is concerned with the conceptual framework that is based on teaching experience, on the musical instrument as embodied mediation technology and on the assessment of musical learning. The core of this framework is the practice of teaching. This aspect will be worked out in Section 4. The second module deals with the development of software and hardware and this will be discussed in Section 5. Finally, there is an experimental framework in which theoretical assumptions are empirically tested and users’ experience and evaluation of the didactic potential of the application are probed. This will be dealt with in Section 6.

4. Backgrounds and conceptual framework

The conceptual design of the Music Paint Machine is based on three backgrounds, namely, on teaching experience, on a theoretical investigation of the relationship between musician and musical instrument, and on research on assessment in part-time music education.

4.1 Daily teaching practice

The concept of the Music Paint Machine is partly influenced by the first author’s teaching experience as a clarinet and chamber music teacher in formal music instrument education. His teaching experiences, as well as the questions that arose from the daily interaction with students, were a source of inspiration for two of the Music Paint Machine’s essential aspects, namely visual performance feedback and the use of specific body movements.

The potential contribution of visual feedback to the development of a sense of musical feeling, and even the development of listening and playing skills, were first explored in the classroom by using waveform visualization in Audacity (http://audacity.sourceforge.net). It was found that visual feedback can reinforce the verbal and gestural feedback of the teacher by providing images that display information on what the student actually played (as sometimes opposed by what they ‘think’ of having played). Next to visual feedback, body movements and postures were used to learn specific musical and instrumental aspects of performing. Figure 2 shows an example of lateral movements with the instrument and the torso that were used to teach students to feel the timing of musical phrases. Figure 3 shows step exercises that were used to teach students to feel the metre of the music with its repetitive pattern of strong and weak beats. Based on this early intuition, it was possible to suggest essential features that a technology-enhanced system for music learning should possess and that could then be further refined and tested. Examples are: the mappings of body movement to a visual parameter, and the round design of the coloured pressure mat.

Fig. 1. Overview of the methodological approach. The concept of the Music Paint Machine is based on a conceptual framework that guided both the design of the system (hard- and software) and the establishment of the empirical framework. The findings from the experiment (e.g. empirical validation of constructs, user feedback) are used to refine the conceptual basis and to adapt the hard- and software in order to optimize the user experience.
4.2 The musical instrument as an embodied mediation technology

Apart from its grounding in teaching experience, the work on the Music Paint Machine has been inspired by the theory of embodied music cognition (Leman, 2007), including a viewpoint on the relationship between musician and musical instrument (Nijs et al., 2009). According to this paradigm, the body is a key component of musical meaning formation processes. What happens in the mind depends on properties of the body and therefore body and body movement have an impact on meaning formation. That way, the body acts as a mediator between experience and physical reality, allowing an engagement with music as some form of behavioural resonance. Given this viewpoint on the human body as a natural mediator, musical instruments can be considered as artificial extensions of the body. These instruments allow the mind to operate within a reality (namely the musical reality) that is otherwise not accessible. Therefore they can be considered as mediation technologies. But musical instruments not only open up new worlds, they also influence the way the body mediates experiences. Musical instruments require certain movements (sound generating gestures) and thereby possibly restrict the body in its freedom to move and freely resonate with the music. By doing this, they have a major impact on musical meaning formation. Therefore it is necessary to establish a relationship with the musical instrument that makes an embodied interaction with the music possible. The paradigm of embodied music cognition also highlights the multimodal nature of musical experience, which suggests that educational feedback in multiple modalities intensifies musical experience and learning processes (e.g. Ng, Larkin, Koerselman, & Ong, 2007; Yu, Lai, Tsai, & Chang, 2010).

Given this theoretical framework, the Music Paint Machine can be seen as an extension of the musical instrument and therefore, as a mediator that is fully connected to the player’s bodily engagement with music. For example, it integrates visual feedback on body movements and stimulates music students to explore the possibilities of their instrument and experiment with movement and musical parameters. By completing drawing tasks, movements can be used to elicit an embodied understanding of certain musical elements such as phrasing, dynamics and articulation (transition between notes or not). Because the Music Paint Machine offers the possibility to represent movement and sound in a common visual stimulus, it accommodates the multimodal nature of musical expression and involvement.

4.3 Flow, presence and a constructivist approach to assessment

Finally, as mentioned in Section 1, the concept of the Music Paint Machine is also based on the literature on flow experience (Csikszentmihalyi, 1990; Custodero, 2005) and on a constructivist approach to education (e.g. Pritchard & Woollard, 2010). This also led to a theoretical investigation of the assessment of flow within the context of the part-time music educational system, and the development of a model for a possible evaluation approach to music education (Nijs, 2008). This background in psychology and education was important for embedding the concept of the Music Paint Machine in a pedagogical framework and, together with the emerging views on assessment, for tailoring the design of the application to different didactic uses, such as experimentation (e.g. Olsson, 2009) and paintings as pedagogical documentation (Dahlberg, Moss, & Pence, 1999; Buldu, 2010).

Flow is defined as an optimal experience that occurs when a person experiences a balance between the perceived challenges of a situation and his or her skills or capabilities for action (Csikszentmihalyi, 1990). It implies that the subject is completely and from moment-to-moment involved in the ongoing activity to the point
of forgetting everything else except for the activity itself (time, personal concerns, instrument). Attention is given to the task at hand, and the person functions at his or her fullest capacity. Flow experience has been used in quite a number of studies on music education, with or without the use of interactive music systems (e.g. Custodero, 1997; Addessi et al., 2006). The presented research fits within this growing field of flow-related educational research.

To further elaborate on the concept of flow (see also: Riva, Waterworth, Waterworth, & Mantovani, 2009) and to refine the knowledge on how musicians interact with both acoustical instruments and technology-enhanced learning tools such as the Music Paint Machine, we also use the concept of presence. Presence can be defined as an internal psychological feedback system that does not involve conscious awareness and relates to a moment-by-moment self-monitoring of the behaviour (Welch, Howard, Himonides, & Brereton, 2005). In other words, presence informs a person whether actions are performed in accordance with his/her intentions and goals (Riva, 2008b; Riva et al., 2009). Up to now, the concept of presence has been mainly used in the domain of human–computer interaction (HCI) and virtual reality, where it is defined as ‘the feeling of being and acting in a world outside ourselves’ or ‘the feeling of being and acting “there”’ (e.g. Schubert, Friedmann, & Regenbrecht, 1999). When bodily sensations, perception and cognition coherently collaborate to keep attention focused on this outer world (‘there’), a maximal sense of presence is experienced.

We are not aware of any studies in which the concept of presence is used in the domain of music education and performance or in which a presence questionnaire is applied to probe subjective experience when using an interactive music system. However, we do believe that the concept of presence is useful to investigate the musician–instrument relation within the context of technology-enhanced learning, especially in the context of tool-development that addresses the enhancement of self-monitoring. We believe that an elaboration on this concept within the field of music research can significantly contribute to revealing the basic components of an embodied interaction during music performance (Leman, 2007; Nijs et al., 2009).

