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HOW CAN REAL TIME VISUAL FEEDBACK SUPPORT LEARNING AND PERFORMANCE OF MUSICAL ARTICULATIONS IN HIGHER EDUCATION PIANO LESSONS?

COMO O *FEEDBACK* VISUAL EM TEMPO REAL PODE AUXILIAR A APRENDIZAGEM E PERFORMANCE DE ARTICULAÇÕES MUSICAIS EM AULAS DE PIANO NO ENSINO SUPERIOR?[2-3]

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Abstract

Recordings of well-known piano performances have been analysed through technology-generated MIDI data — offering insights into certain features of performance, such as timing, dynamics, articulation, and pedalling — nevertheless, the application of digital technologies to the actual process of studio-based piano learning and teaching remains under-re- searched. A research study conducted in Brazil explored the use of visual feedback alongside three teacher-student pairs in the higher education context. An action case approach was conducted and a qual- itative multiple data analysis method was adopted. The technology feedback system involved a digital piano connected to a laptop computer running Digital Audio Workstation (DAW) software via a Musical Instrument Digital Interface (MIDI) interface and an additional computer screen. Three related datasets were collected: (i) digital video recordings of the piano lessons (n = 6), (ii) audio recordings of semi-structured interviews with participants (n = 12) and MIDI data saved in the DAW software. This paper presents the results of the analysis of observational data and MIDI data where the piano lesson focus was to work on musical articulations on the piano. The types of articulation addressed in this paper were finger *legato* in the *Alberti*'s bass performance, melodic conduction in chords and arpeggios, and finger synchrony in chords. Findings suggest that when subtle aspects of articulation are made visible to both teacher and student using this technology system, both become more aware of these issues. In addition, when visual feedback is used, the lesson focus can be

Resumo

Gravações de performances conhecidas têm sido analisadas por meio de programa *Digital Audio Workstation* (DAW) — oferecendo *insights* sobre aspectos da performance, como variações de tempo e de dinâmica, a articulação e o uso do pedal — no entanto a aplicação de tecnologias digitais em aulas de piano ainda é pouco pesquisada. Uma pesquisa conduzida no Brasil explorou o uso de *feedback* visual gerado por tecnologia por três duplas de professor-aluno de piano no contexto do ensino superior. Um estudo de caso-ação foi conduzido e um método de análise de dados qualitativos múltiplos foi adotado. O sistema de tecnologia aplicado era composto por um piano digital conecta- do a um notebook (computador portátil) rodando um programa DAW por meio de uma interface MIDI (Musical Instrument Digital Interface) e uma tela de computa- dor adicional. Os dados coletados foram: (i) observações de aulas de piano registra- das em vídeo (n = 6), (ii) entrevistas semies- truturadas com os participantes gravadas em áudio (n = 12) e (iii) dados MIDI salvos no programa DAW. Este artigo apresenta os resultados da análise de dados obser- vacionais e de dados MIDI, onde o foco na aula de piano foi trabalhar as articulações musicais no piano. Os tipos de articulação abordados neste artigo foram o *legato* de dedos na performance de baixo *d'Alberti*, na condução melódica em acordes e em arpejos, e na sincronia dos dedos em acordes. Os resultados sugerem que, quando os aspectos sutis da articulação ao piano tornam-se explícitos visualmente para professor e aluno, ambos se tornam mais conscientes dessas questões. Além disso,

clearer, and discussions between teacher and student become more effective.

Keywords: Piano performance analy- sis, musical articulations, finger *legato*, vi- sual feedback technology-enhanced piano learning.

quando o feedback visual é utilizado, o foco da aula pode tornar-se mais claro e as discussões entre professor e aluno mais eficazes.

Palavras-chave: Análise da perfor- mance ao piano, articulações musicais, *legato* de dedos, *feedback* visual, aprendi- zagem de piano mediada por tecnologia.

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Introduction

This article is an excerpt from Hamond (2017) doctoral research in relation to the use of visual, combined with auditory, feedback applied in two piano lessons in higher education. In this article, it is argued that the use of real-time visual feedback generated by technology can enhance student learning and musical performance for aspects of articulation in their repertoire in one-to-one and face-to-face piano lessons in higher education. The concept of feedback is central to this paper. Feedback is a crucial aspect in enhancing learning. Wiener (1961) was the first author to use the concept of feedback to describe information about a variable which can be controlled (Schwartz; Andrasik, 2003). In educational settings, feedback involves information about student performance or understanding; it can be delivered by another individual such as the teacher or peer, by the individual themselves, and/or through an external source such as technology (Hattie; Timperley, 2007). Feedback is an essential aspect in motor control and learning (Magill, 1989; Schmidt; Lee, 2011), in classroom educational settings (Hattie; Timperley, 2007), and in music education, particularly in instrumental and vocal learning and teaching (Bryan, 2004; Burwell, 2010; Gaunt, 2007, 2009, 2011; Kostka, 1984; Siebenaler, 1997; Speer, 1994).

In the field of motor control and learning, feedback can be augmented through the use of technology where learners can enhance learning by watching their own recorded performances, or a graphic representation of performances while being assisted by their coaches (Magill, 1989; Schmidt; Lee, 2011). In the field of music education, technology can enhance learning (Himonides, 2012) such as in the Higher Education (HE) music studio (King, 2008), in the music classroom (Savage, 2007) and in instrumental or vocal learning (Zhukov, 2013). There is also evidence that the application of technology can enhance learning, since students can become more conscious of their own performances through self-assessment and the intrapersonal feedback system (Carey; Grant, 2015b; Daniel, 2001; Welch, 1985; Welch; Howard; Rush, 1989; Zhukov, 2010).

Feedback in one-to-one lessons involves intrapersonal feedback from the sensory system as well as interpersonal feedback between teacher and student. Intrapersonal feedback in piano learning and playing has been investigated for an increasing number of research studies in the last few decades which looked at the roles of auditory, visual, and proprioceptive feedback in piano studies, such as in sight-reading, memorisation, rehearsal or performance, ensemble synchronisation, and in learning unfamiliar pieces (e.g. Banton, 1995; Bishop; Goebl, 2015, 2018; Furuya; Soechting, 2010). Intrapersonal feedback also involves other internal mechanisms such as aspects of conscious-awareness (Acitores, 2011; Damasio, 2000; Jeannerod, 2006), self-regulation skills (Nielsen, 2001), metacognitive knowledge (Schraw; Dennison, 1994), and sense of self (Damasio, 2012). These previous studies in intrapersonal feedback have been crucial in understanding which types of feedback are inherently meaningful to the piano student, as well as in understanding variations in conscious-awareness of intrapersonal feedback in piano playing.

Interpersonal feedback has been customarily used by teachers to inform students about what can be improved in their performance, or in their technical or interpretative

playing. This feedback can be general (positive, negative, or ambiguous) or specific. Feedback has been frequently examined in studies that investigate the interaction between teacher and student in instrumental lessons (Benson; Fung, 2005; Burwell, 2010; Duke; Buckner, 2009; Speer, 1994; Siebenaler, 1997; Welch et al., 2005). A synthesis of verbal and non-verbal feedback types in instrumental and vocal learning and teaching resulted in several subcategories (Hamond, 2017; Hamond; Welch; Himonides, 2019; Hamond; Himonides; Welch, 2020). In verbal feedback, these subcategories include giving guidance, asking questions, providing information, giving verbal feedback (positive, negative, or neutral), and commenting on other topics. In non-verbal feedback, there are subcategories such as playing along, modeling (playing or singing), imitating the student's performance, making hand gestures, giving non-verbal feedback (smiling, nodding or shaking the head in agreement or disagreement, making facial expressions), conducting, or tapping the pulse.

Although one-to-one instrumental and vocal learning has the advantage of providing personalised learning, the teacher dominates most of the time (Creech; Gaunt, 2012), especially in the master-apprenticeship model (Hallam, 1998; Jørgensen, 2000). Research studies in instrumental and vocal learning and teaching in HE has demonstrated that teachers expect their students to be independent and have a degree of autonomy over their learning (Carey; Grant, 2015b; Gaunt, 2007), while students expect their teachers to use teaching strategies to develop their (the students') autonomy and independence as learners (Carey; Grant, 2015b; Gaunt, 2009). Since teachers generally dominate one-to-one tuition (Bryan, 2004; Creech; Gaunt, 2012), modelling seems to be a predominant practice; as a result, students feel dependent on the teacher playing for their learning, and do not appear to develop their autonomy as they had expected (Carey; Grant, 2015b). One way to address this challenge in one-to-one music tuition is the use of technology which can bring about transformative change in this traditional teaching style (Creech; Gaunt, 2012).

Interpersonal feedback also involves feedback mediated by the technology. The use of technology was found to be valuable in most of the research studies reported in piano and other-than-piano learning. Audio recording (ZHUKOV, 2010), video recording (Daniel, 2001; Boucher et al., 2021), MIDI technology through piano roll graphs (Riley, 2005; Tomita; Barber, 2008), knowledge of results (KR) and variability of practice (Welch, 1985), real-time visual feedback (Welch, Howard; Rush, 1989; Welch et al., 2005), computer-based feedback (JUSLIN et al., 2006), and several instructional media technologies (Benson, 1998) were considered to have benefits for instrumental and vocal learning. Particularly relevant benefits included the use of technology to increase conscious-awareness of performances (Daniel, 2001; Riley, 2005; Tomita; Barber, 2008; Zhukov, 2010), and to develop student autonomy and responsibility for learning through self-evaluation, self-reflection and critical thinking (Carey; Grant, 2015a; Riley, 2005; Zhukov, 2010).

The application of real-time visual feedback (RTVF) in the HE singing studio in the UK supported specific aspects of voice learning and varied across teachers in their individual pedagogical approaches and lesson time spent using technology (Welch et al., 2005). However, the type of visual representation of RTVF has an effect on the performance outcome when students imitate a rhythmic pattern in percussion learning (Brandmeyer, 2006). Furthermore, the imitation can be more accurate for dynamics (loudness) rather than duration (timing) (Sadakata et al., 2008). RTVF in piano-related studies indicates the potential of recently designed technological devices for prospective applications in piano performance (McPherson, 2013), and experimental uses in piano improvisation (François et al., 2007). Apart from Welch et al. (2005), previous studies do not appear to have applied technology-mediated feedback in a real-world HE context. However, there is a need to examine the use of technology-mediated feedback in HE piano learning and teaching in a live learning context, with a teacher working alongside a student in their lessons.

Analyses of musical performances have been conducted through technology-generated MIDI data which seemed to have a relationship with certain musical performance parameters such as timing, dynamics, articulation, and pedalling (e.g. Bernays; Traube, 2014; Bresin; Battel, 2000; Palmer, 1989; Repp, 1994). This musical performance analysis was possible because of the technology-generated data derived from the application of MIDI technology to computer-controlled pianos. In these studies, MIDI data were used in order to analyse recorded piano performances quantitatively by relating articulation, timing, dynamics or pedalling through analysis to MIDI parameters that reveal data about pianist keyboard and pedalling activity (e.g. Bernays; Traube, 2014; Bresin; Battel, 2000; Palmer, 1989; Repp, 1994). By using digital technologies, aspects of piano performances can be analysed for quantitative analysis, by looking at inter-onset-interval (IOI), key overlap time (KOT), and key detached time (KDT) (Bresin; Battel, 2000; Palmer, 1989). However, a qualitative analysis of MIDI parameters, by looking at MIDI note colours, sizes, note asynchrony and overlaps, can inform piano teachers and students about aspects of musical performance they aim to improve. These previous studies provide insights for this research by suggesting an association between MIDI parameters and those of musical performance. This article, therefore, focuses on the application of real-time visual feedback generated by technology in piano lessons, aiming to understand pedagogical approaches to enhance musical articulation in students' piano performances who were practicing classical sonatas in the context of higher education. Different types of musical articulation were addressed, including finger *legato* in the performance of the *Alberti*'s bass, voice leading within chords, arpeggio playing, and finger synchronization within chords.

Materials and Methods

This study adopted an action case approach (Braa; Vidgen, 1999), using a hybrid research approach, encompassing elements of case study (Stake, 1995; Yin, 2014), and action research (Kemmis, 1993). For Braa and Vidgen (1999, p. 44), an action case approach reflects 'a method that is a hybrid of action research (intervention) and soft case study (interpretation)'. The case studies here are three teacher-student pairs in HE piano studio, while the intervention is the application of assistive technology facilitated by the researcher (lead author). The characteristics of action case study approach as stated by Braa and Vidgen (1999) therefore make this approach the most appropriate for this study.

Participants

The participants were three piano teachers and their students who had been working together on a regular weekly basis for at least two years in an HE institution in Brazil. Case study A consisted of a teacher and second instrument piano student, while case studies B and C consisted of a teacher and their first instrument piano students. All students had chosen a movement of a classical sonata to work on in this study.

All teachers had long-term experience in teaching the piano, in giving live performances and in CD recording. At the time of data collection (January 2014), they also had previous experience of applying digital technology in their lessons through videos of world-class pianists (teacher A, female, 51 years old), and audio or video recordings student performance using iPad or mobile phones (teacher B, female, 53 years old; teacher C, male, 43 years old). Students of case studies A (male, 25 years old) and B (female, 23 years old), and to a lesser extent student C (male, 30 years old), had previous experience with technology such as playing a digital piano, and audio or video recording their own performances as a self-study aid. Consent to take part in the study was also received from teacher and student participants[1].

Materials

The set of materials used in this study can be classified into two: (1) materials used to apply technology-mediated feedback in piano lessons; and (2) equipment used to collect data through video observation, technology-generated MIDI data, and interviews.

[1] The study involving human participants was reviewed and approved by the Ethical Advisory Committee of the UCL Institute of Education (University College London). Written consent to take part in the study was also received from teacher and student participants. Using the British Educational Research Association (BERA, 2011) guidelines, participants were informed in advance about the nature of the current research study and the confidentiality of data pertaining to this research study.