The conceptual framework that underlies the Music Paint Machine fully subscribes a constructivist approach to education. This approach emphasizes (i) the autonomy and self-regulation of the students in the process of learning, and (ii), the creation of powerful learning environments in which this autonomy can grow and the knowledge, skills, and attitudes associated with self-regulation can be acquired. It is exactly in this creation of the learning environment that the flow theory, in combination with the theory of embodied music cognition, corresponds with constructivism. Flow theory links to the constructivist idea of the learners' autonomy by attributing an important role to the personal experience and the way learners shape this experience through different behavioural strategies (Custodero, 2005). The theory of embodied music cognition adopts a specific viewpoint on the role of the human body and the technological tools used for interaction. These theories are linked with the idea that an optimal learning environment is created through an activity that is perceived as meaningful and challenging within reach of one's skills. Perceiving this balance between challenge and skills is achieved through the process of self-monitoring.

The Music Paint Machine is assumed to contribute to the establishment of such a powerful learning environment by providing students with a ‘phenomenarium’ (Perkins, 1992) that introduces learning as an active process in which meaning is constructed on the basis of experience. Thereby, it contributes to a learner-centred approach and promotes exploration and experimentation, both important aspects of a constructivist approach to education. It engages the student in an interactive loop between playing and visual output in which the visual output gives immediate and intrinsic feedback on movement and sound. Through this interactive process, it helps students to construct their own knowledge. It also provides students and teachers with an elaborated off-line feedback on their playing by showing different visualizations of the painting and data on movement (e.g. amount of movement) and sound (pitch, dynamics) by means of the integrated log system. Both the creative output of the Music Paint Machine and the off-line objective feedback, can function as important pedagogical documentation that makes the combination of product evaluation on the one hand and participatory and formative evaluation on the other possible (Dahlberg et al., 1999; MacDonald, 2007). Furthermore the paintings can be used for student portfolios and peer evaluation (e.g. Goolsby, 1995; Daniel, 2004).

5. Hard- and software: implementing the concept in a first prototype

5.1 Overview of the system

The Music Paint Machine allows a musician to make a painting on a computer screen by playing music and moving on a coloured mat (see Figure 4). Sound and movement are tracked, analysed and transformed into a visual output. The musician engages in an interactive loop between playing music and moving on the one hand and the visual output on the other hand. The system as presented in this section, is the result of the iterative process as described in Section 2.
5.2 System design

5.2.1 Motion sensor

The user’s movements are tracked using inertial measurement sensors. The motion tracker incorporates four sensors: an LY530AL (single-axis gyro), LPR530AL (dual-axis gyro), ADXL345 (triple-axis accelerometer), and HMC5843 (triple-axis magnetometer), resulting in nine degrees of inertial measurement. Individual sensor output is processed by an on-board ATmega328 using a Direction Cosine Matrix (DCM) to obtain the orientation of the motion tracker. The resulting orientation vector is then sent to the computer using a wireless Bluetooth connection. The motion tracker is powered by a 800 mAh Li ion battery, capable of providing power to the device for several hours. Everything is built into a small enclosure, measuring 7.5 cm × 5 cm × 2.5 cm, which can be attached to the back of the subject without restricting movement.

5.2.2 Coloured mat

The coloured mat consists of 16 pressure points that can be activated by stepping onto them. Twelve round pressure points represent the twelve different colours that can be chosen while playing. Their size equals the size of a CD (12 cm) and they are organized in a circular configuration (70 cm). Each of these pressure points consists of three monostable micro switches that are wired in parallel and establish a connection between a mass and its respective digital input on an arduino board. The latter is programmed to send changes in its state (the last button pressed) over the serial link to the computer. Four other monostable micro switches are positioned outside the circle of colours and serve additional functions (start, stop, erase, save). They are connected to the analogue input on the arduino board. Micro switches, wires and arduino board are embedded in a round MDF panel (115 cm).

5.2.3 Softwares

The software for the recognition and processing of sound and movement is programmed in MaxMSP, a graphical programming environment for real-time audio processing (M. Puckette & D. Zicarelli. Max/MSP. Cycling 74/IRCAM, version 5.0, 1990–2010). Pitch and amplitude of the sound are tracked by the Sigmund-object (Puckette, Apel, & Zicarelli, 1998).

The visualizations are programmed in Processing, an open source programming language and environment used to create images, animations, and interactions. The painting consists of a black canvas, projected onto the entire screen, and a round brush used to move inside this canvas. The brush has several parameters: position, radius, colour and transparency. These parameters are sent from Max/MSP to Processing using the OSC protocol.

5.3 Mapping

An important aspect of the Music Paint Machine is related to the idea that the unity of body and the acoustic musical instrument becomes the controller, i.e. a device

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1Sparkfun Razor 9DOF IMU AHRS: http://www.sparkfun.com/products/9623

2Processing 1.0, retrieved May 7, 2009, from www.processing.org
to control what happens on the screen. The visual display is the result of playing the instrument and at the same time moving the body in a way that is not limited to sound producing gestures. Accordingly, sound and movements are mapped to the visual domain (see Figure 5). Because producing the music is a question of playing the musical instrument, movement is not directly mapped to sound. However, by requiring additional movements to use the Music Paint Machine, the sound generation might be influenced (as it is in ‘normal’ playing) by the musician’s movement and this can change the visual output. Thereby, it can affect the interactive loop between music, movement and painting.

5.3.1 Mapping body movement

Two kinds of movement are central to the mapping of the Music Paint Machine: the movement of the torso and the movement of the feet. Movements of the torso are tracked with the motion tracker. After calibration, two parameters are extracted: the left–right orientation of the user’s torso and the amount of bending forward. Lateral movement (roll) of the torso determines the position of the paintbrush on the horizontal axis. When the torso is oriented to the right, painting goes from left to right and vice versa when the torso is oriented towards the left. Vertical movement of the torso (pitch) influences the opacity of the currently activated colour by increasing transparency when bending forward.

To activate colours, users move their feet on the coloured mat and step on the coloured pressure points. Numbers are sent to MaxMsp and associated in Processing with the colour of the pressure point.

5.3.2 Mapping musical features

Apart from the colour, the drawing direction and the transparency, all other drawing commands are determined by musical features. To block out the surrounding noise, wireless clip-on microphones are placed on the instrument. When no sound is produced, nothing is drawn on the screen. Consequently, a sustained note produces a horizontal line, while a very short note (e.g. staccato playing style) produces a dot. The vertical position of the paintbrush on the canvas is determined by pitch (notes). Therefore a melody produces a curved line. The stroke size of the paintbrush is determined by the loudness of what is played. The louder a user plays, the bigger the stroke size becomes.

5.4 Play modes

We foresee two ways to use the Music Paint Machine. A first play modus allows musicians to freely explore the combination of moving, playing and drawing. This is the play mode that has been used in the experiments discussed in this paper. We foresee a second play mode in which methodically designed learning paths (e.g. articulation, melodic contour, tone production) are implemented.

6. Experimental setup

An experimental protocol was established to investigate the Music Paint Machine’s potential to induce an optimal experience in the musician and to learn about the way musicians (both teachers and amateur musicians) evaluate the didactic potential of this application. In this paper, we report on experiments with amateur musicians as participants.

6.1 Participants

Fifty-one amateur musicians participated in the experiment. They were recruited through social network sites and through contacts with different music schools.

![Fig. 5. Overview of the mapping of movement and sound to the visualization. Movements of the feet and torso control colour, colour transparency and drawing direction. Sound parameters are mapped to vertical direction and stroke thickness.](image-url)
Furthermore, websites were created to inform possible participants on the experiment and to organize the sessions. All participants were informed about the procedure and participated on a voluntary basis.

Over two-thirds (68.63\%) of the participants were female. Their average age was 21 years and 78.4\% of them were under the age of 25. Participants’ main instruments are flute (31\%), saxophone (24\%), clarinet (16\%), violin (12\%) and a mixture of other wind instruments (17\%). They have been playing their instrument for 1–7 years (53\%) or longer (47\%). The majority (78\%) of them are currently following music lessons in the department of classical music within formal music education. Most participants play at least once a week at the music school (80.4\%). Furthermore, participants reported that they mostly (35\%) or even always (47\%) play music from a score. Over half of the participants stated that they never (18\%) or rarely (35\%) improvise. Most of the participants use the computer daily (56\%) or every two days (33.3\%). Computer applications for music are rarely used.

6.2 Materials and setting

The material that was used for the experiment comprised the Music Paint Machine and its components (i.e. coloured mat, computer, motion sensor, clip on microphones). The computer screen was projected onto the classroom wall or screen using a beamer. Two digital video cameras were used: one videotaped the musician, the other the screen.

Experiments were mostly conducted in music schools, involving 73\% of the participants. Amateur musicians, who no longer followed instrument lessons and therefore were not able to attend the sessions in schools, tested the Music Paint Machine at the research lab (27\%). Apart from the different locations, material and setup used were identical.

6.3 Procedure

Prior to the experiment, a pilot study involving students (n = 9) and teachers (n = 6) was conducted to refine the methodology. Results from this study lead to the refinement of pre- and post-questionnaires. The timing for testing the application was set to 10 min of actual testing, based on observatory information gained during the pilot study and on inspection of the video recordings.

The actual experiment consisted of three sequential parts. During the first part, participants were first asked to fill in a background questionnaire. Participants were requested to answer general questions related to age and gender. They also had to specify to what extent they agreed with statements about their musical background and their computer use. A non-forced seven-point Likert scale was used to do this. A final set of questions probed participant’s personality, based on the Dutch version of the Big Five Inventory (Denissen, Geenen, van Aken, Gosling, & Potter, 2008). These questionnaires were done prior to the actual testing during which participants performed with their musical instrument while interacting with the Music Paint Machine. Because this experiment involves the testing of a prototype technology-enhanced learning tool, we assumed that personality might play a role in the way the Music Paint Machine is experienced and in how its didactic potential is evaluated.

During the second part, the Music Paint Machine was tested. Firstly, participants were informed on how to use the system so that they could learn about the mapping of the system. This step included the calibration of the system according to the skills of the player, such as the adaptation of the screen resolution to the range of notes the participant could play or the adaptation of the brush size to the dynamical range of the participant’s playing capabilities. Finally, the participant was allowed to test the system for 10 minutes. The task was formulated as follows: ’Please draw one or more paintings on the screen, by playing music with your instrument and by moving on the coloured mat’. It was clearly said that they could draw whatever they wanted, whether figurative or abstract and that the label of bad or good was not applicable to the paintings. Within the given 10 minutes, each participant could try out the tool and ‘draw’ one or more paintings by playing their instrument, depending on their personal way of completing the task. This part of the experiment was videotaped.

During the third part of the experiment, participants were asked to fill in a post-questionnaire with three sets of questions. The first two sets of questions aimed at measuring the quality of their subjective experience (dependent variable) while playing music and interacting with the Music Paint Machine (independent variable) to make a painting. The first set comprised the questions of the Flow State Scale (Jackson & Eklund, 2004). The second set of questions, the Presence State Scale, was designed on the basis of the presence factors as defined by Witmer and Singer (1998). Finally, a third set of questions was asked to learn more about the way participants evaluate the didactic potential of the Music Paint Machine (dependent variable) after having experienced playing with it (independent variable).

The Flow State Scale (Jackson & Eklund, 2004) probes the participants’ experience with the system by means of 36 questions that can be grouped into nine dimensions of flow experience (Csikszentmihalyi, 1990). These nine dimensions can be grouped into conditions, characteristics and consequences (Chen, Wigand, & Nilan, 1999). The scores of these dimensions are combined to measure an overall scale that represents the flow state of the participant (see Table 1). The Flow State Scale questionnaire (Jackson & Eklund, 2004) was translated into Dutch. We used a seven-point Likert scale
ranging from ‘completely disagree’ to ‘completely agree’. Both the consistency of the results (when comparing individual questions and dimensions) and a Cronbach’s alpha test ($\alpha = 0.921$) confirmed the reliability of the questionnaire.

The Presence State Scale probes the participants’ experience with the system by means of 20 questions that were based on the presence factors as defined by Witmer and Singer (1998) (see Table 2) and elaborated on control, distraction, sensory experience and realism of the system. We used a non-forced seven-point Likert scale from ‘completely disagree’ to ‘completely agree’. Cronbach’s alpha for this questionnaire was 0.610. Therefore it is important to further refine the presence questionnaire for future experiments and to optimize its internal consistency. Following the Flow State Scale procedures, we calculated an overall score for Presence, the Presence State Scale (PrSS).

A third series of questions was devoted to the didactic possibilities of the Music Paint Machine. Questions focused on improvisation, creativity, listening skills and feedback. We are aware of the fact that the actual didactic potential of the system does not necessarily coincide with the perception and opinions that teachers and students might have about the didactic potential of the system after having experienced the prototype once. However, we acknowledge and value the students’ and teachers’ practical knowledge as a basis for an evaluation of the system. Additionally, some students ($n = 8$) participated in an exploratory focus group and were asked to discuss the didactic potential of the Music Paint Machine.

**6.4 Data analysis**

Statistical analysis of all questionnaire data was performed using PASW 18.0. The aim of the analysis was to gather knowledge (1) on the users’ experience while being engaged in the interactive loop between playing music, moving and drawing when using the Music Paint Machine.
Machine in its explorative modus (no specific drawing or musical tasks) and (2) on their evaluation of this application’s didactic potential. The data analysis process involved descriptive statistics (e.g. background, didactic potential), correlation and regression analysis of flow and presence and variables. Analysis was performed on the level of individual variables (e.g. enjoyment, focus of attention), groups of variables (e.g. flow dimensions, presence factors) and total scores (e.g. Flow State Scale, Presence State Scale). The non-parametric Spearman’s rank correlation test was used to cope with deviations from normality. Furthermore linear regression was used to compare groups of variables with calculated total scores.