The first list of materials encompassed: one digital piano (Yamaha Clavinova CVP-403); two MIDI cables (THE SSSNAKE SK366-3-BLK MIDI); one laptop computer (SONY VAIO) running Cockos' Reaper DAW software with piano roll screen option via a MIDI interface (MIDISPORT 1X1 USB); one additional PC screen (LG FLATRON W1943SE) to be placed in front of the piano student; and one VGA cable to connect the laptop computer and the additional PC screen.

The second list of equipment included two digital cameras (SONY HDR-CX280E handy cam), two tripods for the digital cameras for the video data collection, and one voice recorder (a Zoom H1 Handy Portable Digital Recorder) for the interview data collection. MIDI data were collected when the Reaper projects were saved in the software DAW.

Regarding to the use of DAW software, particularly Cockos' Reaper (http://www.reaper.fm/), the teachers reported they did not have experience with this program whilst students of case studies A and B reported they had experience in using DAW software, for the purposes of music production, i.e., for recording, editing, processing, mixing and mastering. In addition, the three pairs teacher-student reported they had never experienced a technology system like this used in the study in their piano lessons in the HE context. The technological system was chosen because it can provide both a recording and playback of the performance-related data generating piano roll visualizations on the computer screen. Through this system, the keyboard and pedalling activity of the teacher or student when playing the piano can be recorded and reproduced as faithfully as possible in lessons. In addition, this set of materials appears user friendly and affordable; this would allow it to be adopted in a piano studio by HE teachers and even by their students themselves.

Data collection

In the main research (Hamond, 2017), three related data sets were collected: digital video recordings of the piano lessons (n = 6), semi-structured interviews with participants after each piano lesson (n = 12) and technology-generated MIDI data through the use of DAW software. Although the completed research (Hamond, 2017) to have involved the three data, this paper will focus on reporting research outcomes of the data analyses of observational data (videoed lessons) and MIDI data where the articulation was the piano lesson focus with teacher-student pairs.

The video data were collected by recording two piano lessons of the regular teacher-student pairs working on a chosen memorised piano piece, a movement of a classical sonata. The technology was facilitated by the researcher and author of this article. The MIDI data were collected through the recordings of performance-related data in DAW software Cockos' Reaper whilst participants played the chosen piece in each piano lesson. The MIDI data were saved on the laptop computer as projects in the DAW software for each case study and each piano lesson.

Data analyses

Data analysis in this study involved a qualitative multi-method approach for video and MIDI data, and case triangulation to enhance trustworthiness (Flick, von Kardoff, & Steinke, 2004; Guba, 1981; Shenton, 2004). Thematic analysis (Braun & Clarke, 2008) was used to analyse transcriptions of the video data. A CAQDA software package, QSR International NVivo10, was used to assist in analysing the videoed lessons such as to transcribe, edit and code data, as well as for promoting storage, searching and retrieval of data (Flick, 2009).

Video QDA (qualitative data analysis) revealed verbal and non-verbal behaviours, including feedback, and musical performance parameters, particularly related to articulation, which were observed in each lesson with the teacher-student pair. The purpose of MIDI QDA was to gain a clearer understanding of additional visual feedback used in piano lessons by looking at piano roll visualisation of the keyboard and pedalling activity on the digital piano. MIDI (QDA) revealed information about student's performance of articulation by looking at the synchronies and asynchronies of MIDI notes available on the computer screen.

Digital piano keyboard and pedalling activity were recorded using DAW software whilst the student, teacher, or both participants were playing the chosen piano piece. When participants played the piece, the performance-related MIDI data were being recorded using the DAW software and presented visually in piano roll form as a black and grey Reaper interface. This feedback was called real-time visual feedback (RTVF) and it was used by participants when looking at the computer screen whilst playing.

In addition, the previously recorded performance-related MIDI data for the keyboard and pedalling activity could also be played back to the participants using the DAW software. When played back, the recorded performance-related data were presented in piano roll form as a coloured Reaper interface with gradations from green to red. This feedback was called post-hoc visual feedback (PHVF) and it was used by participants when looking at the computer screen and/or listening back to the recorded performance whilst not playing.

Thus, additional visual feedback was available, simultaneously, to both teacher and student in two forms: in real-time and post-hoc. Although both types of feedback were available to participants, this article was focused on the understanding of the role of realtime visual feedback for enhancing articulation when performing a movement of a classical sonata in HE piano lessons.

Results

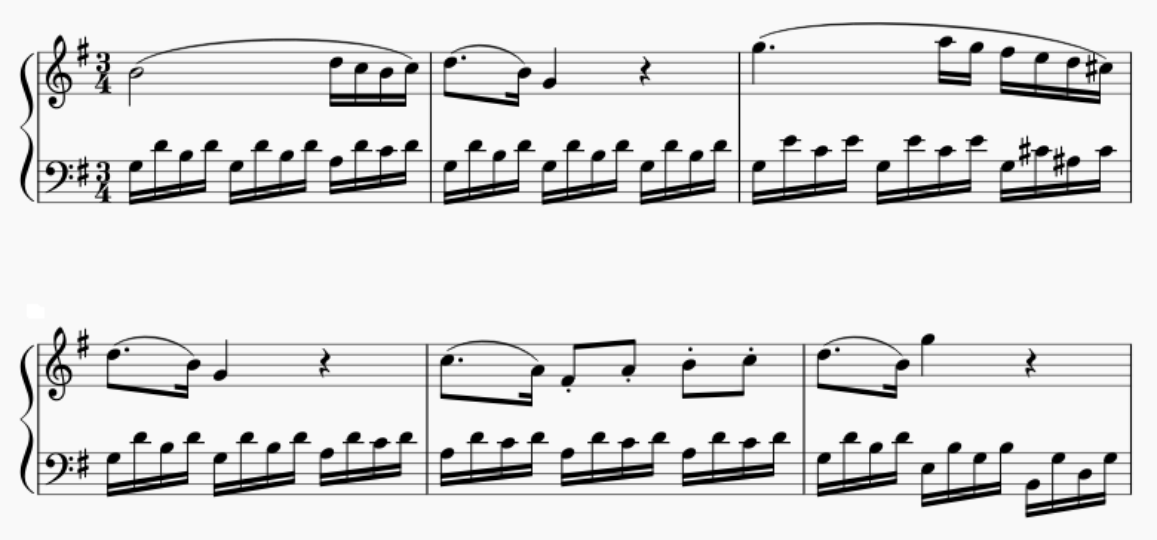
The type of additional feedback used by participants when they were looking at a computer screen while playing the piano is real-time visual feedback (RTVF).The application of RTVF by participants served two prime functions. First, RTVF was used by students to meet their individual learning needs as the lesson unfolded, as demonstrated by case study A. Second, RTVF was used as shared experience when the teacher worked alongside the student to assist their learning needs as in case study B. RTVF was not available to participants if a teacher requested this whilst

students were playing. There was no evidence that case study C used the RTVF generated by this technological system in piano lessons. Next, evidence of how the use of RTVF can have an effect on piano articulation learning and performance in higher education piano lessons is presented.