7. Results

7.1 Flow experience

The scores of the Flow State Scales varied from 3.63 to 6.59 on a seven-point Likert response format from strongly disagree to strongly agree. The moderately high overall mean (5.06, SD = 0.7) indicates that the Music Paint Machine is likely to have the potential to turn the experience of playing music, moving and drawing, into an optimal or flow experience. A statistical analysis of flow experience aimed at finding the components that need to be considered when developing this application.

Firstly, scores for individual flow variables were compared, using the non-parametric Spearman’s rank correlation test to look for significant associations. To select the most important associations between variables, rank correlations were considered to be significant when \( p < 0.05 \). They were considered to be strong when \( r_s > 0.600 \) and moderate when \( r_s > 0.400 \).

Secondly, a descriptive analysis was done on the level of dimensions. Table 3 clearly shows that the dimensions 1 (balance between skills and challenge), 5 (focused attention), 7 (loss of self-consciousness) and 9 (autotelic experience) have the highest scores. These results indicate the Music Paint Machine has the potential to elicit a fun experience in which musicians can play with the system at every skill level. This means this application can be used for all grades, from beginner to advanced student. Apparently using this application makes attention very focused, even to the degree that one loses self-consciousness.

However, one of the core aspects of the Music Paint Machine, namely providing clear and immediate feedback, receives a lower score (\( M = 4.44, SD = 0.95 \)). The dimension of ‘clear goals’ had the lowest score (\( M = 4.12, SD = 1.12 \)). This is possibly the result of the explorative character of the experiment. They could play, move or draw in whatever way they wanted. Although participants could set their own goals (e.g. ‘I will draw my name’), receiving no specific tasks may have contributed to the fact that participants scored still positive but lower for this dimension. In order to see how the possible lack of clear goals affected the other flow dimensions, we first performed a Shapiro–Wilk normality test. Only the dimensions of ‘loss of self-consciousness’ and ‘concentration on the task at hand’ were not normally distributed.

To determine the relationship between the normally distributed dimensions, Pearson correlation tests were performed and showed different significant relationships between flow dimensions. Significant positive relationships were found between ‘clear goals’ and ‘Unambiguous and immediate feedback’ (\( r = 0.734, p < 0.001 \)), ‘sense of control’ (\( r = 0.555, p < 0.001 \)) and ‘merging of action and awareness’ (\( r = 0.541, p < 0.001 \)). This means that the lack of clear goals has an effect on the way feedback is experienced and to what degree one feels in control of the system. Furthermore, ‘merging of action and awareness’ was significantly positively correlated to ‘Unambiguous and immediate feedback’ (\( r = 0.612, p < 0.001 \)) and to ‘sense of control’ (\( r = 0.788, p < 0.001 \)). Because ‘merging of action and awareness’ is the flow variable with the second most strong positive correlation with the Flow State Scale (\( r = 0.799, p < 0.001 \)) and because of the strong correlation between clear goals, unambiguous feedback and sense of control, further use of the Music Paint Machine needs to take into consideration the setting of clear goals.

To see how both non-normally distributed dimensions affected the other dimensions, Spearman’s rho test was used. Results did not show significant correlations with the other dimension, only a moderate but significant positive association between ‘concentration on the task at hand’ and ‘loss of self-consciousness’ (\( r_s = 0.410, p = 0.003 \)).

Table 3. Means and standard deviations (SD) of the scores for flow dimensions, categories and scale. Results indicate the application’s potential to elicit a fun experience in which musicians can interact with the system at every skill level.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Challenge/skill balance</td>
<td>5.19</td>
<td>0.86</td>
</tr>
<tr>
<td>2. Clear goals</td>
<td>4.12</td>
<td>1.12</td>
</tr>
<tr>
<td>3. Unambiguous and immediate feedback</td>
<td>4.44</td>
<td>0.95</td>
</tr>
<tr>
<td>4. Merging of action and awareness</td>
<td>4.18</td>
<td>1.47</td>
</tr>
<tr>
<td>5. Concentration on the task at hand</td>
<td>6.05</td>
<td>0.90</td>
</tr>
<tr>
<td>6. Sense of control</td>
<td>4.75</td>
<td>1.28</td>
</tr>
<tr>
<td>7. Altered time perception</td>
<td>5.09</td>
<td>1.26</td>
</tr>
<tr>
<td>8. Loss of self-consciousness</td>
<td>5.77</td>
<td>1.00</td>
</tr>
<tr>
<td>9. Autotelic experience</td>
<td>6.03</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Characteristics

Conditions

Consequences

Flow State Scale

9.07 0.70
The findings described above not only confirmed the internal consistency of the Flow State Scale questionnaires, they also reveal the variables (e.g. ‘clear goals’) that can be influenced and therefore used as dependent variables in forthcoming experiments.

Thirdly, the categories of flow conditions, characteristics and consequences were measured in the same way as the Flow State Scale, that is, by calculating the average of the dimensions that belong to each category. The Shapiro–Wilk test for normality was then used to provide us with evidence to use a simple linear regression analysis. It was found that flow conditions (independent variable) significantly predicted flow characteristics (dependent variable) scores ($b = 0.793$, $t(49) = 6.731$, $p < 0.001$). Flow conditions also explained a significant proportion of variance in flow characteristics scores ($R^2 = 0.48$, $F(1,49) = 45.3$, $p < 0.001$). Furthermore, flow characteristics (independent variable) predicted flow consequences (dependent variable) scores ($b = 0.322$, $t(34) = 2.740$, $p < 0.001$). Flow characteristics also explained a significant proportion of variance in flow consequences scores ($R^2 = 0.18$, $F(1,34) = 7.51$, $p < 0.001$). These results empirically confirm the categorization of flow variables into the three dimensions of conditions (when flow can occur), characteristics (what happens when it occurs) and consequences (effects of flow).

Because it was assumed that the participants’ background might influence their subjective experience, we carried out a Spearman’s correlation test in order to look for possible correlations between background and flow variables. Results showed moderate negative correlations. However, considering the non-normal distribution of participants’ age, the same procedure was applied to all participants under the age of 25. The results for all participants were confirmed and additionally some correlations became stronger and more significant. In Table 4, we present an overview of these results.

The same procedure was followed to detect possible correlations between musical background (which instrument the participant played, for how many years, in what kind of situation they mostly play or whether they use scores or rather play by heart or improvise) and flow variables. Results show no clear correlations between the instrument that was played and flow experience. This means that the Music Paint Machine can be used with many different musical instruments. Moderate but significant negative correlations were found between the fact that a participant was still following lessons and the dimensions of ‘challenge/skill balance’ ($r_s = -0.278$, $p = 0.048$) and ‘merging of action and awareness’ ($r_s = -0.301$, $p = 0.032$). Participants who were still following lessons tended to score higher for these dimensions. We followed the same procedure for participants under the age of 25. Most importantly, the correlation between the fact that a participant was still following lessons was stronger and more significant for two flow dimensions, namely ‘challenge/skill balance’ (under 25: $r_s = -0.422$, $p = 0.007$; all participants: $r_s = -0.278$, $p = 0.048$) and ‘sense of control’ (under 25: $r_s = -0.413$, $p = 0.008$; all participants: $r_s = -0.244$, $p = 0.084$). Even if a large majority of the participants rarely or never improvise or play by heart, previous experience with both was not significantly correlated to the different flow variables.

### 7.2 Presence factors

For the analysis of the presence questionnaire data, the following steps were undertaken: (1) a descriptive analysis and Spearman’s rank correlation test for the scores of individual questions, (2) the Pearson correlation test to assess the relationship between the different presence factors, (3) the Spearman’s rank correlation test to test for correlations between background variables and presence variables, and (4) the Pearson correlation and Spearman’s rank correlation tests and simple linear regression analysis to find associations between flow and presence variables.

First, an analysis of the individual variables was done. A descriptive analysis showed that, although three quarters of all participants (76.5%) felt the need to get used to the application before they could really manage it, 43.1% of all participants nevertheless disagreed that the Music Paint Machine requires a long learning process before being able to use it spontaneously. By far the most

<table>
<thead>
<tr>
<th>Table 4. Spearman’s correlation coefficients for the relationship between age and flow dimensions and scale. Results suggest that the fun factor of the application is age-related: the younger participants were, the more likely they had a fun experience.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flow</strong></td>
</tr>
<tr>
<td><strong>all participants</strong></td>
</tr>
<tr>
<td><strong>Clear goals</strong></td>
</tr>
<tr>
<td><strong>Unambiguous</strong> and <strong>immediate feedback</strong></td>
</tr>
<tr>
<td><strong>Merging of action and awareness</strong></td>
</tr>
<tr>
<td><strong>Sense of control</strong></td>
</tr>
<tr>
<td><strong>Altered time perception</strong></td>
</tr>
<tr>
<td><strong>Autotelic experience</strong></td>
</tr>
<tr>
<td><strong>Conditions</strong></td>
</tr>
<tr>
<td><strong>Characteristics</strong></td>
</tr>
<tr>
<td><strong>Flow State Scale</strong></td>
</tr>
</tbody>
</table>
participants (92%) stated that they succeeded in drawing something on the screen in different ways and 72.5% even felt they could do what they wanted. It was encouraging to see that three quarters of the participants (76.5%) experienced the mapping of movement and sound to the visual output as natural. Nevertheless, only 43.1% of participants found that the actions necessary to draw do not deviate too much from the way they normally play their instrument and 41.2% stated that using the Music Paint Machine requires a mental effort. This can be explained by the fact that there was no learning phase included in the experiment. Finally, 90.2% reported that the Music Paint Machine stimulated them to be more creative with musical parameters.

To assess the relationship between the different presence variables, Spearman’s rank correlation coefficients were calculated. The strongest positive correlations were found between the need to get used to the system and the feeling that ‘a long learning phase is necessary’ (\( r_s = 0.549, p < 0.001 \)), between ‘it felt natural to use the system’ and ‘the system responded well to one’s actions’ (\( r_s = 0.491, p < 0.001 \)), between ‘the ability to predict the effect of one’s actions’ and the experience that ‘the coupling between actions and effects felt natural’ (\( r_s = 0.563, p < 0.001 \)), between ‘it felt natural to use the system’ and the fact that ‘mediating technologies did not distract attention from the task at hand’ (\( r_s = 0.607, p < 0.001 \)) and the experience that ‘the coupling between actions and effects felt natural’ (\( r_s = 0.536, p < 0.001 \)) and finally between the feeling that ‘a long learning phase is necessary’ and the feeling that ‘using the system requires a mental effort’ (\( r_s = 0.626, p < 0.001 \)). Strong negative correlations were found between the feeling that ‘the system responded well to one’s actions’ and the feeling that ‘a long learning phase is necessary’ (\( r_s = -0.541, p < 0.001 \)) and the feeling that ‘using the system requires a mental effort’ (\( r_s = -0.597, p < 0.001 \)). These results suggest that (1) the immediacy of the visual feedback strongly influences the way the system is experienced, (2) it is important that the used technologies do not require too much attention and (3) the mapping makes sense.

Secondly, we performed an analysis of the presence factors and the presence state scale. To calculate the presence state scale, scores for questions on learning phase, abnormality of task-related aspects and attention were reversed. Next, the averages of the scores related to the different factors were calculated to determine the scores of the presence factors. The presence state scale was calculated by averaging the presence factor scores, following the same procedure as the calculation of the flow state scale score. In Table 5, the mean and standard deviation for the different presence factors and the overall presence score or presence state scale are presented. The factor with the highest score (\( M = 5.13, SD = 0.82 \)) is the realism factor. This factor is related to the way in which participants experienced the system with regard to the mapping of movements and sound to visual effects. It also refers to the degree to which users experience the system as stimulating creativity with musical parameters. These results indicate that no important changes in the current mapping are necessary.

The Shapiro–Wilk test for normality enabled us to make use of the Pearson correlation test to assess the relationship between the different presence factors. Results show a strong positive correlation between control factors and realism factors (\( r = 0.578, p < 0.001 \)) and a moderate correlation between sensory factors and distraction factors (\( r = 0.364, p = 0.012 \)). It is interesting to learn that the presence state scale shows a significantly strong correlation with the control factors (\( r = 0.833, p < 0.001 \)) and the realism factors (\( r = 0.686, p = 0.001 \)). This means that mapping (realism factor) and the ability to exert a fine-grained control over the different parameters (control factor) are determinant aspects of engaging with the Music Paint Machine.

Thirdly, we assessed relationships between presence and background because, as is the case with flow experience, we assumed that background variables might influence the subjective experience of the participants. Regarding the total number of participants (\( N = 51 \)), Spearman’s correlation test showed significant negative correlations between the control factor and age (\( r_s = -0.388, p = 0.005 \)) and between the control factor and whether a participant was currently following lessons (\( r_s = -0.319, p = 0.022 \)). Perhaps counter intuitively but in line with the Music Paint Machine’s goal to make the application suitable to all skill levels, the control factors were not positively correlated with the number of years that participants had been playing their instrument but results showed a weak but nevertheless significant correlation (\( r_s = -0.290, p = 0.005 \)). We are of course aware that the number of years does not necessarily say something about the skill level. On the other hand, we found a positive correlation between the sensory factor and number of years playing the instrument (\( r_s = -0.481, p = 0.001 \)). Because of the non-normal distribution of age and participants following

<table>
<thead>
<tr>
<th>Scale</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control factors</td>
<td>4.51</td>
<td>0.99</td>
</tr>
<tr>
<td>Sensory factors</td>
<td>4.56</td>
<td>0.63</td>
</tr>
<tr>
<td>Distraction factors</td>
<td>4.64</td>
<td>0.81</td>
</tr>
<tr>
<td><strong>Realism factors</strong></td>
<td><strong>5.13</strong></td>
<td><strong>0.82</strong></td>
</tr>
<tr>
<td>Presence State Scale</td>
<td>4.69</td>
<td>0.45</td>
</tr>
</tbody>
</table>
lessons or not, we applied Spearman’s correlation test to the scores of participants that were under 25 and still following lessons. Correlations were confirmed, became slightly stronger but the significance of the probability was lower. It is worthwhile to mention the fact that within this subset an additional moderate but statistically significant correlation was found between the amount of time participants played from the score and the presence control factor \((r_s = 0.449, \ p = 0.006)\). This is rather remarkable because, apparently, people who are not used to improvising, felt nevertheless in control over the system regardless of the fact that they were actually improvising. Again this corresponds to one of the aims of the Music Paint Machine, that is, introducing painting as a familiar activity to lower the threshold for an activity one is not familiar with, namely improvising. In order to determine correlations between background and presence, the experiment has to be repeated with participants that are older than 25, that don’t follow lessons anymore and that are familiar with improvisation and with playing by heart.