Real-time visual feedback (RTVF): individual use led by the student

RTVF was used individually by the student in case study A. The teacher-student pair chose to work on the second movement of the Mozart Piano Sonata No. 16 in C major, K. 545, (Figure 1). The student used RTVF with regard to articulation when playing the *Alberti*'s bass for the left hand in bars 1-4 of the chosen movement. By the time the research was conducted, the teacher had already given information about *legato* for the bass d'*Alberti* left hand in lessons prior to conducting this research. However, the student was only able to understand the feedback given by the teacher when using this technological system. The lesson 1 lasted 1 hour and 13 minutes while lesson 2 lasted 1 hour and 4 minutes.

Figure 1: Mozart Piano Sonata No. 16 in C major, K. 545, fragment, second movement, bars 1-6 (adapted from Hamond, 2017, p. 242).



The student used RTVF as an individual experience whilst playing rather than using it as a shared teacher-student experience. This happened in lesson 2 when the student had become more familiar with the technology. By examining non-verbal behaviours in videoed lesson 2, the student looked at the computer screen in real-time 31 times whilst playing (lesson 2, coded 8'25" – 15'33"). The student also reported monitoring his left-hand articulation whilst using RTVF when he discussed it with his teacher in lesson 2. In addition, the student demonstrated engagement with the technology through verbal behaviours combined with observed non-verbal behaviours, such as looking at the screen, pointing to the screen, making gestures alongside the computer screen interface and making associations between his playing and the visual feedback available on

the computer screen. The implications of the use of RTVF for individual learning needs by the student are illustrated by examining exchanges of verbal and non-verbal behaviours between teacher and student in lesson 2 (lesson 2, coded 26'16" – 27'33").

In lesson 1, the teacher fedback that the student was holding his fingers 5 and 3 of the left hand too long on the keys when playing the *Alberti*'s bass. In lesson 2, when asked by the teacher, 'Is there anything you have noticed there (looking at the screen) that you hadn't realised before? Something positive that you can say: "Ah, that I did it right, it worked out!"?', the student replied that RTVF was used to monitor articulation of the left hand:

> It's cool, you can see it like this, in real time, right (**S** *looking at the screen*, **S** *pointing to the screen, laughs*). Because… when you're playing, you don't have a time marker to guide you, right? Here there is [a time marker]! It is running, like this. (**S** *looking at the screen*, **S** *gesture alongside interface/timeline in real-time*).

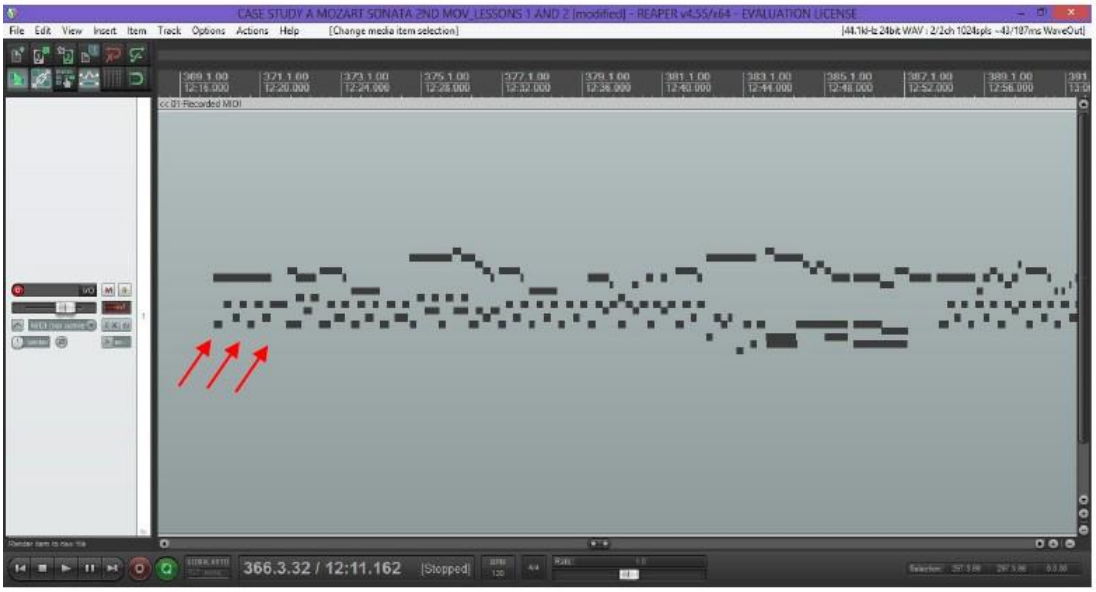
The student explained how he used RTVF for his learning needs in articulation of the left-hand *Alberti*'s bass by relating the explanation to the visual feedback available to him, as follows:

> Because I see the duration of one note (**S** *placing hands on the piano*), I see the duration of other note, then I can calculate, like this, (**S** *looking at the screen*) the distance [here]. (**S** *pointing to the screen*). So, it is a minimal thing, but when you play alone you don't have it, it's only you with yourself.

It was evident that the use of RTVF in case study A's piano lessons had an effect on student learning and performance of Alberti's bass articulation in the span of just two lessons. Student keyboard activity could be seen in the visualisation available on the DAW software interface which showed the MIDI notes corresponding to the musical notes. Differences in articulations performed by the student in lesson 1 and in lesson 2 can be associated with the sizes and asynchronies between the MIDI notes corresponding to the musical notes of the *Alberti*'s bass. In lesson 1, left hand activity overlapped indicating that the student was holding the piano keys too long as perceived by the teacher (Figure 2). In lesson 2 most of the MIDI notes did not overlap but were in a more consecutive mode indicating that the student was playing *legato* as requested by the teacher (Figure 3). This improvement in performance between lessons 1 and 2 suggests that the student was more aware of how his *legato* was being played, i.e., that he was holding keys too long when playing. The left hand *legato* for the *Alberti*'s bass was enhanced when the student was conscious of how he was playing, by seeing overlapping or consecutive MIDI notes in RTVF and by associating with the desired articulation or not. By using the visual information that the computer screen was providing, the student changed his behaviour and improved his piano articulation performance.

Figure 2: DAW software screenshot focusing on articulation in case study A, lesson 1. Key: The arrows show MIDI notes corresponding to the left-hand activity of student playing in holding notes too long in case study A, lesson 1 (Hamond, 2017, p. 242).

Figure 3: DAW software screenshot focusing on articulation in case study A, lesson 2. Key: The arrows show MIDI notes corresponding to the left-hand activity of student playing in a more consecutive mode indicating *legato* articulation (Hamond, 2017, p. 243).