Fourthly, relationships between flow and presence variables were investigated. Regarding individual variables, we found many significant associations between flow and presence questions by using the Spearman’s rank correlation test, which indicates a close relationship between both kinds of subjective experience. The presence variables that often correlated (positively or negatively) with individual flow variables were ‘mediating technologies did not distract attention from the task at hand’ (non-mediation), ‘the coupling between actions and effects felt natural’ (natural mapping) and ‘using the system requires a mental effort’ (cognitive load). To assess the relationship between flow and presence variables at higher levels, we compared individual presence variables to flow dimensions and to the Flow State Scale. Spearman’s rank correlation coefficients were calculated and showed many significantly moderate to strong correlations, confirming the relationship between flow and presence as qualities of participants’ subject experiences (see Table 6).

The results of comparing individual variables with each other and with the flow dimensions (means of individual variables) were mirrored in significant correlations between flow dimensions and two presence factors, namely the control and realism factors. This means that the concept of presence, i.e. an unconscious action monitoring system that informs the agent whether actions are under control, can be used to elaborate on the control dimension of flow. The correlation between

Table 6. Spearman’s correlation coefficients for the relationship between individual presence variables and flow dimensions, categories and scale. Results empirically validate the theoretically elaborated relationship between the concepts of flow and presence.

<table>
<thead>
<tr>
<th>Presence variables</th>
<th>Flow dimensions</th>
<th>Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>feeling of being able to do what one wants to do the system responded well to one’s actions perceived ability to predict effect of actions it felt natural to use the system feeling successful in drawing in different ways attention directed to screen attention directed to musical instrument mediating technologies did not distract attention from the task at hand the mapping of the system felt natural using the system requires mental effort</td>
<td>0.357</td>
<td>0.453</td>
</tr>
</tbody>
</table>
flow and the realism factor points at the importance of the way a tool is experienced to allow for flow to occur in a tool-mediated activity. Finally, Pearson’s correlation test revealed a significant strong correlation between the Presence State Scale and the Flow State Scale ($r = 0.506$, $p < 0.001$). To further assess the relationship between both scales, a simple linear regression was performed after the inspection of the corresponding scatter plot and a Shapiro–Wilk normality test. The Presence State Scale (independent variable) significantly predicted the Flow State Scale (dependent variable), ($b = 0.815$, $t(45) = 3.934$, $p < 0.001$). The Presence State Scale also explained a significant proportion of variance in the Flow State Scale, ($R^2 = 0.256$, $F(1,45) = 15.5$, $p < 0.001$). These results confirm the relationship between both variables and support the link between both concepts. However, further experiments are necessary to learn more about their exact relationship.

7.3 Didactic potential

To rate the practical relevance of the application, questions about the didactic potential of the Music Paint Machine were included in the questionnaire. From the answers to these questions, we learned that most participants (78.4%) agreed that the visual feedback (what happens on the screen) has an added value and that it gives useful feedback on what and in which way they play (78.4%). Slightly fewer participants (74.4%) say that the visual feedback can help them to pay more attention to musical parameters. A remarkably large group reported that it could help them to understand these parameters better (80.4%) and to use them more prominently (84.3%). A number of participants stated that the required movements (turning left–right, bending, step with feet) interfere with their playing technique (33.3%) and their musical expression (23.5%). Because the different instrument groups show different means for the scores of these variables, one might be tempted to conclude that the scores of these variables are instrument related. However, the samples are too small for some groups to make this conclusion. More than two thirds (70.6%) of all participants think that an application like the Music Paint Machine might help them to learn how to play a musical instrument. Interestingly, most participants who acknowledged the application’s potential to stimulate learning to play an instrument, also believed that the application stimulates one to discover the instrument’s possibilities (97.2% or 88.2% of all participants), to experiment with these possibilities (91%), to discover music (86%), to experiment with musical parameters (91% or 80.4% of all participants), to experiment with body movements (86.1% or 84.3% of all participants) and to experiment with what happens on the screen, i.e. the visual feedback or output (94.4% or 94.1% of all participants).

Spearman’s rank correlation test did not show significant correlations between flow variables and variables concerning didactic potential, except from the fact that ‘autotelic experience’ shows some weak-to-moderate but significant correlations with several variables on didactic potential. This might indicate that having fun with the Music Paint Machine influenced the way participants evaluated the didactic potential of the application.

When comparing presence variables with variables on didactic potential, Spearman’s correlation coefficients indicated weak-to-moderate but significant correlations between individual variables and between presence factors and variables on didactic potential. A significant moderate negative correlation was found between the presence control factors and the participants’ evaluation of the visual feedback as disturbing ($r_s = -0.419$, $p = 0.002$) and the participant’s evaluation of the movements as disturbing musical expression. This means that when visual feedback and movements were experienced as disturbing, participants experienced less control.

8. Discussion of the correlation study

8.1 The subjective experience

The results suggest that the Music Paint Machine has the potential to induce a particular experience that is relevant within an educational context and that can moreover be probed with questionnaires about flow and presence. This is an important finding for several reasons. First of all, it shows that the tool, and in particular the feedback provided by the tool, does not hinder the user to be fully involved with the music. The fact that flow and presence score high suggests that the tool is able to provide students with intrinsic (task-related) feedback that is embedded in the experience of playing music and making a painting (cf. merging of action and awareness). Furthermore, the tool provides an immediate and highly responsive feedback (cf. control factors) that seems to support engagement and motivation (cf. autotelic experience). Both the aforementioned elements and the Music Paint Machine’s additional possibility to provide offline feedback are essential aspects of intrinsic feedback. This finding supports therefore our hypothesis that self-monitoring can be enhanced by technology and that it has the potential to become fully integrated within an education context.

Secondly, the results about flow experience suggest that the tool has a potential to cope with the user’s personal skill level. This result is reflected in the fact that the number of years that participants played their instrument was not a determining factor for the occurrence of flow. A feedback system that would not be able to cope with different skill levels is likely to show
The Music Paint Machine

more variance in flow experience among its users because the tool’s feedback would somehow occur as an obstacle for music playing, hence flow would be expected to be low. Moreover, even if most participants had almost no experience in improvising, they were able to experience flow to a certain degree while the task involved an activity they were not familiar with, namely improvising. None of the participants used a score and few of them played melodies from memory. This would suggest that the tool has a potential to stimulate improvisation.

Thirdly, the results suggest that another aspect of flow, namely the importance of clear goals and immediate and unambiguous feedback, is highly appreciated. It is known from the literature that flow can occur when goals are clear every step of the way and when feedback is immediate and unambiguous (Addessi & Pachet, 2005). Considering the monitoring capacities of the application, this is a crucial quality that can be attributed to the straightforward nature of the mapping from audio and movement to visual feedback. This mapping can be further explored but these first results indicate that a natural feel of the feedback in relation to music is an important flow-generating factor of the present tool. Moreover, the results show a strong correlation between the two flow dimensions, namely ‘clear goals’ and ‘unambiguous and immediate feedback’. This confirms the importance of working with clear musical tasks and clear mappings in order to see whether feedback is effective.

The above results support the idea that when experiencing flow, there is less psychic energy invested in conscious self-monitoring. In such a state, the self-monitoring of action is processed at a subpersonal level that still enables one to discriminate between self-determined and world-determined changes in input (Russell, 1997). Therefore, with a view to stimulating these intrinsic feedback mechanisms, it is important that the technology-enhanced learning tool allows unconscious self-monitoring so that one can keep on concentrating on the action while playing the musical instrument instead of being engaged in an additional monitoring of the action while playing.

The self-monitoring of action is captured in the notion of presence, which is a mechanism that unconsciously compares the intended outcomes of an action to its actual outcome. Results from our experiment suggest a strong correlation between the occurrence of flow and presence. Thereby they support the idea that combining the concepts of flow and presence offers a valuable framework for probing the subjective experience that makes effective learning possible. In particular when learning is supported by technology enhanced tools. Indeed, while flow rather pertains to attention and focus in relation to skills, presence is more related to the interaction with the tools (e.g. acoustic musical instrument, a technology-enhanced learning tool) that are involved in the activity. Probing presence therefore informs on the degree to which a tool allows focusing on the task at hand and thereby disappears from consciousness (illusion of non-mediation). It is exactly this aspect that fully complies with the concept of embodied music cognition and the idea that the technology-enhanced learning tools can be developed as genuine mediators, that is, tools that connect to and even become a natural extension the human body (Leman, 2007; Nijs et al., 2009). In that sense, the Music Paint Machine can be seen as an extension of the musical instrument that is itself an extension of the human body. Therefore we believe that the concept of presence can offer an interesting extension of the flow concept, in particular to elaborate the control dimension of flow with regard to the use of technology-enhanced learning tools. The close relationship between both qualities of a subjective experience implies that soft- and hardware adaptations that optimize the system in function of the presence factors, will also positively affect its flow potential. That way it contributes to the embedding of feedback in the performance experience. An important related finding is the correlation between the control factors and realism factors. It confirms the importance of finding a good mapping between music, sound and movement. In the case of the Music Paint Machine, results show that the mapping is experienced as natural. Moreover, even if using the Music Paint Machine requires movements that one does not normally do while playing most instruments, this is not experienced as being too disturbing.

With regard to the probing of the participants’ subjective experience, it is important to point out that the sample data (e.g. age, following lessons, background in improvisation) have a non-normal distribution. In forthcoming experiments participants will be selected in order to obtain a more balanced sample structure. Another aspect that needs to be taken into account is the explorative nature of the participant’s task for the experiment. In the present experiment, participants could draw whatever they wanted, and consequently, their goals were not always very clear. Some people actually asked the researcher (who was behind the computer) ‘What should I draw?’ Presumably, this has affected the interactive loop and their evaluation of the visual output as possible feedback. Therefore, in forthcoming experiments, we may consider more concrete tasks, such as draw a ‘wave’. Such specific tasks may enable us to verify to what extent certain drawing tasks influence musical understanding. It might be that the use of certain drawing tasks is effective in allowing the musician to better understand the playing technique in relation to different musical parameters.

To conclude: so far, the results show that the concepts of flow and presence can be used to probe the subjective experience with the Music Paint Machine in such a way
that relevant information can be obtained about the conditions that would make an efficient learning process possible. However, we have not yet been able to prove that learning becomes more efficient with than without the Music Paint Machine. Nevertheless our first results suggest that the conditions for efficient learning to occur are present.

8.2 The didactic potential

In this experiment, we also probed how participants estimate the didactic potential of the Music Paint Machine. Obviously, one should make a clear distinction between the user’s estimated didactic potential, and the veridical didactic potential, as the user may not always be able to estimate the learning effect while learning. Therefore, these results should be considered as indicative and less reliable. However, despite this difficulty, we believe that with regard to the importance of embedding the development of a technology-enhanced music learning tool within a pedagogical context, it is of interest to know what musicians, whether they are professional or amateur, whether they are teacher or not, consider the possible value of this application in music instrument lessons to be. We also believe that feedback from future users is essential for the development of the tool as a relevant didactic tool. The veridical didactic potential of this learning tool can only be tested by measuring learning effects. At this stage of the research, the latter was not yet feasible, but we believe that this approach may already provide us with interesting information for further development.

In any case, the results show a high degree of agreement about the Music Paint Machine’s didactic potential. The main finding is that the Music Paint Machine stimulates exploration of and experimentation with body movements, music and visual output. This is an important finding in view of using the Music Paint Machine as a support for an constructivist approach to music teaching and learning. Furthermore, participants agreed mostly that this application could be helpful for learning to improvise. Because exploration, experimentation and improvisation are often neglected in traditional music instrument lessons (Van Regenmortel & Strobbe, 2010), the Music Paint Machine can play a complementary role by providing an engaging and motivating experience.

9. General discussion

The development of a technology-enhanced learning tool for music education requires combining engineering skills, pedagogical expertise, and musico-logical insights into the nature of instrumental use and subjective experiences that can set the ground for effective learning.

We believe that the Music Paint Machine project has initiated a proper way of thinking about how music education can be made more efficient with a technology-enhanced learning tool. Yet, we are not yet able to scientifically prove that learning to play music is indeed more efficient with than without the Music Paint Machine. What we can show so far is that the Music Paint Machine does not seem to hinder the playing, and perhaps promotes the conditions for efficient learning to take place. With that result in mind, it is important to reflect on the central contribution of a technology-enhanced learning tool for music education, namely the role of self-monitoring in learning and technology-enhanced learning with the Music Paint Machine.

9.1 Exploration and experimentation to promote self-monitoring

In a constructivist approach to education, exploration and experimentation by the student are essential components of the learning process. These processes provide a creative space in which basic skills can be developed autonomously. Research on expertise indeed indicates that learning becomes more efficient with a technology-enhanced learning tool. Yet, we are not yet able to scientifically prove that learning to play music is indeed more efficient with than without the Music Paint Machine. What we can show so far is that the Music Paint Machine does not seem to hinder the playing, and perhaps promotes the conditions for efficient learning to take place. With that result in mind, it is important to reflect on the central contribution of a technology-enhanced learning tool for music education, namely the role of self-monitoring in learning and technology-enhanced learning with the Music Paint Machine.