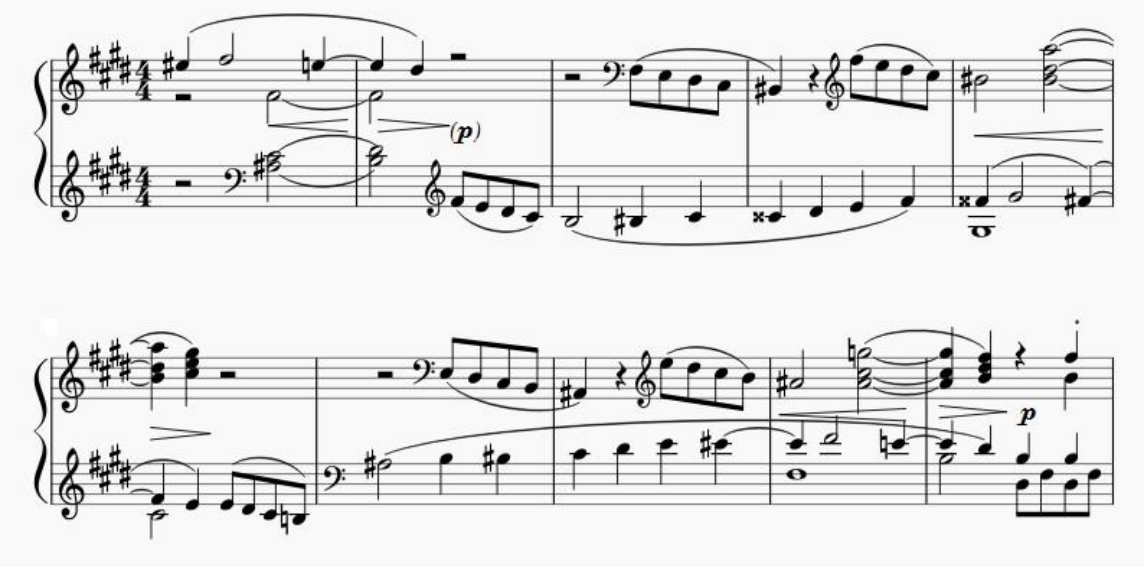
The use of the RTVF was individual by the student in case study A. Through the use of the RTVF, the student became aware that he was holding fingers 5 and 3 on the keys for a longer time when playing the *Alberti*'s bass and improved the articulation of the left hand. Although the teacher provided information to the student on about this articulaton issue, the improvement in the student's performance only occurred through the student's perception and association between what was happening on the computer screen — visual feedback — and the way the student was playing. The application of RTVF in case study A seemed related to personal interaction with the technology in order to meet individual needs.

Real-time visual feedback (RTVF): the teacher working alongside the student

RTVF was used as a shared experience between the teacher and student in case study B. The teacher used the additional RTVF alongside the student to make the student aware on specific aspects of articulation of student's performance. The teacher had already noticed some articulation issues through listening to the student's performance and these issues were confirmed by the graphic representation available on the computer screen. RTVF was applied in case study B in order to improve the student's performance for three aspects of articulation: (1) finger *legato* for top notes between chords; (2) holding fingers too long when playing arpeggios; and (3) chord attack and release. The teacher-student pair chose to work on the first movement of the Beethoven Piano Sonata No. 9 in E major, Op. 14, No. 1. Lesson 1 was 48 min long whislt lesson 2 was 43 min long.

The first application of RTVF happened in lesson 1 (38'31" - 44'39") as the teacher-student pair worked on the articulation of finger *legato* between the top notes of chords in the right hand in bars 33-34 and bars 37-38 of the chosen sonata movement (Figure 4).

Figure 4: Beethoven Piano Sonata No. 9 in E major, Op. 14, No. 1, fragment, first movement, bars 29-38. (adapted from Hamond, 2017, p.245).



In lesson 1, the teacher had noticed visualizations available on the computer screen and began to make associations between visual feedback generated by the technology and aspects of musical performance related to articulation. There was evidence of teacher engagement with the technology through some observed non-verbal behaviours such as: looking at the computer screen in real-time and pointing to the computer screen – behaviours not commonly used in a conventional piano studio. Teacher B used RTVF alongside other types of feedback (verbal and non-verbal) commonly used in conventional piano lessons, i.e., without using this technology, such as playing (modelling), singing, saying the name of notes, using gestures for expressing articulation, and pointing to the score.

The excerpt of lesson 1 below (39'29"- 40'36") illustrates the lesson episode that the teacher was using RTVF with the student as a shared experience[2]. Figure 5 shows the screen capture of the DAW software at the time of lesson 1 where the focus was on performing the finger *legato* of the upper notes of chords. The RTVF shows that there were no overlaps of the upper MIDI notes demonstrating that there was no connection between the fingers in the intended finger *legato* performance.

S *playing* **T**: Now [pay attention to the] right hand…

S *playing* (**T** *singing*, T saying ta-ta-ta, **T** *gestures for note support*, **S** *looking at the screen in real-time*)

S *playing*

T: No, no, no.

T: Can you see? Do not disconnect…

S: Uh huh (**S** *looking at the screen in real-time*)

S *playing* **T**: That's right. Mainly from A to G...

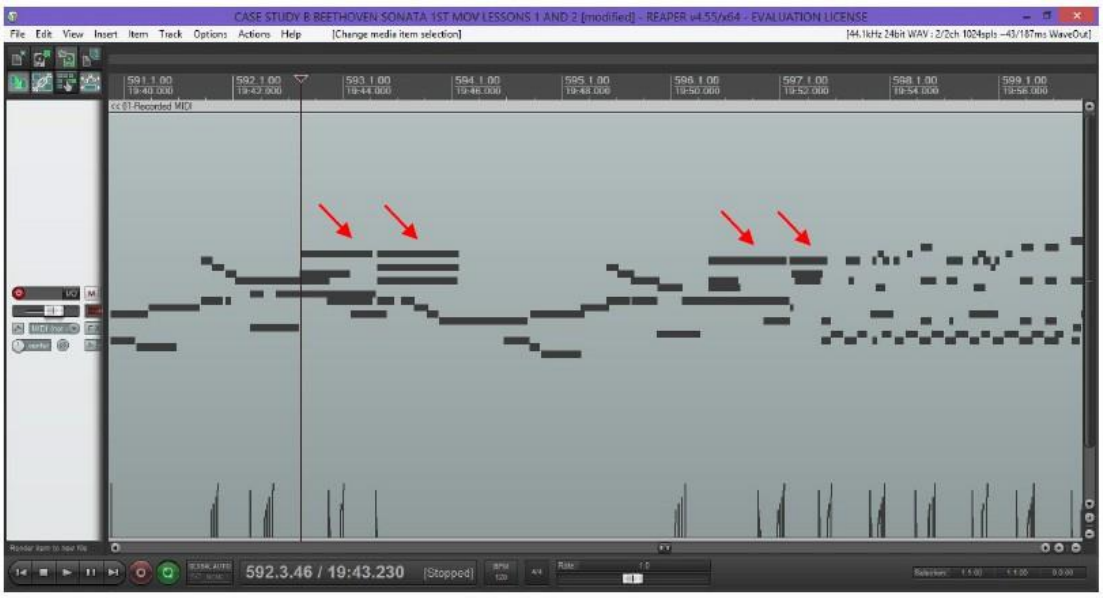
S *playing*

S *playing* **T**: It is still disconnected.

S: Really?

T: You can even see it from the graph, look. (**T** *pointing to the scree*n, **T** *looking at the screen in real-time*; **S** *looking at the screen in real time*)

Figure 5: DAW software screenshot focusing on articulation in case study B, lesson 1. The arrows indicate the top notes of the chords which the student was requested to play with *legato* articulation (Hamond, 2017, p.245).