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a sophisticated but unconscious form of monitoring of action and experience (Riva, 2008a). It is a control mechanism that tracks variations in subjective experience (breakdown or optimal experience). When no variations are sensed, all attention can be devoted to task related feedback and it becomes possible to be completely absorbed in the task. When this is the case, feedback is embedded in the performance and becomes intrinsic. Therefore, it is important to create powerful learning environments in which a carefully designed learning path integrates exploration and experimentation and provides students with engaging experiences. The goal of the technology-enhanced learning tool is thus to intervene in these processes in such a way that self-monitoring is enhanced.

9.2 New technologies and the role of real-time visual feedback

The development of new sensor technologies has led to the design of tools that aim at enhancing learning by real-time visualizations of different aspects of the performance. For example, a wide range of applications uses visual feedback to develop singing skills (e.g. Hoppe et al., 2006; Howard et al., 2004). Other applications aim at extending the music score with annotations that give feedback, for example, on accuracy and intonation (e.g. Kun, 2004; Fober, Letz, & Ortlarey, 2007; Johnson & Han, 2009). Visual feedback is also used in learning tools that address music conducting (e.g. Borchers, 1997), learning to improvise (e.g. François, Chew, & Thurmond, 2007), and developing musical expressiveness (e.g. Dixon, Goebl, & Widmer, 2005). An important and recent development is the design and implementation of monitoring tools that support the learning process by measuring the instrumental gestures and posture of for example string players (e.g. Schoonderwaldt, Hansen, & Askenfeld, 2004; Ng, Larkin et al., 2007; Schoonderwaldt & Wanderley, 2007). In other words, being able to give visual feedback on music performance and on learning is a rather common goal, and it has been used in many different applications.

The introduction of visual feedback in music instrument lessons by using monitoring technologies has indeed several important advantages. A first advantage is the ability to complement the interpersonal feedback processes between teacher and student. Interpersonal feedback always involves a certain ambiguity (Welch et al., 2005) which real-time monitoring systems can ignore to a certain degree. This more ‘objective’ feedback may reduce the possible misinterpretations of discontinuous (e.g. comments after playing) or even of continuous (e.g. the teacher playing or singing along) feedback from the teacher by providing students and teachers with a more immediate and unambiguous feedback.

A second advantage of visual feedback is that it can contribute to the students’ goal imaging, their motor production skills and finally, their self-monitoring skills. By engaging students in an interactive loop with the visual feedback, they get stimulated to autonomously set and adapt goals. Motor production can then be fine-tuned on the basis of self-monitoring processes in which these goals and motor production are compared on the basis of feed forward models and intrinsic feedback.

However, despite the possible benefits, the integration of monitoring tools in instrumental didactics must be undertaken with some precautions. In the first place, it is important that the use of these technologies goes further than merely providing information. Providing students with feedback on their playing by means of monitoring technologies can still support traditional ways of teaching that consolidate a teacher-centred approach. What matters is the way in which this information is used to help students developing the necessary self-monitoring skills.

It should be added here that the visualization of aspects of the learners’ performance as a continuous concurrent feedback is not undisputed. Although its essential role in skill acquisition is acknowledged and shown in different studies (Shea & Wulf, 1999; Wulf, Shea, & Matschiner, 1998), other studies show that continuous concurrent feedback can also degrade learning (Schmidt & Wulf, 1997).

A possible explanation for the differences in findings on the effect of continuous feedback might be that it depends on how the feedback is presented and to which degree it fits both the learning context and the learners. Augmented feedback needs to engage learners in an immersive experience that enables them to get intrinsic feedback and that motivates the learner. Furthermore, it must be used in situations were users find it difficult to use intrinsic feedback because of a lack of experience (e.g. no experience with improvising). It must be avoided that the learner becomes dependent on the feedback. Therefore, we believe that it is important to develop the technology-enhanced learning tool in a proper pedagogical context and in combination with concepts that justify its development and testing at long term. With the Music Paint Machine, these concepts are rooted in a constructivist pedagogy, the theory of embodied music cognition and how medication technologies relate to the human body, and in concepts of flow and presence, which allow the probing of the subjective experiences that may determine the learning effect.

9.3 The Music Paint Machine: exploring a novel way of monitoring

The Music Paint Machine complements existing applications such as developed in the project I-Maestro (Ng, Larkin et al., 2007) or sound visualization systems (e.g.
Ferguson et al., 2005) by exploring new ways of visualizing monitoring data in agreement with informed theories of music cognition and pedagogy, such that a visual feedback system can be optimized for enhancing imagination and musicality. The Music Paint Machine introduces a game-like experience in which the musician creates an artistic output based on the music that is played and the movements that are used. Starting from the viewpoint that a symbolic representation of objective feedback on a computer screen might just as well give rise to a disembodied way of dealing with the feedback, the Music Paint Machine provides students and teachers with feedback that is also based on objective measurement of sound and movement but is represented as a creative output (the painting). Seemingly monitoring is not the primary use. However, because of the mapping of music and movement to a visual representation, and because this mapping is based on a monitoring of the performance, monitoring is an essential element. The slightest variations in movement and sound affect the visual output and thereby address the musician’s goal setting, motor production and self-monitoring. For example, when the musician’s goal is to draw a straight line that becomes thicker, but the output shows a slightly curved line, self-monitoring is essential to adapt motor production (playing technique) in function of the goal. This may cause a breakdown in the experience and call for a reflective moment during which it becomes apparent that playing louder caused a small change in pitch. In this case, self-monitoring is conscious. However, when the musician is completely absorbed in the act of creating a visual output with music and movement, he/she will engage in an interactive loop between actions and visual output. Self-monitoring will be based on the unconscious processing of intrinsic feedback. As long as the player’s skills and the challenge remain in balance, dynamically setting goals and adapting motor production in function of these goals will, on the one hand, be based on the direct perception of task-related feedback and, on the other hand, rely on the skills of the musician. Over time, we believe that the frequent use of the Music Paint Machine may establish a set of action–perception couplings that form part of the musician’s toolbox of creativity. Challenged by the myriad of possibilities for the transformation of movement and sound into an artistic output, musicians will be pushed to the boundaries of their musical abilities.

10. Conclusion

In this paper, we described our approach of designing a technology-enhanced learning tool, called the Music Paint Machine. This tool aims at enhancing music performance skills by using concurrent visual feedback that is based on real-time monitoring of audio and movement. The approach is practice-based and has a firm ground in the theoretical frameworks of embodied music cognition, of flow and presence, and of educational constructivism. Furthermore, it involves an empirical framework that is set up to initiate an iterative process between theory, practice and soft- and hardware development. In this empirical framework, the collaboration between researchers, teachers and students is very important. We presented the first series of experiments that probe the subjective experience of students and their evaluation of the application’s didactic potential. The results show that the Music Paint Machine copes with positive assessments of flow and presence, which suggest that it potentially may become a tool that enhances music learning.

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