[2] Here **S** refers to the student, **T** refers to the teacher. Simultaneous verbal and non-verbal behaviors are written on the same line. Non-verbal behaviors are written in italics in parentheses, with the exception of playing, which designates when the student or teacher was playing the piano. The completion of the speeches is given [in brackets] for better comprehension.

In lesson 1 (41’44”- 41’52”), after observing the computer screen with the visualization corresponding to the performance of this excerpt, the student also reported that he may not have played *legato* between the chords due to the fingering he was using for the upper notes of chords. The student was using the same finger 5 to connect a sequence of two chords in bars 33-34 and 37-38 so that the student had to release the top note of the first chord in order to play the next one, which caused the sense of disconnection between chords. For this articulation issue, the teacher also gave non-verbal feedback by playing the musical excerpt to the student by demonstrating the finger *legato* between chords, and verbal feedback by providing the following information to the student: ‘you can disconnect the rest of the chord [T playing the bottom chord notes], but if you don't disconnect the top notes of the chords, we understand that as [you played] *legato*.’ (Teacher, lesson 1, 41’52”- 42’08”).

After realising this, the student understood the need to change her fingering to play *legato* between chords by connecting finger 5 from the first chord to finger 4 of the second chord. The teacher also provided verbal feedback in lesson 1 (41’52”-42’08”) on the quality of the *legato* that she expected for this musical excerpt by differentiating pedal and finger *legato*: ‘since we have this resource [technology], we see that sometimes the *legato* we make is the pedal *legato*, instead of making hand *legato*. […] When we look at it, we see that there is a big space between one note and the other and it made no connection.’

Therefore, the use of the RTVF led by the teacher and shared with the student alongside the teacher verbal and nonverbal feedback allowed an understanding that the performance of a *legato* in this case depended on an adequacy and change of fingering by the student. RTVF and the teacher feedback had an effect on student’s awareness and learning who changed her behaviour in musical performance related to articulation of finger *legato* for top note between chords. Thus, RTVF as shared use occurred when the teacher realized that the additional visual feedback was showing pertinent information on the computer screen that could support student learning of articulation in the piano lesson.

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The second application of RTVF in case study B happened in lesson 2 (24’00” – 27’26”) when the teacher-student pair worked on articulation of fingers on left-hand note arpeggios, particularly in bars 65-66 of the same piano piece (Figure 6). RTVF supported the teacher who used the visual feedback to provide information on articulation when he noted the asynchronies between MIDI notes available on the computer screen. The asynchronies between the left-hand arpeggio notes were evident since the second arpeggio note was represented as a long rectangle rather than a square as the other MIDI notes in the piano roll visualisation on the computer screen (Figure 7).

Then, the teacher played left hand ascendant arpeggios to check the most appropriate fingering, and also gave verbal feedback on fingering saying that finger 4 was more appropriate than finger 3 for that passage as the arpeggio was a second inversion of four-note broken chord. The student was using finger 3 on the second note of the left-hand ascendant arpeggio in order to make it a pivot finger in this passage and this was causing the articulation asynchrony. After having teacher verbal and non-verbal feedback, through playing, and using RTVF with a clear focus, the student became more aware and played several episodes of arpeggio performance with the new fingering. Once the student becomes aware of some aspect of performance that can be improved, he can then change her behaviour and, therefore, improve her performance.

Figure 6: Beethoven Piano Sonata No. 9 in E major, Op. 14, No. 1, fragment, first movement, bars 65-68. (adapted from Hamond, 2017, p.246).

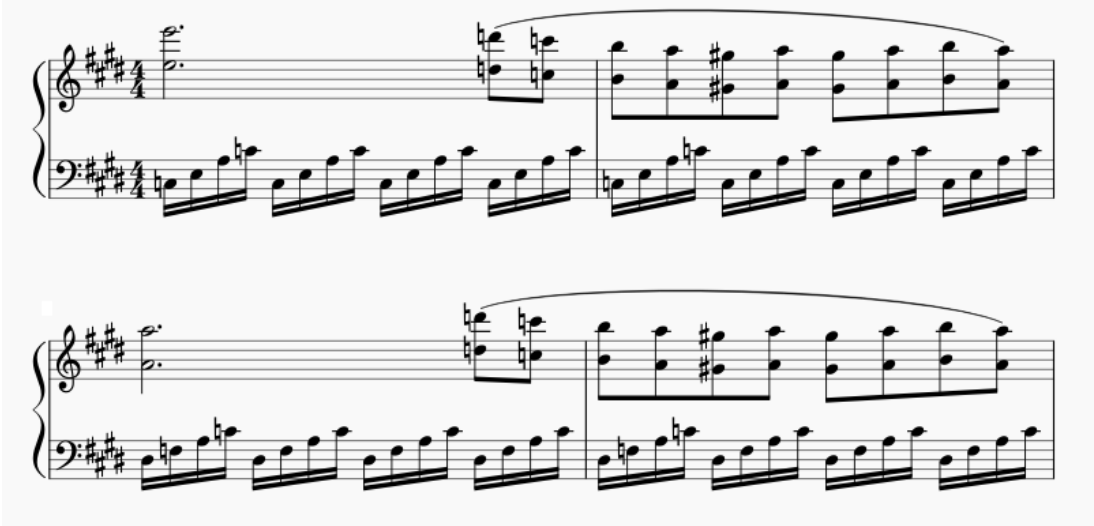
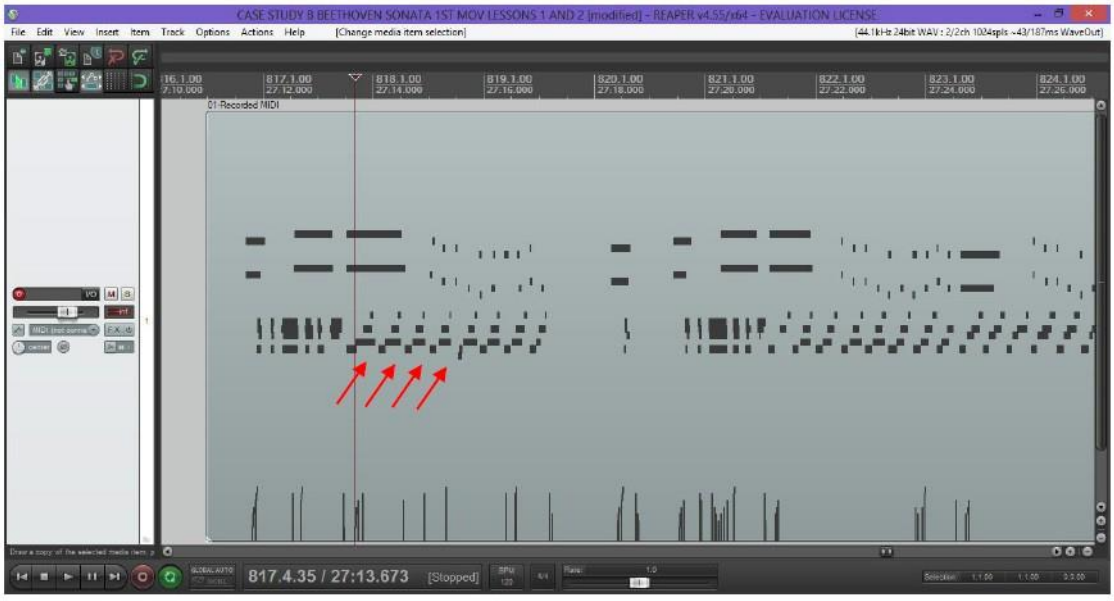


Figure 7: DAW software screenshot focusing on articulation in case study B lesson 2. The arrows show MIDI notes corresponding to notes of the arpeggios in the left hand which were held too long, when using finger 3 (Hamond, 2017, p.247).



The third application of RTVF in case study B happened in lesson 2 (37'14"- 40'08") when the pair worked on articulation of chord attack and release in bars 112 to 113 of the chosen piece. RTVF was used mostly by the teacher to identify the chord asynchrony and make the student aware of this issue. Figure 8 shows the chords as an excerpt of the music score, whilst Figure 9 shows the correspondent visualisation on DAW software interface of the student's performance trials.

Figure 8: Beethoven Piano Sonata No. 9 in E major, Op. 14, No. 1, fragment, first movement, bars 107-113. (adapted from Hamond, 2017, p.248).

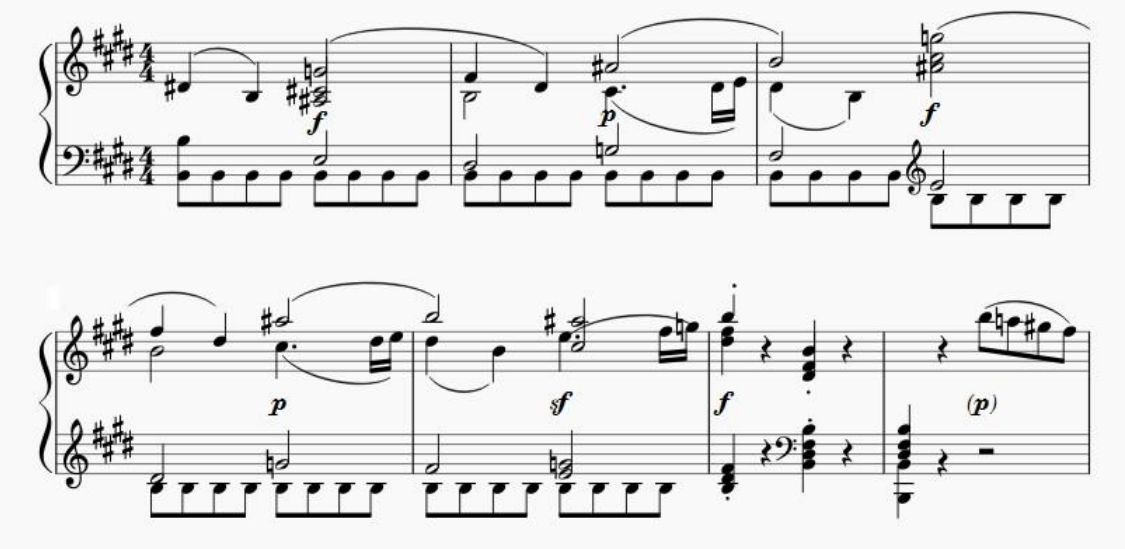
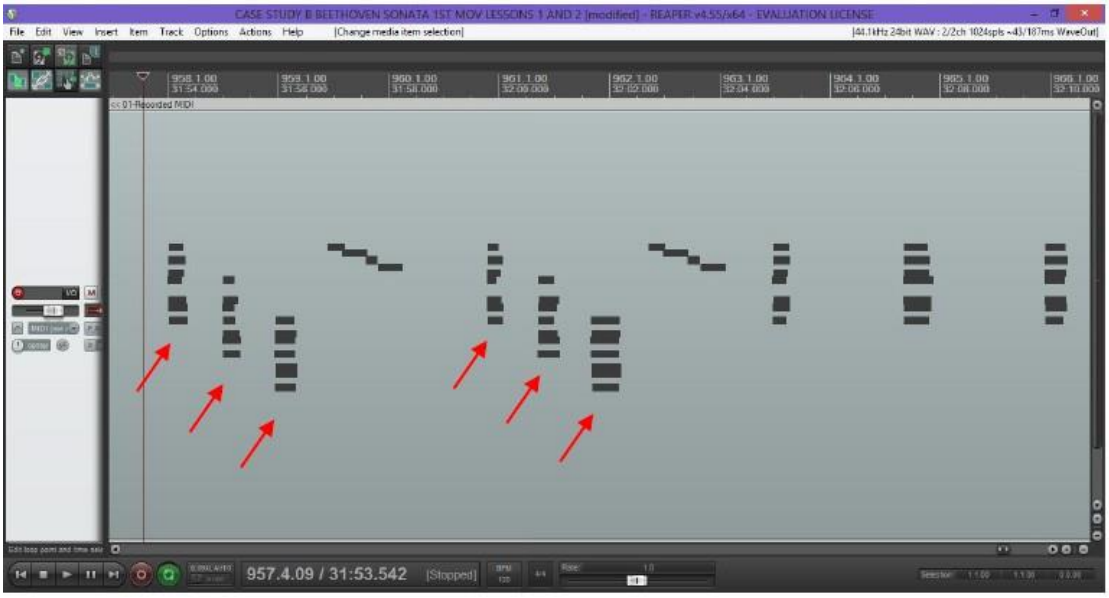


Figure 9: DAW software screenshot focusing on articulation in case study B, lesson 2. Key: The arrows show MIDI notes corresponding to chord notes attack and release which were identified to be in asynchrony (Hamond, 2017, p.248).



In lesson 2, the teacher asked the student to practise chord attack and release without the right foot pedal - – sutain – so that the student could have a better understanding of how she was playing the articulation. An episode of lesson 2 (37'35"-38'28") illustrates the moment in which the teacher was making sense of the RTVF use to support her own verbal feedback on chord asynchrony so that it could also improve student B's learning and performance for this musical excerpt. In this episode, most of the time both teacher and student are looking at the computer screen while the student repeatedly plays the chords with the focus on attack and release of chord notes/keys (Figure 9).

> **T**: So just for you to play [the chords] (**T** *singing*, **T** *saying tchan tchan, tchan*, **T** *using gestures as if playing in the air*)
>
> **T**: without the pedal, just to see how they [the chords on the computer screen] release
>
> **S** *playing* (**S** *looking at their own hands*, **T** *looking at the screen in real-time*)
>
> **T**: [Play it] again (**T** *looking at the screen in real-time*, **S** *looking at the screen in real-time*)
>
> **S** *playing* (**T** *looking at the screen in real-time*, **S** *looking at the screen in real-time*)
>
> **T**: That's right. The chord attack, look.
>
> **S** *playing*
>
> **T**: You have to improve the chord attack.
>
> **S** *playing* (**T** *looking at the screen in real-time*, **S** *looking at the screen in real-time*)
>
> **T**: That's right.
>
> **S** *playing* (**T** *looking at the screen in real-time*; **S** *looking at the screen in real-time*)
>
> **T**: That's right.

The teacher uses the RTVF to show the student how much asynchrony there is between chord notes. The use of RTVF provided information on the extent to which the student was playing chord keys with a more or less consistent movement of attack and release across different fingers. The aim of this lesson episode was to improve the asynchrony between the chord notes rather than to have a perfect synchrony between them. A perfect synchrony is not ideal because it does not represent a human performance with several nuances, but a performance reproduced by a sheet music converted into MIDI with an exact pitch and duration parameters in the DAW software.

The application of RTVF appeared to be closely related to the particular way that it was perceived by individuals, influenced by their individual differences and intrapersonal feedback. In these examples, the evidence is that RTVF can support student learning and performance for articulation if either the teacher or the student (or both) engages with technology. In case study A, the student used RTVF for his individual learning needs to enhance the *legato* articulation of his left-hand *Alberti*'s bass, as he was aware of the performance goal from discussion with the teacher in the previous lesson (lesson 1).

In case study B, the teacher appeared to have understood the applicability of RTVF in a much clearer way than student B, so she used RTVF as a shared experience alongside her usual verbal and nonverbal feedback. Consequently, the teacher was able to support student B in making sense of the visual feedback available on the computer screen more often. In case study B, the teacher used additional visual feedback in identifying the performance goals to be worked on in lessons, and in supporting student learning through its use.

In conclusion, the effective application of RTVF in an HE piano studio was evidenced in a rapid and simultaneous understanding of its application by the student individually as well as by the teacher when guiding the student. Thus, RTVF can be used individually or collaboratively between the teacher and the student through clear and well-defined goals related to articulation aspects when learning and performing a classical sonata.

Discussion

In this paper, it is argued that two types of feedback are considered to be present when technology-mediated feedback is used in HE piano studios: intrapersonal and interpersonal feedback. Intrapersonal feedback was seen to be intrinsic to each individual participant of this study. Intrapersonal feedback is related to sensory feedback, such as visual, auditory and proprioceptive feedback, and associations between these (Bishop; Goebl, 2015; Brown; Palmer, 2012; Halwani et al., 2011; Moore et al., 2016). Intrapersonal feedback also refers to aspects of conscious-awareness (Acitores, 2011; Damasio, 2000; Jeannerod, 2006), self-regulatory skills (Nielsen, 2001), metacognitive knowledge (Schraw; Dennison, 1994), and sense of self (Damasio, 2012), which are also part of the internal systems of each participant of this study. Since additional feedback contains aspects related to student performance, the student can associate visual, auditory, and proprioceptive feedback through their intrapersonal feedback system in order to improve their learning, and performance. Associative learning and multiple couplings of the auditory-visual-proprioceptive system are widely held to enhance conscious-awareness (Acitores, 2011; Edelman, 2001; Lahav et al., 2007; Mathias et al., 2015). Additional visual and auditory feedback generated by technology augmented intrapersonal feedback of teacher and student participants not only in terms of sensory feedback, but also their conscious-awareness of performance outcomes. When comparing intended and actual performance outcomes, students become more conscious of their own performance outcomes (Acitores, 2011; Damasio, 2012; Edelman, 2001). Students can also become more conscious of their performance outcomes using RTVF when they are able to self-assess and self-monitor their learning process.

*Inter*personal feedback was seen to be extrinsic to each individual participant of this study. It is related to feedback provided by an external source, such as the teacher or technology or both. The nature of teacher feedback was verbal and non-verbal; this agrees with previous studies (Benson; Fung, 2005; Burwell, 2010; Siebenaler, 1997; Speer, 1994; Welch et al., 2005). These verbal and non-verbal interpersonal feedback types were linked to technology, such as MIDI parameters, including MIDI note colours, sizes, and velocity key numbers. Findings of this study

agree with those of previous experimental studies which analysed piano performance recordings by associating performance and technology parameters, in terms of MIDI parameters, for example, dynamics and MIDI key velocity numbers, and timing and IOI (Bernays; Traube, 2014; Bresin; Battel, 2000; Palmer, 1989; Repp, 1994).

Real time visual feedback (RTVF) optimized articulation learning in HE piano lessons. RTVF was used in two ways: (2) for individually self-perceived learning needs and led by the student; and (2) as a shared experience between teachers and students and led by the teacher. The use of RTVF had an effect on students' learning and performance of piano articulation in: playing: (a) *legato* in the left-hand *Alberti*'s bass; (b) *legato* between two chords; (c) ascendent arpeggios in the left hand; and (d) attack and release of chord notes. First, RTVF was used for individual learning needs when the student in case study A then used it independently in terms of seeking an improvement in the articulation of his left hand. Second, RTVF was used for shared experience when the teacher in case study B drew on RTVF and supported the student in its simultaneous use with a clear lesson focus to improve student articulation. These findings are also in line with those of previous studies on the usefulness and benefits of the application of RTVF in instrumental and vocal lessons (Brandmeyer, 2006; Sadakata et al., 2008; Welch et al., 2005).

Conclusion

This paper discussed outcomes on the application of real time visual feedback (RTVF) mediated by the technology with three teacher-student pairs working on aspects of articulation in one memorized movement of a classical sonata of their repertoire during two face-to-face HE piano lessons. Although additional visual feedback was available for the three teacher-student pairs, they engaged with the technology in different ways so that only two out of the three used RTVF in their lessons. The application of RTVF supports and potentializes teacher verbal and non-verbal feedback particularly when teacher guidance does not have impact on the student's learning. This happens because recorded MIDI data on the DAW software, when visualized in the piano roll form, can be associated with musical performance parameters, such as articulation, intensity, melodic and rhythmic accuracy, and pedal use. Participants who made the associations in this study understood the impact that RTVF can have in piano learning and teaching focusing on articulation.

The nature of feedback in HE piano learning and teaching when technology-mediated feedback is applied, is both intrapersonal and interpersonal as well as it happens in conventional piano lessons. Thus, the difference between them is in how this additional feedback will be interpreted and assimilated in a piano lesson with technology. It can be argued that the presence of additional visual feedback can augment intrapersonal feedback of each participant, optimizing piano learning and performance, particularly articulation. Piano performance involves very specific voluntary movements. RTVF can also have an effect on proprioceptive feedback by enhancing a piano performance since it can stimulate the motor

control system of the student alongside teacher verbal and non-verbal feedback. Thus, the student can become aware of articulation aspects he was previously not aware of and then he is able to change aspects related to the motor control and to improve his performance aligned with teacher feedback.

Although this study was conducted in the face-to-face teaching context, there are potential applications of this technological system in distance learning,
urgent remote teaching, or online piano teaching. This technology system allows teachers and students to share their performance-related data through the internet (online) and to discuss the visual feedback correspondent to aspects of piano performance in a very detailed way. The use of visual feedback as a supporting tool in HE piano online learning and teaching might enhance the learning and teaching experience, making both student and teacher more aware of the executed movements and all keyboard and pedalling activity through associations with piano roll visualization.

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